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Integrated Pest Management in Maize with special reference to Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith)

Compiled by

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Perspective of Maize Scenario in India: Way Forward

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Abstract

The requirement of maize is increasing due to burgeoning population.In order to meet the growing demand, there is need to increase maize production. The maize area, production and productivityof India have increased by 1.97, 15.62 and 4.6 timesduring 1950 to 2017. However, achieving such progress in future is the major challenge considering depleting land and water resources on one hand, and increased biotic and abiotic stresses on the other hand. In spite of above major challenges, there are opportunities to enhance the productivity of maize provided the strategy must involve all stakeholders like researchers, planners, farmers, maize based food, feed and other processing industries and consumers,who are directly or indirectly responsible for enhancing the maize production. The most important among several strategies would be bringing maize area under single cross hybrids from present 60% to100%,development of climate resilient hybrids through germplasm diversification, accelerated development of new and improved hybrids through application of advanced tools and techniques like doubled haploids, marker assisted election, genomic selection, genetic engineering techniques like CRISPR-Cas9 etc. Thus, it is possible to increase the maize production to meet the growing demand.

Keywords

Genetic improvement, single cross hybrids, climate resilient cultivars, mechanization, production and protection technologies, backward and forward linkages, utilization pattern, value addition,

Introduction

The world population is increasing exponentially and food requirement is also increasing proportionately. Hence, , and this is to be achieved under the scenario of changing climate and depleting availability of arable land and water (Rakshit et al. 2014). Climate change is evident in every sphere of life including agriculture. Its impact on production of agricultural commodities is likely to be the most drastic in tropical and subtropical regions of the world. South Asia with low adaptive capacity is the most vulnerable region for multiple stresses (IPCC, 2007; ADB, 2009; Rodell et al. 2009; Niyogi et al. 2010). Ground water level at various parts of Asia more particularly in north western Indo-Gangetic plains is at very critical level.al.The challenge of increasing food production from depleting land and water resources on one hand, and increased biotic and abiotic stresses on the other can be achieved through higher crop yields per unit area (Foulkes et al. 2011) and developing and growing climate resilient crops (Rakshit et al. 2014). Among the principal cereals, water requirement of maize is the lowest (500 mm) compared to rice (2100 mm) and wheat (650 mm).Beside this maize has the versatility to beused as food, feed, fodder and raw material of over three thousand industrial products.

Maize scenario

India produced over 281 million MT food grains in 2018-19, out of which cereals share the major part. Among cereal grains rice represent 44% of the gross cultivated area followed by wheat (30%), maize (9%), pearl millet (8%) and other millets. Rice and wheat constitute 44%

and 39% of cereal production, respectively while maize represents little over 9% of cereal production (Rakshit et al. 2017).

Maize production between 1950-51 and 1958-59 almost doubled from around 1.73 million MT to 3.46 million MT. This happened due to nearly 35% increase in area and 48% in yield (Yadav et al. 2015). With the level of 1950s the production has increased by 15.62 times. This has happened due to 1.97times increase in area and 4.6times increase in productivity. They dynamics of yield gain and productivity in India has always remained very intriguing (Fig. 1). Annual increment in maize area during 1949-60 was 109 thousand ha per year, while the productivity enhanced by 24.7 kg/ha/year. The corresponding figures in the 1960s were 168 thousand ha/year and 7.4 kg/ha/year, respectively. During 1970s and 1980s the maize area was almost stagnant, while in 1980s India experienced significant yield increment at 29 kg/ha/year. During 1990s the figure was 37 kg/ha/year. From 2000-10 the yield gain was over 46 kg/ha/year, while current figure is nearly 52 kg/ha/year. Though during 1980-90 there was a slowdown in area increase, the maize area has increased substantially and maintaining a growth rate of around 200 thousand ha per since beginning of this millennium. The five yearly average areas under maize is 9.2 million ha and production is 23.3 million MT.

Maize was a rainy season (*kharif*) crop predominantly in India. It was largely grown in northern India the states of Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh. After 1980s a significant shift in area towards peninsular region was noticed. "Currently this region represents nearly 40% of the total area under maize and over 52% of production. The major maize growing states are Karnataka (14.8%), Maharashtra (10.9%), Madhya Pradesh (10.8%), undivided Andhra Pradesh (10.4%), Rajasthan (10.6%), Uttar Pradesh (8.3%), Bihar (7.9%), Gujarat (5.0%) and Tamil Nadu (3.6%), accounting for nearly 80% of the total maize area of the country. However, productivity of maize in many of these states like in Rajasthan (1.6t/ha) and Gujarat (1.6 t/ha) are quite low, while that in Uttar Pradesh (1.7 t/ha), Madhya Pradesh (1.9 t/ha) and Maharashtra (2.3 t/ha) are below the national average of 2.6 t/ha" (Rakshit 2018).

Maize with its wide adaptability is cultivated throughout the country during all the three seasons. However, in few states like Kerala and Goa has very little area under maize, where specialty corns have more presence. The kharif maize is cultivated almost across the country winter or *rabi*maize is cultivated more in Bihar, West Bengal and Peninsular India. Summer maize is gaining popularity in Punjab, Haryana and western Uttar Pradesh. Kharif maize represents around 80% of maize area while rabi maize represent 19% of area. Summer maize occupies 1-2% of total maize area in India. Out of three maize seasons nearly 80% of kharif maize is cultivated under rainfed condition, while rabi and summer maize is cultivated under assured ecosystem. Thus rabi maize has yield level of over 4.0 t/ha, while kharif maize has little over 2 t/ha productivity. To increase the yield level of maize productivity of kharif maize needs to be augmented.

Out of 24 million MT requirement of maize in India around 60% is used as feed, 14% for industrial purposes, 13% directly as food, 7% as processed food and around 6% for export and other purposes (Fig. 1). The demand growth trend suggests an increase in demand of 7.18%, leading to targeted demand for maize of 50-60 million MT by 2025 (Rakshit 2018). Not only domestic demand the international demand for maize is also increasing and will continue to increase. Thus, maize opens up a unique opportunity not only to supplement the maize-based industry but the export as well. The demand for maize is increasing not only as grain but for specialty purposes as well. Among specialty corns, sweet corn, baby corn and pop corn have not only immense market potential but can contribute significantly towards crop diversification and doubling farers income.Maize is extensively being used in dairy industry not only as feed stock but the as fodder, which is used as both green fodder and silage.

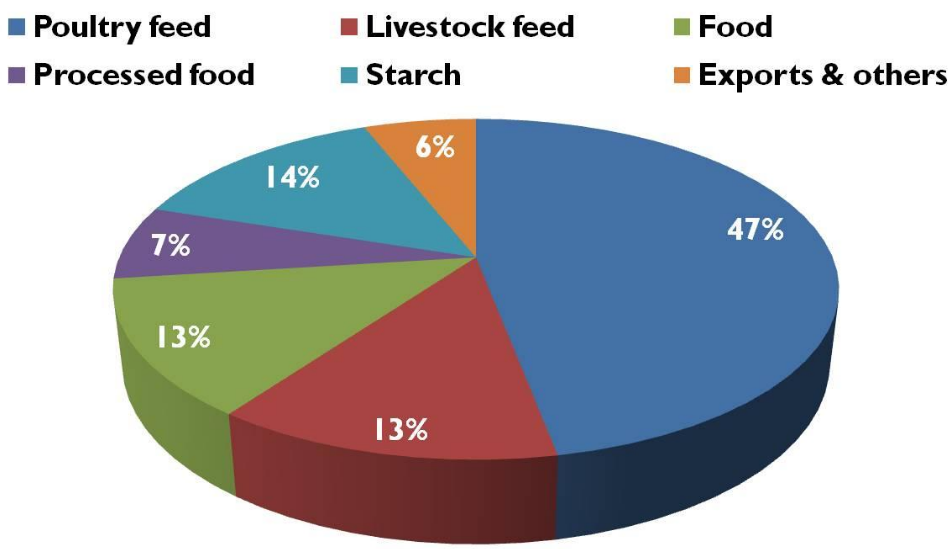

Fig. 1. The usage pattern of maize in India

Progress in maize research

Genetic improvement

The All India Coordinated Research Project (AICRP) on Maize was initiated in 1957 and showed its significant impact in increasing maize production in India. Rightly during the initial period the emphasis was on hybrid research. This led to release of first set of double cross hybrids, *viz*., Ganga 1, Ganga 101, Ranjit and Deccan in 1961. However, slowly the main focus diverted towards composite breeding, leaving hybrid research in the backburner. This may be considered as a major setback to progress of maize research and development in India. Some centres under AICRP on Maize continued their focus of research on hybrids, this lead to release of first single cross hybrid, Paras by Punjab Agricultural University in 1996. This was followed by shifting of maize research on single cross hybrids alone. This may be evident from the significant increase in maize yield gains post 2000 (Fig. 2). During late 1960s onwards focus of research was also diverted towards development of quality protein maize (QPM). The initial QPM varieties did not gain success due to chalky grain, susceptibility to storage pests etc. However, with availability of hard endosperm QPM sources first three-way cross QPM hybrid, Shaktiman 1 was released in India in 2001. Since then though several QPM hybrids (mainly single cross hybrids) have been released in the market by various AICRP centres, in roads of these hybrids remained restricted due to non-availability any additional price to QPM produce, with little yield penalty to QPM hybrids and non-cultivation of QPM in large contiguous field leading to reduction in quality of the produce. Since 2000 a total of 237 cultivars have been released in India, out of which 82% (195) are hybrids. Public sector contributed 50% of released hybrids, while remaining have been released by private sector companies. In the public maize breeding except QPM none of the specialty corns received focused attention until recently.

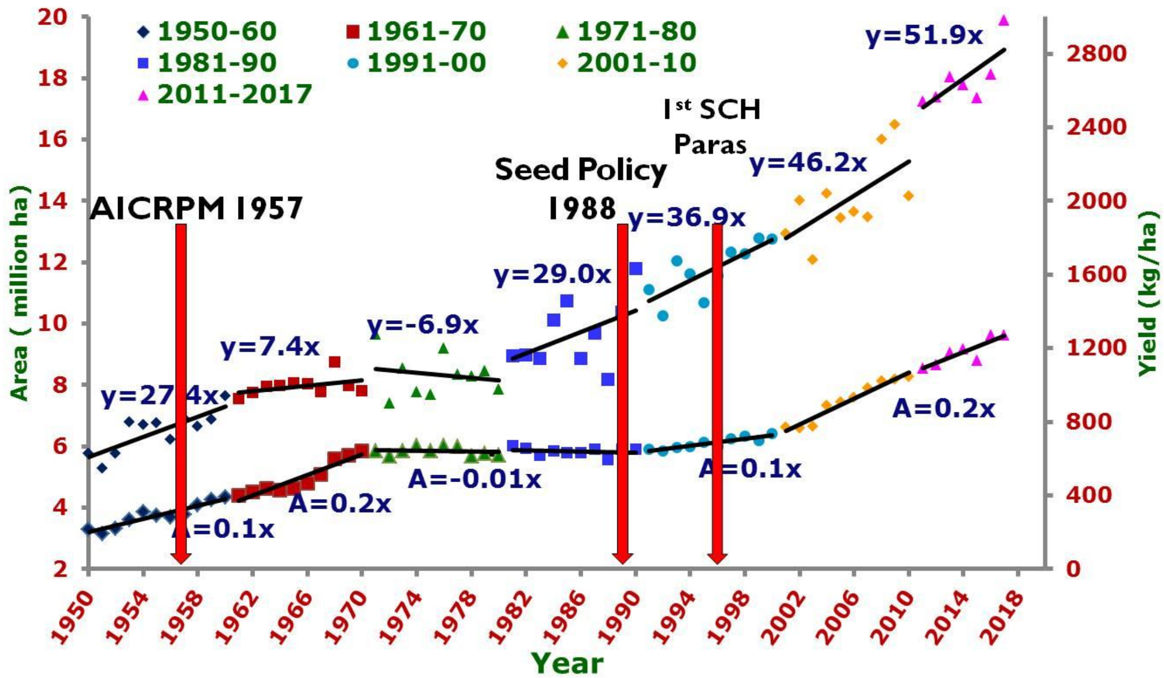

Fig. 2. The scenario of maize area and productivity in India during 1950-2017.

Crop production and management

No yield gain in any crop is achieved through genetic gains alone but effective crop production technology and management practices play a very important role in this regard. Right plant stand for different growing conditions,method of sowing, **s**ite-specific nutrient management, intercropping with various crops (particularly rabi maize), weed management etc. have been proved significant intervention to increase productivity of maize. Consistent research efforts on resource conservation technology (RCT), particularly Zero tillage (ZT) technology and crop residue incorporation in maize-based cropping system have been found to be highly remunerative. Maize system productivity of 11.3–12.9 t/ha with reduced water requirement by 40–65 ha-mm under ZT has been reported in maize (Parihar et al. 2016). RCT practices are becoming popular in the Indo-gangetic region and in peninsular India. Effective plant protection is key to sustainable production. Over period of time the project as strive hard to contain the onslaught of various biotic and abiotic stresses. Sources of resistance against major diseases and insect pests have been developed and deployed to strengthen host plant resistance (HPR) to combat these stresses. Effective chemical and cultural control measures have been developed against these stresses in an integrated manner.

Mechanization

With reduced availability of labour farm mechanization from land preparation, sowing to post-harvest handling play a very important role. Unlike other cereals mechanization in maize cultivation is not much in practice except land preparation. In recent past combined harvesters are being introduced on hire and use basis in southern states. But this needs much popularization with governmental support. Dehusker cum sheller and grain driers need to be integrated with maize production and processing system. Unlike rice and wheat maize is more prone to damage during storage due to aflatoxin infection and damage by rice weevil. This problem is more severe if grains are not dried properly (<14%).

Value addition

Over period of time maize has maize being a food crop has gained its popularity as feed crop. However, considering the low glycemic index of maize it can be an important part of dietary component as well. Many maize-based ready-to-cook (RTC) and ready-to-eat (RTE) products can be developed. QPM grains may further add value to these products. Rajendra Agricultural University, Dholi and University of Agricultural Sciences, Mandya have made significant contribution in this direction. In recent past UAS, Mandya is marketing many of the value added products in the brand name of 'Maizy' in the state of Karnataka.Besides grain corn, specialty corns – sweet corn, baby corn and pop corn assumes immense potential in terms of value addition.

Strategies for enhancing maize production

The strategy must involve all stakeholders who are directly or indirectly responsible for enhancing the maize production. The main stakeholder is the farmer, the actual producers of maize. However, farmer needs technology and policy support; the extension personnel located at krishi vigyan kendras, department of agriculture of different states can take an active role in transfer of technology whereas the planners and government can devise policies to provide financial security to farmers involving in maize cultivation. The backward and forward linkages through Public-Private-Producer Partnership (PPPP) can go a long-way to sustain the interest of farmers in maize cultivationwhich is the back-bone for enhancing the maize production through increasing the maize productivity in a sustainable manner. The following strategies could be adopted to bring sustainable increase in maize productivity:

- Development of high-yielding climate resilient cultivars
- Expansion of area under hybrid cultivars
- Production and protection technologies
- Development of backward and forward linkages
- Policy interventions

Strategies for development of high-yielding climate resilient cultivars

Diversification of maize germplasm

Maize has tremendous genetic diversity;significant yield gain achieved in maize as compared to other cereal crops during the last six decades across the globe signifies the fact that maize is the crop with highest yield potential. However, the hidden potential existed in the form of genetic diversityavailable in different landraces and its wild relatives has not yet explored largely. The growing demand for maize by entirely different kinds of industries like bio-fuel, paper and bio-degradable plastic and changing climate especially the vagaries of monsoon has necessitated the need to explore the possibility to use genetic diversity existed in landraces and wild-relatives . In addition, the heterosis between temperate into tropical germplasm has not yet been exploited largely in developing countries and particularly in India.Development of novel germplasm through temperate into tropical crosses and also introgression of exotic germplasm into active breeding material would create genetic variability to further enhance the yield potential.

Development of climate resilient cultivars

The intra-seasonal fluctuations in rainfall and temperature in different agro-ecological zones demand for cultivars with climate resilience trait. Identification of cultivars with tolerance to various kinds of moisture stress like drought and waterlogging at critical crop growth stages would help to reduce the yield losses due to different kinds of moisture stresses. Development of phenotyping network in different agro-climatic zones by creating managed stress conditions would assist in selection of right kind of cultivars. Thus the focused research on development of climate resilient hybrids and deployment of such climate resilient hybrids in targeted areas would certainly increase the productivity of rainfed areas. The large-scale demonstration of climate resilient hybrids on farmers' field across multiple locationswould increase the rate and percentage of adoption of such hybrids by farmers.

Applications of novel methods to accelerate the rate of cultivar development

The maize genome sequence information is out in public domain, several thousands of gene(s) and quantitative trait locus (QTL) determining key traits like resistance to different biotic stresses, tolerance to abiotic stresses; different yield contributing traits, quality traits etc. have been identified. The novel precise targeted gene editing technique like CRISPR-Cas9 is also available. In addition, other advanced technique like doubled haploid techniques (DH), marker assisted selection (MAS) and of late speed breeding technology would facilitate accelerated breeding.. Application of such novel tools and techniques in maize improvement would help in breeding by design. The techniques have also increased the rate of cultivar development by substantially reducing the breeding cycles. The simultaneous development in high-throughput field-phenotyping facilities, statistical algorithms for analysis of complicated data etc. together can help in increasing the genetic gain thus help in developing new, high yielding, climate resilient cultivars.

Development of genetically modified (GM) maize

The area under genetically modified maize across the globe has been continuously increasing and the number of countries adopting GM maize is also increasing. In India also several transgenic events against insect resistance, herbicide tolerance have been tested under contained conditions under supervision of the Genetic Engineering Appraisal Committee (GEAC). In fact transgenic events with tolerance to abiotic stress like drought have been developed;DroughtGard™, the first commercial genetically modified maize hybrid released for drought tolerance. Similarly for other traits where the sources of resistance are not available or available in low frequency could be considered to improve through transgenic approach..

Expansion of area under hybrid cultivars

Presently around 60% of the total maize area of the country is under hybrid maize, whereas the national average productivity of maize is around 3 t/ha. There is scope to bring additional 40% of maize area under hybrid cultivars to further increase the productivity by at least by 50%. In order to expand the maize area under hybrids, the promotion of hybrid seed production in different parts of the country would bring awareness among farmers about hybrids.. Several sites have already been identified in different states like Rajasthan, West Bengal, Bihar, Jharkhand etc. to enhance the hybrid seed production capacity involving National Seed Corporation (NSC) and other state seed corporations like Rajasthan Gujarat etc. The government policy push to bring more area under hybrid maize would certainly help to increase the maize productivity.

Production and Protection Technologies

Adoption of improved agronomic practices and also undertaking timely plant protection measures depending on the need would help in reducing the yield gaps substantially and reduces the losses due to various insect pests respectively. The plant production practices like crop diversification, crop rotation, intercropping, adoption of conservation agriculture practices help in enhancing the soil health in long-run. The application conservation agriculture (CA) practices like residue retention would serve as moisture conservation technique. Retention of soil residue would modulate soil temperature, soil pH, organic carbon, soil micro-biome etc. The CA practices also reduce the cost of cultivation which in turn helps in enhancing the farmers' income. In order to augment and enhance farmers' income, the specialty corn cultivation like sweet corn and baby corn can be promoted in selected areas around urban areas. Contract farming approaches can provide market stability to farmers and also continuous supply to traders. The government's policies can also focus consider to promote specialty corn cultivation due to huge export market for specialty corn.

Development of backward and forward linkages

The maize production in India is increasing gradually.During the last one decade (2007-2017), the area, production and productivity of maize have increased by 15, 51 and 31 per cent respectively. In order to avoid post-production losses and also maintain the farmer's interest in maize cultivation, there is need to create adequate large-scale storage facilities and also provide the farmers the market stability respectively. The diversified uses of maize coupled with increased maize production have directly or indirectly helped several industries to expand their consumption capacity. The policy support in this direction to promote further industrial growth is needed. The policy should consider all the stakeholders like farmers, industrialist and consumers. One of the current developments in this direction is the initiative taken by Haryana Government with respect to crop diversification. The Haryana government has announced the comprehensive package to farmers cultivating maize. The government has giving assurance to farmers that the government will buy-back all their maize produce at MSP; such kind of policy support would not only increase the maize productionbut also help in conserving the precious natural resources like water. Further, promotion of maize as food crop is also required by highlighting the nutritional importance of quality protein maize (QPM). The advantages of QPM over other cereals like rice and wheat would increase maize consumption as food. The number of persons with diabetic is increasing in India; initiative like promotion QPM would certainly reduce the burden on spending on health. However, the strategy should be developed to link, QPM producing farmers, food processing industries and the consumer. Considering the existing infrastructure and business models in India like omni-presence of super markets, the health awareness the task is easy to accomplish. Similarly linking maize producers, starch industry, poultry industry and consumers could create enabling environment to further enhance the maize production and productivity.

Policy intervention to further enhance the maize production in India

- Establishment of centralized state-of-the-art research facilities or centre of excellence to carryout advanced research on DH, MAS, gene editing techniques etc. to further enhance maize productivity.
- Mission mode approach to bring 100% maize area under hybrids through National Seed Corporation (NSC), State Seed Corporations (SSC) and private companies by linking with State Agriculture Departments to supply hybrid seeds at the door steps in subsidized rate.

- Large-scale campaign to promote mechanization in maize cultivation from land preparation to sowing to harvesting and facilitating either subsidy or through PPP to establish custom-hire centres to rent big and small machineries.
- Linking food, feed and starch industries with farmers to purchase the maize produce from the farmers door-steps along withestablishing community based large scale dryers to produce, market and procure quality maize.

Challenges and future outlook of maize research and development in India

The challenges in maize production are dynamic. The major challenge is the low productivity in rainfed areas of kharif season. The major reason for low yield is the vagaries of monsoon as 70% of maize area is under rainfed condition which largely depends on the monsoon rains. The 70% of maize area often experience moisture stress either in the form of low moisture (drought) or high moisture (waterlogging) at different growth stages. About 80% of maize area is being cultivated during kharif season. The kharif season and dependencies on monsoon rains are the two major factors which is responsible for low productivity. Heavy incidence of weeds and losses due to weed infestation during kharif season is the other major challenge. However, in recent years one or two post-emergence herbicides are available to control weeds but use of herbicides increases the cost of production. On the contrary we are aiming to double the farmers' income which is possible either by increasing the yield or by reducing the cost of cultivation. The third most important challenges is scarcity of labor and lack of customized small to medium to big machineries for complete mechanized cultivation of maize by small to marginal to large farmers.The labor wages are increasing across all states and percentage of agriculture laborers is decreasing. On the contrary, in order to reduce the cost of cultivation and also to overcome the labor scarcity, mechanized maize cultivation is not happening mainly due to lack of desired machines in sufficient number. The fourth most important challenge is lack availability of quality seed in sufficient quantity at affordable price at the farmer's door step. The hybrid maize seed production has concentrated largely in coastal Andhra Pradesh and some parts of Telangana and most of the hybrid seed produced is get sold-out in peninsula part of India. Recently an invasive pest fall armyworm has created an alarming situation in most parts of India. The losses may go up to 100% if proper measures not taken at right stage of infestation. Finally, the application of modern tools and techniques in India to develop new and improved maize cultivars is not comparable with other parts of World.

The domestic demand and international demand for maize is increasing continuously. Presently India is self sufficient to meet the domestic demand. However, it is estimated that the future demand for maize in India would increase at increasing rate. In order to meet the future demand India has to increase the rate of genetic gain in increasing rate in coming years which is not easy under decreasing natural resource base and changing climate. However, by application of advanced tools and techniques like DH, coupled with germplasm diversification, genomic selection, the future demand can be met, provided 100% adoption of hybrid technology. The application advanced tools and techniques, would help in identification of gene(s) determining tolerance to different kinds of stress like biotic and abiotic stresses. Integration and use of genotypes carrying such gene(s) in active germpalsm would help in developing climate resilient cultivars. Further, integration of DH, MAS and genomic selection (GS) would further accelerate the rate of cultivar development.

The policy intervention towards ensuring 100% adoption of hybrid technology, availability of quality seeds at affordable price at the door step of farmers would not only increase the productivity but also enhance the farmers' income.

Conclusion

India has to achieve the maize production target of 50-60 million MT by 2025. Presently India is producing around 28.75 million MT of maize (2017-18). During last ten years (2007-2017), India has increased its maize production from 18.96 to 28.75 million MT. The challenge looks daunting; but, it is achievable through strong policy support. Because, presently large number of single cross hybrids are already available with yield potential of 6-7 tons/ha during kharif season and 9-10 t/ha during rabi season. However, the only major challenge is to adoption of already available technologies like single cross hybrids on 100% area and ensuring availability of quality seeds at the door steps of farmers. In addition, focused research on germplasm diversification, development of climate resilient hybrids, accelerated development of hybrid cultivar through application of advanced tools and techniques, promotion and popularization of new and improved hybrids, adoption of improved production and protection practices would ensure sustainable increase in maize production and productivity.

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Maize Biology

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Maize, third most important cereal crop in India after wheat and rice; with its wide adaptability is cultivated throughout the country during all the three seasons. *Kharif* maize represents around 80% of maize area while *Rabi* maize represents 19% of area. Summer maize occupies 1-2% of total maize area in India. It is also called queen of cereals because of its highest genetic yield potential among the cereals and is a C_4 plant. The demand for maize is increasing not only as grain but for specialty purposes as well. Among specialty corns, sweet corn, baby corn and pop corn are very popular have an immense market potential. Other than food purpose, maize is also used as livestock feed, poultry feed, various other industrial uses etc.

Taxonomy

Maize belongs to the tribe Maydeae of the grass family Poaceae. "Zea" (zela) was derived from an old Greek name for a food grass. The genus Zea consists of four species of which Zea *mays* L. is economically important. The number of chromosomes in *Z. mays* is 2n = 20.

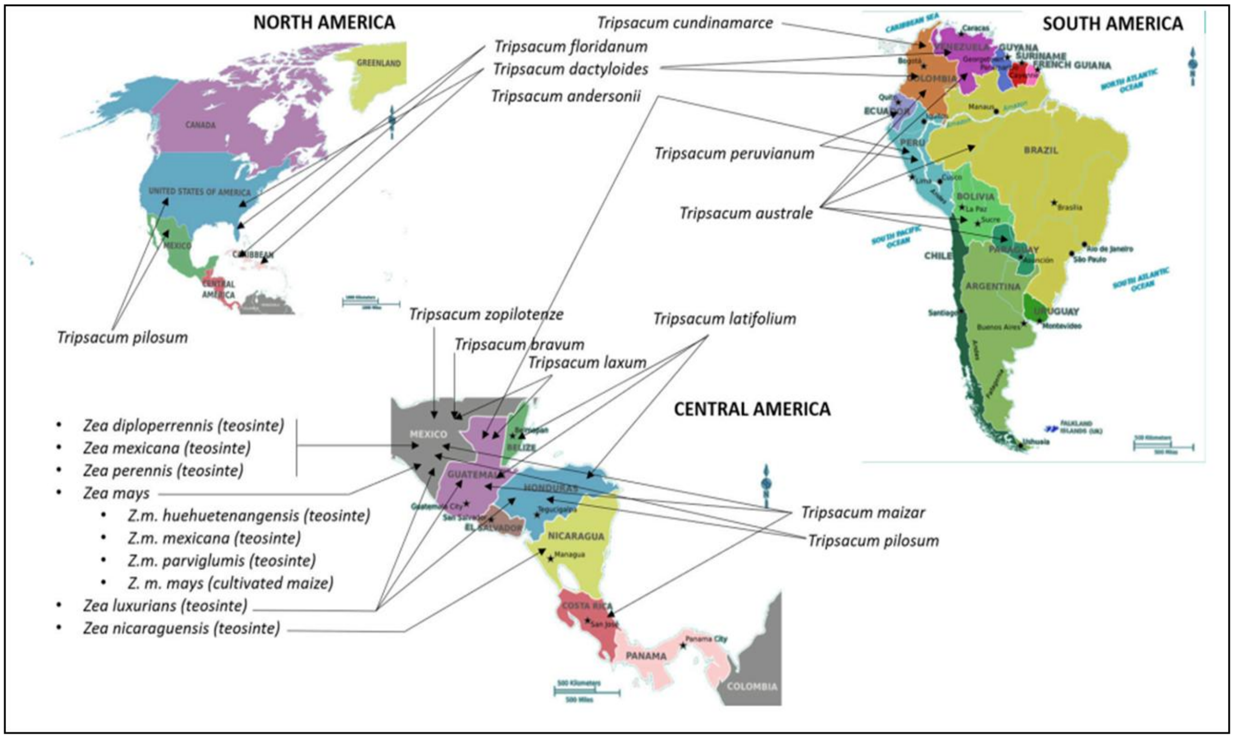
Name	**Maize**
Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Order	Poales
Family	Poaceae
Genus	*Zea*
Species	*mays*

Tribe Maydeae comprises seven genera which are recognized, namely Old and New World groups. Old World comprises Coix (2n = 10/20), Chionachne (2n = 20), Sclerachne (2n = 20), Trilobachne (2n = 20) and Polytoca (2n = 20), and New World group has Zea and Tripsacum. The genus Zea consists of four species of which only Z. *mays* L. (2n = 20) is economically important. The other Zea sp., referred to as teosintes, is largely wild grasses native to Mexico and Central America (Doebley, 1990b). It is generally accepted that maize phylogeny was largely determined by genera Zea and Tripsacum, however it is also accepted that the genus Coix also contributed significantly to the phylogenetic development of Z. *mays* (Radu et al., 1997).

Geographic Origin and Distribution

The center of origin for Z. *mays* has been established as the Mesoamerican region, now Mexico and Central America (Watson & Dallwitz, 1992). Figure clearly shows the centers of origin and primary geographical distribution of cultivated maize and its relatives.

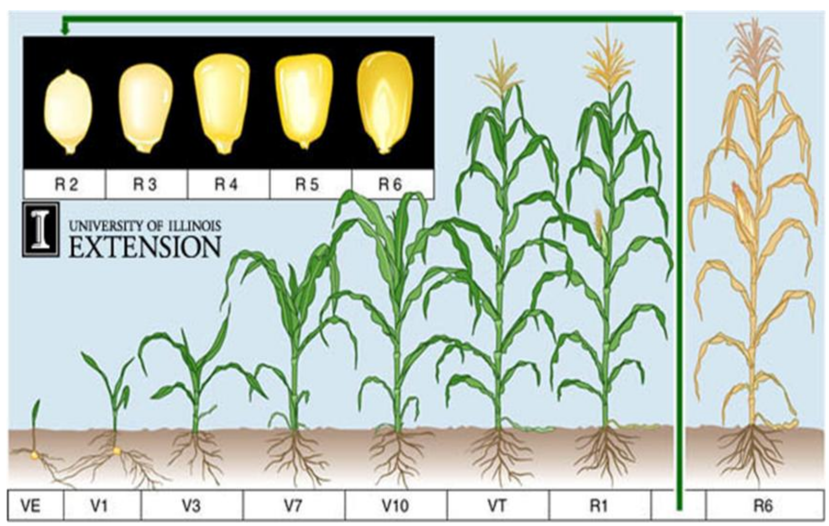
Archaeological records suggest that domestication of maize began at least 6000 years ago, occurring independently in regions of the southwestern United States, Mexico, and Central America (Mangelsdorf, 1974). The Portuguese introduced maize to Southeast-Asia from the America in the 16th century. In India, Portuguese introduced maize during the 17th century. From India, it went to China and later it was introduced in Philippines and the East Indies.



Mammadov et al. 2018

Phenology (Life Cycle)

Typical Maize is a monoecious plants with determinate type of plant habit usually develop 18 to 22 leaves in total, silk appears about 55 days after emergence, and mature in around 125 days after emergence (Ritchie et al., 1993). The specific time interval, however, can vary among hybrids, environments, plantings date, and location. The length of time between each growth stage, therefore, is dependent upon these circumstances. For example, early maturing hybrids may produce fewer leaves or progress through the different growth stages at a faster rate. In contrast,



Different developmental stages in plants [Ritchie et al., 1993].

a late – maturity hybrids may develop more leaves and progress through each growth stage at a slower pace.

Almost all pest management decisions for maize are based on the vegetative stage. These are identified by the number of collars present on the corn plant. The leaf collar is the light – colored collar – like "band" located at the base of an exposed leaf blade, near the spot where the leaf blade comes in contact with the stem of the plant. Leaves within the whorl, not fully expanded and with no visible leaf collar are not included. For example, a plant with 3 collars would be called a V3 plant, however, there may be 6 leaves showing on the plant.

VE - Emergence

Coleoptile reaches the soil surface and exposure to sunlight causes elongation of the coleoptile and mesocotyl to stop. Embryonic leaves rapidly develop and grow through the coleoptilar tip. Seminal root growth begins to slow and nodal roots are initiated at the crown.

V1 - First leaf collar

Lowermost leaf (short with rounded tip) has a visible leaf collar. Nodal roots begin elongation. Again, weed control at this growth stage will result in little yield loss, but seed from weeds that emerge later in the growing season may contribute to the soil seed bank if a residual herbicide has not been applied.

V3 - Third leaf collar

The growing point remains below the soil surface as little stalk elongation has occurred. Lateral roots begin to grow from the nodal roots and growth of the seminal root system has ceased. All leaves and ear shoots that the plant will produce are initiated at this stage. Since the growing point remains below the soil surface, cold soil temperatures may increase the time between leaf stages, increase the total number of leaves formed, delay tassel formation, and reduce nutrient uptake.

V7 – Seven leaf collar

During the V7 and V8 growth stages the rapid growth phase and kernel row determination begins. Senescence of lower leaves may occur if plant is stressed, but must still be counted when staging plants.

V10 – Ten leaf collar

At the V9 and V10 growth stages the stalk is in a rapid growth phase a accumulating dry matter as well as nutrients. The tassel has begun growing rapidly as the stalk continues to elongate. Many ear shoots are easily visible when the stalk is dissected.

VT – Tasseling

Initiation of the VT stage begins the last branch of the tassel is visible and silks have not emerged. This stage begins about 2-3 days before emergence. The plant is almost at its full height and pollen shed (anthesis) begins. Pollen shed typically occurs in the morning or evening. Plants at the VT/R1 are most vulnerable to moisture stress and leaf loss (hail).

R1 – Silking

This stage begins when any silk is visible outside the husk. Falling pollen grains are captured by the silk and grow down the silk over a 24 hour period ultimately fertilizing the ovule. The ovule becomes a kernel. It takes upwards of three days for all silks on a single ear to be exposed and pollinated. The number of fertilized ovules is determined at this stage. If an ovule is not fertilized, it will not produce a kernel and it eventually degenerates. Environmental stress at this time is detrimental to pollination and seed set, with moisture stress causing desiccation of silks and pollen grains. Nutrient concentrations in the plant are highly correlated with final grain yield as nitrogen and phosphorous uptake are rapid.

R2 to R6 stages

Active grain filling takes place during these stages and its final critical production stage. Any stress at this point can reduce the number, size and weight of the harvestable kernels. This stage of kernel development is directly linked to production levels of crop.

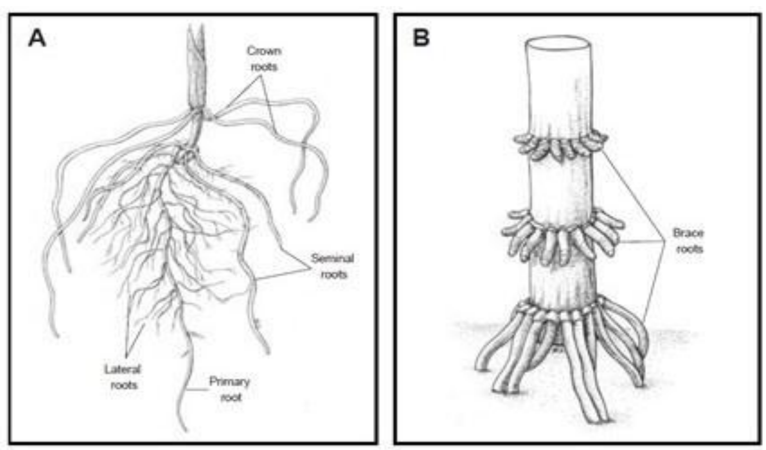
R6 - Physiological Maturity

Occurring approximately 45 days after silking, all kernels on the ear have attained maximum dry weight. A black or brown layer has formed where the kernel attaches to the cob, indicating physiological maturity has been attained. The stalk of the plant may remain green, but leaf and husk tissue has lost its green colour at this stage. Kernel moisture content ranges from 30-35% at this stage, with much variation among hybrids and environmental conditions.

Botanical Features

Maize is a tall, determinate annual C4 plant with varying in height producing large, narrow, opposing leaves, borne alternately along the length of a solid stem. The botanical features of various plant parts are as follows:

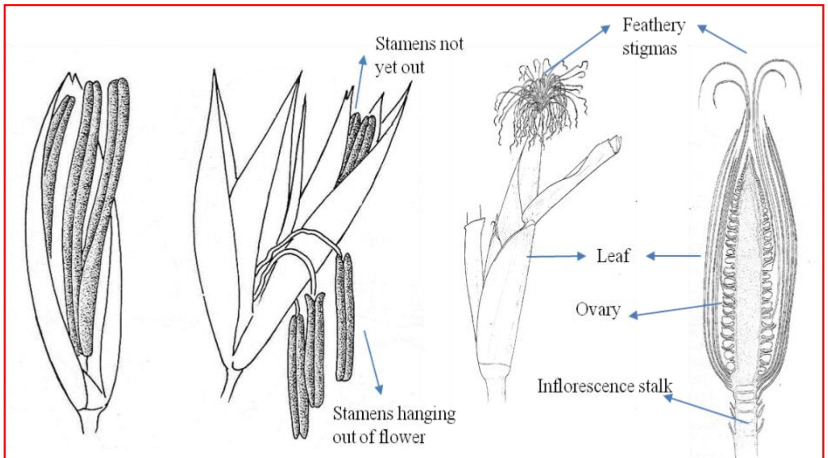
Root: Normally maize plants have three types of roots, i) seminal roots - which develop from radical and persist for long period, ii) adventitious roots, fibrous roots developing from the lower nodes of stem below ground level which are the effective and active roots of plant and iii) brace or prop roots, produced by lower two nodes. The roots grow very rapidly and almost equally outwards and downwards. Suitable soils may allow corn root growth up to 60 cm laterally and in depth.



Stem: The stem generally attains a thickness of three to four centimeters. The internodes are short and fairly thick at the base of the plant; become longer and thicker higher up the stem and then taper again. The ear bearing internode is longitudinally grooved, to allow proper positioning of the ear head. The upper leaves in corn are more responsible for light interception and are major contributors of photosynthate to grain.

Floral Biology

Maize is a monoecious plant, i.e. the sexes are partitioned into separate pistillate (ear), the female flower and staminate (tassel), the male flower (Fig). It has determinate growth habit and the main shoot terminates in a staminate tassel. Maize is generally protandrous, i.e. the male flower matures earlier than the female flower. Within each male flower spikelet, there are usually two functional florets, although development of the lower floret may be delayed slightly in comparison to the upper floret. Each floret contains a pair of thin scales i.e. lemma and palea, three anthers, two lodicules and rudimentary pistil. Pollen grains per anther have been reported to range from 2000 to 7500 (Kiesselbach, 1949). The pollen grains are very small, barely visible to the naked eye, light in weight, and easily carried by wind. The wind borne nature of the pollen and protandry lead to cross-pollination, but there may be about 5% self-pollination.



Maize: Male and Female flowers

The female (pistillate) inflorescence, a spike, produces pairs of spikelets on the surface of a highly condensed rachis. The female flower is tightly covered over by several layers of leaves, and so closed in by them to the stem that they don't show themselves easily until emergence of silks from the leaf whorl at the end of the ear. The silks are the elongated stigmas that look like tufts of hair initially and later turn yellowish, greenish or purple in color. Each of the female spikelets encloses two fertile florets, one of whose ovaries will mature into a maize kernel once sexually fertilized by wind-blown pollen. Silks are covered with numerous hairs, trichomes which form an angle with the silk where pollen grains are harboured. The base of the silk is unique, as it elongates continuously until fertilization occurs. The cobs bear many rows of ovules that are always even in number. The female inflorescence or ear develops from one or more lateral branches (shanks) usually borne about half-way up the main stalk from auxillary shoot buds. As the internodes of the shanks are condensed, the ear remains permanently enclosed in a mantle of many husk leaves. Thus the plant is unable to disperse its seeds in the manner of a wild plant and instead it depends upon human intervention for seed shelling and propagation.

Pollination and Fertilization

In maize, the pollen shed is not a continuous process and usually begins two to three days prior to silk emergence and continues for five to eight days. The silks are covered with fine, sticky hairs which serve to catch and anchor the pollen grains. Pollen shed stops when the tassel is too wet or too dry and begins again when temperature conditions are favourable. Under favourable conditions, pollen grain remains viable for only 18 to 24 hours. Cool temperatures and high humidity favour pollen longevity. Under optimal conditions the interval between anthesis and silking is one to two days. Under any stress situation this interval increases. Fertilization occurs after the pollen grain is caught by the silk and germinates by growth of the pollen tube down the silk channel. Within minutes of coming in contact with a silk, pollen tube grows and enters the embryo sac in 12 to 28 hours. Pollen is light and is often carried considerable distances by the wind. Pollen of a given plant rarely fertilizes the silks of the same plant. Under field conditions, 97% or more of the kernels produced by each plant are pollinated by other plants in the field. Fertilization of ovules begins about one third of the way up from the base of the ear.

Seed Dispersal

Seed dispersal of individual kernels naturally does not occur because of the structure of the ears of maize. Maize, as a thoroughly domesticated plant, has lost all ability to disseminate its seeds and relies entirely on the aid of man for its distribution (Stoskopf, 1985). The kernels are tightly held on the cobs. In case ears fall to the ground, so many competing seedlings emerge that the likelihood that any will grow to maturity is extremely low.

Grain: The individual maize grain is botanically a caryopsis, a dry fruit containing a single seed fused to the inner tissues of the fruit case. The seed contains two sister structures, a germ which includes the plumule and radical from which a new plant will develop, and an endosperm which will provide nutrients for that germinating seedling until the seedling establishes sufficient leaf area to become autotrophy. The germ is the source of maize "vegetable oil" (total oil content of maize grain is 4% by weight). The endosperm occupies about two thirds of a maize kernel's volume and accounts for approximately 86% of its dry weight. The endosperm of maize kernels can be yellow or white. The primary component of endosperm is starch, together with 10% bound protein (gluten), and this stored starch is the basis of the maize kernel's nutritional uses.

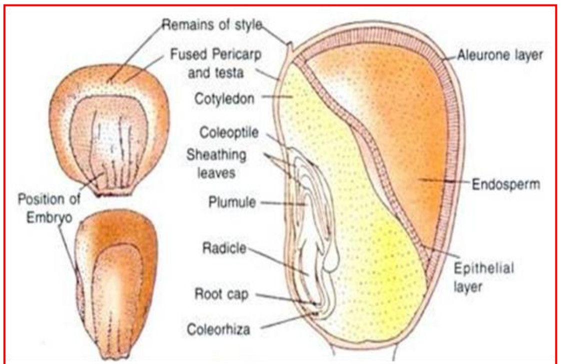


Image taken from http://cdn.biologydiscussion.com

Relatives of Maize

Teosinte and Tripsacum are two CWRs that have been extensively characterized as donors for economically important traits that could be used for improvement of maize. It took nearly a century to confirm that Balsas teosinte (Z. *mays* ssp. *parviglumis* Iltis & Doebley) is a progenitor of maize (Matsuoka et al., 2002). Teosinte is a wild grass natively grown in Mexico and some Central American countries.

Among teosintes, the nearest teosinte relative to Zea *mays* is Zea *mays* ssp. *mexicana* (Schrader) Iltis, which grows in central highlands of Mexico. It possesses the same diploid chromosome number as maize (2n = 20). The other teosintes include perennial teosintes, viz. Zea *diploperennis* (2n= 20) and Zea *perennis* (2n= 40), distributed in Jalisco, Mexico. The annual teosintes include Zea *luxurians* from southeastern Guatemala, Zea *mays* spp. *parviglumis* of southern and western Mexico and Zea *mays* spp. *huehuetenangensis* from the western highlands of Guatemala. The main morphological differences between teosinte and maize are their branches and inflorescences. Teosinte plants contain more branches and smaller female inflorescences than maize.

Zea *mays* spp. *parviglumis* A - Tillering ; B - Infloresence; C - seeds

Tripsacum has been considered closely related to Zea due to morphological similarities including the highly specialized cupulate fruitcase, and the ability to cross with Zea and produce viable but generally infertile hybrids (Galinat, 1961). The genus Tripsacum comprises nine species of warm-season, perennial grasses that are native to the area starting in southern Canada (North America) and extending as far south as Chile (South America) (Eubanks, 2006); One species of Tripsacum that has been broadly used to generate intergeneric hybrids with maize is T. *dactyloides*, or Eastern gamagrass (De Wet et al., 1981).

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Management of Insect pests of maize

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Maize is popularly known as "Queen" of cereals because of its highest yield potential. Globally, it is leading cereal in terms of area (over 183 m ha), production (over 717 m tonnes) and average productivity (over 5.0 t/ha). It can play a vital role in ensuing food and nutritional security for India and world as a whole. Maize accounts for 15% of world's proteins and 19% of the calories derived from food crops. In India, maize is cultivated in 9.38 m ha with production and productivity of 28.75 m t & 3.07 t/ha. Maize is used in diversified ways *i.e.*, for human consumption (24%), as poultry feed (52%), as animal feed (11%), as raw material in many industries (11%), as seed (1%) and for brewery (1%). Major maize growing season is *Kharif*, which accounts for about 85% of total maize area whereas *Rabi* maize contributes >25% of annual production with <10% of total maize growing area in the country.

Pest scenario over the years:

About 250 species of insects and mites are reported in maize crop, among all the insect pests of maize, stalk borers, *Chilo partellus* (Swinhoe) during *Kharif* and *Sesamia inferens* (Walker) during *Rabi* are the most serious pests in our state and causes yield loss of 25-80% during severe conditions. Fall armyworm *Spodoptera frugiperda* an invasive pest was first reported in India during *Kharif*, 2018 and caused havoc. Among sucking pests, incidence of aphids is observed in maize particularly in sweet corn.

Various pests, causes damage to leaves, stem, tassel, and cob and reported to cause significant yield losses. These pests not only affect quantify of the produce but also quality of the produce. Maize pests broadly classified in to stalk borers, sucking pest, leaf feeders, root feeders and cob borers. The major stalk borers are spotted or striped stem borer and pink stem borer, which causes economic yield losses due to dead hearts if unnoticed. Now and then aphids also reported to cause considerable damage in seed production plots due to infestation of tassel. In recent years, often termites causing severe damage by lodging crop, particularly in light soils under rainfed situation. Some times *Spodoptera litura/ S. exigua* is causing severe damage to maize seedlings during *rabi* season. Cob borer damage is reported in sweet corn by *Helicoverpa armigera*, however its incidence on commercial crop is 1-2 % only. Recently silk cutter (Euproctis) incidence is increasing in *Kharif* maize. Often *Chiloloba* beetles are observed on tassel, feeding on anthers as results grain formation may be affected.

Stalk borers / Stem borers:

1. Spotted /striped stem borer (*Chilo partellus*):

Moths are medium sized and in straw colour. 20-25 creamy white oval scale like eggs are laid in clusters at night. Fecundity is around 250-300 eggs. Dirty greyish white larva has black head and four longitudinal stripes on the back. Larval period ranges from 14-28 days. Pupation occurs inside the stem. Moth emerges through the exit hole made on the stem by the larva. Total life cycle is completed in 4-6 weeks. There are 5-6 overlapping generations in a year. In peninsular India, it remains active throughout the year.

Symptoms of damage:

Immediately after hatching, larvae crawl over the leaf for about 15-30 minutes and then feed on the surface of tender leaves, bore downwards through the whorl and reach the growing point of the plant. As the whorl opens, pin holes or shot holes (occur in a parallel fashion) are seen on the leaf surface. The larvae cut the growing point resulting in drying up of the central shoot and subsequent formation of "**dead heart"** which on pulling comes out easily. Larvae feed on the tissues (pith) inside the stem and tunnels are formed due to which not only plant vigour is lost but also reduction in grain yield. With slight wind, plant collapses and dries. Caterpillars also damage by boring into immature cobs and tassels. Losses in yield vary from 26.7 to 80.4% and are attributed to early attack (10-20 days old crop) on the growing plant (Narsimha Reddy *et al.*, 2012).

Dead heart

Parallel holes on leaf blade

2. Pink stem borer (*Sesamia inferens*):

Straw coloured adults have coppery shining scales. Fore wings have a mid longitudinal brown triangular streak. Round pearl like 80-300 white eggs are laid in 2-3 longitudinal rows within the sheaths of bottom leaves of young plants (2-3- weeks old). Eggs become pinkish before hatching. Larva is stout, purplish pink on the dorsal side with reddish brown head. Larval period is 3-4 weeks. Life cycle is completed in 6-7 weeks and there are 4-5 generations in a year (Lavakumar Reddy, 2001).

Symptoms of damage:

Young larvae feed on the epidermal layer of leaf sheath and later bore into central shoot resulting in drying up of growing point and formation of **dead hearts**. Grown up plants show many oval elongated holes on leaf blades. Tunnels formed in the stem are filled with excreta and exit holes are seen. Bottom internodes show circular ring like cuts due to larval feeding. Severe damage causes the stem to break. Larvae also feed on immature cobs and tassels. Larvae have migrating tendency and may attack a number of plants. In peninsular India, it is more serious during *Rabi* season. Losses caused by this varied from 25.7 to 78.9%.

Management of Stem borers:

- Farm sanitation: Removal of infested plants, ploughing the field soon after harvest and collection and burning of stubbles to kill the hibernating larvae and pupae.

- Growing stem borer tolerant hybrids (DHM 117).
- Adjusting the sowing time to avoid peak activity of the borers to coincide with critical stage of the plant (10-12 days old).
- Maintaining optimum plant density in the field (33,000 plants/ac).
- Intercropping with legumes such as cowpea, soybean, redgram and green gram in 2:1 ratio encourages the buildup of natural enemy population.
- Trap crop: Sorghum is the preferred host for *C. partellus*. Sowing 2-3 rows of trap crop on all sides of maize and uprooting it after 45 days.
- Clipping of lower leaves of maize on which most of the eggs are laid.
- Crop rotation with non-host crops destroys the buildup of pest due to non-availability of host.
- Release of egg parasitoid, *Trichogramma chilonis* @ 8 cards per ha twice *i.e.*, at 12 and 22 days after germination.
- *Cotesia flavipes* is the dominant and most widely distributed larval parasitoid.
- Use of recommended dose of fertilizers, avoiding excessive use of nitrogen that increases pest attack.
- Prophylactic spray of Chlorantriniliprole 20 SC @ 0.3 ml/l of water at 10-15 DAG followed by Carbofuran 3G @ 7.5 kg/ha in plant whorls in case of severity.

II. Sucking insects

1. Aphid (*Rhopalosiphum maidis*): Small soft bodied, greenish blue, pear shaped aphids are found in colonies on top leaves, whorls, tassels and on cob husks. Aphids attack the plants at the end of mid whorl stage. It is in serious form during drought years. Colony gets a whitish appearance with the exuviae shed by the developing aphids. Aphids secrete honey dew on which black sooty mould develops.

Symptoms of damage:

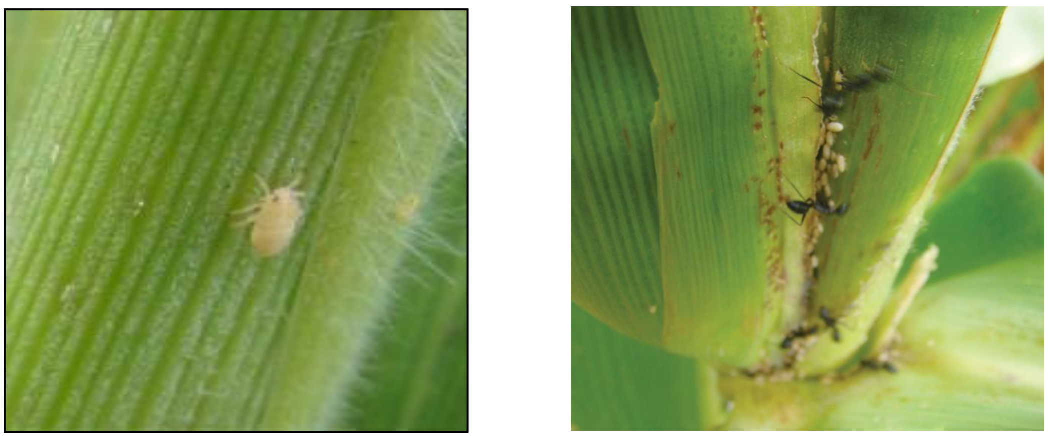
- Both nymphs and adults suck sap from plants causing yellowing and stunting.
- Tassel emergence is prevented and pollen shed is reduced when emerging tassels and the leaves surrounding the tassels are covered with aphids.
- Ear and shoots are also infested and seed set may be affected.

Aphid colony on tassel and leaf

2. Shoot bug (*Peregrinus maidis*): Yellowish to dark brown adults and yellowish nymphs suck sap from leaves, inner side of leaf sheaths and leaf whorls resulting in stunted yellow plants. Leaf midrib turns red due to laying of cigar shaped eggs in rows. Ants are attracted and black sooty mould is formed for the honey dew secreted by the bugs. It is a vector of stripe disease. Life cycle ranges between 18-31 days.

Management:

- The natural enemies will take care of the sucking insects in field conditions.
- Spraying Dimethoate 30 EC @ 2 ml/l or Monocrotophos 36 SC @ 1.6 ml/l of water.

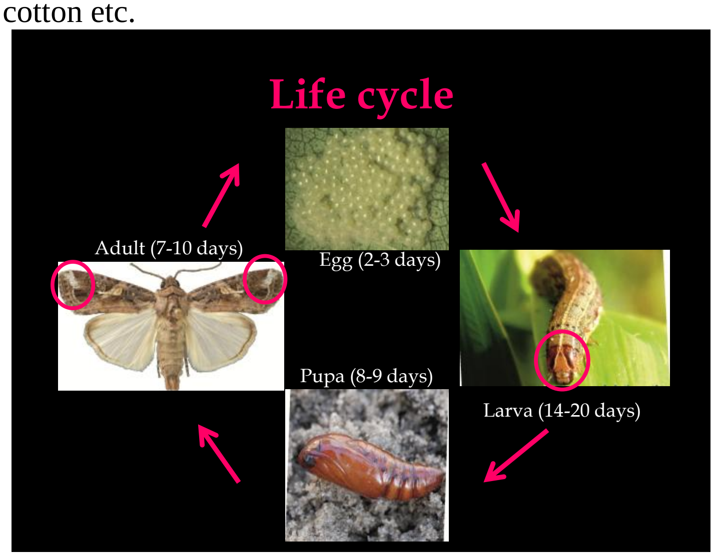


Shoot bug nymphs & adults sucking sap

III. Leaf feeders:

Fall Army Worm (*Spodoptera frugiperda*):

It is polyphagus pest. Prefers grasses, field corn, sweet corn, Sorghum, Grass weed, *Digitaria* spp, Alfalfa, Barley, Buck wheat, Cotton, millet, Peanut, Rice, Sugercane, Soybean, Tobacco, Wheat, Amaranthus spp and vegetables etc., Fall armyworm *Spodoptera frugiperda* (FAW) is reported to have two strains, one is corn Strain and other one is Rice Strain. Corn strain infests sorghum and cotton etc.



Life cycle is competed in 31-40 days and may be prolonged in winter. Number of generations may vary from region to region based on weather and 4-6 generations per annum were reported. No diapause is recorded in FAW. Egg mass (100-200) laid on either side of the leaf and each female lays 1500-2000 eggs after emergence up to 10 days. Size of the egg is 0.3 to 0.4 mm and dome shaped. Incubation period is 2-3 days. Six instars were observed during summer. Young larvae are greenish with black head. Later on, the grownup larva becomes brownish with reddish brown head. A full grown larva has marked with a white inverted 'Y' shaped suture. Four black dots will be observed on last segment of the larvae. The larval period is 14-20 days. The full grown larval size is 34.2 mm. Pupation takes place in soil at a depth of 2-8 cm in cocoon. Cocoon is oval shaped and measures 20-30mm.Pupa is reddish brown in color and measures 14-18 mm in length and 4.5 mm width. Pupal period is 8-9 days. Adult is grey and brown in color. Hind wings are silvery white with a narrow dark marking on edges. It is nocturnal and active during warm and humid evenings. Life span is 10 days with a range of 7-10 days.

Symptoms of damage:

- Young larvae initially feed on leaf tissues from one side leaving the opposite epidermal layer intact (window pane).
- 2nd and 3rd instars larvae feeds and makes holes on leaves and also eat from the edge of the leave inward.
- Feeding in the whorls often produces a row of perforations (holes) in the leaves
- Older larvae cause extensive defoliation often leaving only the ribs and stalks of corn plants or a ragged appearance
- It also burrows through the husk into the ear feeding on kernels.
- In sweet corn 0.2 to 0.8 larvae / plant in late whorl stage cause yield loss by 5 to 20%.

Management:

- Avoid staggered sowing of maize particularly sweet corn..
- Treat the seed with Cyantraniliprole 19.8% + Thiamethoxam 19.8% @ 4 ml per kg seed
- Installation of pheromone traps @8-10 per acre.
- Clean cultivation to avoid alternate hosts.
- Balanced application of fertilizers helps to reduce the incidence of fall armyworm, because of vigor of the plant (enhances immunity).
- Intercropped maize with suitable crops is less preferred over pure maize crop. FAW avoids egg laying on intercropped maize and it also helps to build natural enemies.
- Erection of bird perches @10/acre in early stage of the crop helps to reduce the population.
- Use of trap crops like napier grass which attracts egg laying.
- Desmodium act as a repellant in case of FAW.
- Release of *Telenomus remus* or *Trichogramma pretiosum* @ 50,000/ac at weekly intervals (soon after observation of egg masses in the field).
- Whorl application of *Metarhizium* or *Beauveria* or *Nomuraea* @ 5 g/liter for control of early instars is recommended.
- Application of Sand+lime (9:1 ratio) in whorl @ 10 kg /acre
- Whorl application of Neem formulation (Azadirachtin, 1500ppm) @ 5 ml /l or one lit/acre (to avoid egg laying and to kill the eggs / early instar larvae).
- For management of 2^{nd} and 3^{rd} instars, whorl application of Emamectin benzoate 5 SG 0.4 g per liter or 80 g/acre or Spinetoram 0.5 ml/l or 100 ml/acre (when 5-10%, leaf damage is observed).
- If incidence is very high (>20%) whorl application of Chlorantraniliprole 18.5% SC @ 0.4 ml/l or 80 ml/ac.
- Application of poison bait in whorls for the control of grownup larvae.
  Preparation of poison bait: 10 kg rice bran + 2 kg jiggery and add 2-3 l of water then mix thoroughly and keep 24 hours for fermentation, later on mix 100 g of thiodicarb in the rice bran mixture before 30 minutes of application.

Tobacco caterpillar : *Spodoptera litura* (F.)
Spodoptera exigua (Hubner)

Moth is dark brownish with wavy markings on forewings and whitish hind wings. Egg mass (200 to 300 numbers) is laid on underside of the leaves and covered with brown hairs. First instar larvae are gregarious. Mature larvae are cylindrical, pale greenish brown with rows of dark spots. Pupate in a small cell in the soil. Total life cycle is completed in 30-40 days. Nocturnal larvae defoliate the leaves.

Spodoptera **adult**

Larva feeding on cob

Symptoms of damage:

On hatching, larvae feed on tender leaves in groups. They scrape the surface but do not actually perforate it, creating a window pane effect. Under severe infestation, the entire young plant may be consumed. Later on they migrate and feed on the leaves which give thin papery appearance. The pest activity is observed in *Rabi* season**.**

Management

- Hand picking and destruction of larvae.
- Installation of pheromone traps @ 10/ ha for monitoring purpose.
- Release of egg parasitoid *Telenomus remus* @ 1,25,000/ha for 4 times at 7-10 days interval.
- Application of NPV solution at 250 LE/ha.
- Spraying 5% NSKE or Neem formulation @ 5 ml/l or Monocrotophos @ 1.6 ml/l or Thiodicarb @ 1.5 g/l of water for the management of early instar larvae.
- Application of poison bait (5 kg rice bran + 500 g jaggery + 500 ml Monocrotophos or Quinalphos mixed with sufficient amount of water) on fields during evening times to control later instar larvae.

IV. Cob borer *Helicoverpa armigera* (Hubner):

This pest is polyphagous and feeds on Cotton, sorghum, soybean, groundnut, tobacco, many legumes and vegetables crops.

Moths are large sized with grey forewings and a crescent mark on hind wings. Round eggs are laid on the silks. Newly hatched larvae are light grey with conspicuous small dark hairs, larval colour varies from red/brown to green with striped appearance. Large reddish brown pupae are found on ears/fallen leaves/earthen cocoon.

***Helicoverpa* adult**

Larva feeding on sweet corn cob

Symptoms of damage:

- When fresh silk is available the eggs are laid on the silk
- The larvae first feed on the leaves or bore directly into the silk and the kernels at the tip of the ear are eaten down to the cob.
- The damage reduce the market price of green cob.

Management

- Hand picking and destruction of larvae.
- Installation of pheromone traps @ 10/ ha for monitoring purpose.
- Release of *Trichogramma chilonis* @ 8 cards/ha.
- Natural enemies present in maize ecosystem will control *Helicoverpa* population (*Trichogramma*, *Braconids* and *Tachinids*).
- Spraying of HNPV @ 500 LE/ha
- Spraying of Neem based products @ 5 ml/l or Bt. formulations (Dipel) @ 2 g/l of water at cob formation stage with boom sprayer.
- Spraying Spinosad (45 SC) @ 0.3 ml/l of water at cob formation stage with boom sprayer (Ranga Reddy *et al.*, 2015).

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Stored grain pests of maize and their management

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Introduction

Maize is the most important cereal crop grown in diverse range of environments providing food for human, poultry, live stock and have great nutritional, industrial values. Over the last 6 decades, even though the production of maize has been increasing from 1.73 million tonnes (mt) to 28.75 mt in 2017-18, the productivity remains low. Biotic factors including insect pests are one of the reasons for low productivity of maize in India. Over 130 insect pests, have been reported causing varying degree of damage attacking from seedling to maturity stage and some pests destroy stored products in godowns, bins, storage structures and packages causing huge amount of loss to the stored food and also deterioration of food quality. In India, according to recent estimate by Ministry of Food Processing, agricultural produce worth 580 billion Rupees gets lost every year during storage. Management of post-harvest losses is challenging in tropical and sub tropical regions because of the prevalent climatic conditions. In India, post-harvest losses of food grains are estimated to be around 10 per cent from farm to market level (Fig. 1). In case of maize at farm level, the losses were estimated to be around 3.02 kg/ quintal at various operations (Basappa *et al*. 2007). Maximum losses were observed (2.55) during storage particularly due to insect pests. The most economically important storage pests of maize are rice weevil, (*Sitophilus oryzae* L. Coleoptera: curculionidae), angoumois grain moth, (*Sitotroga cerealella* (Oliv.) Lepidoptera: Gelechidae), rice moth, (*Corcyra cephalonica* Stainton Lepidoptera: Pyralidae), lesser grain borer, (*Rhizopertha dominica* Bostrichidae: Coleoptera) and red flour beetle (*Tribolium castaneum* (Herbst.) Lepidoptera: Tenebrionidae). Among them, *S. oryzae* is the most destructive pest causing both quantitative (weight loss, economic loss) and qualitative (chemical changes, seed viability, contamination, nutritional deterioration) losses by feeding on the kernels. This weevil can infest crop at maturing stage in the field itself or during storage as well. The per cent damage of 53.30 and weight loss of 14% is observed due to *S. oryzae* attack within four months storage (LakshmiSoujanya et al. 2013). Though, post-harvest losses can be reduced by the use of synthetic insecticides during storage these are not recommended due to chances of food contamination, development of insecticide resistance, environmental hazards, chemical residues in food and side effects on non-target organisms.

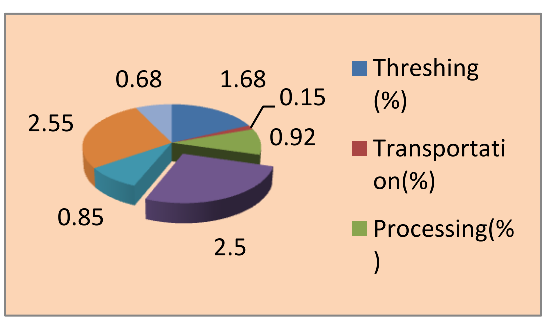

Fig1: Post Harvest losses of food grains in India

1. Rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae)

This pest is widely distributed in tropical and sub tropical regions of the world. The alternate hosts are paddy, wheat, sorghum and barley. The adult is tiny weevil about 2.5 mm long, dark brown or reddish brown in colour. Females lay about 150-300 eggs and hatches in about 3 days. The grub is short, stout “C” shaped that is creamy-white, curved, translucent, yellow or brown head with biting jaws. The larvae feed inside the grain kernel for 18–20 days. The pupa is naked and the pupal stage lasts for 6-7 days. Adults live for 4-5 months. The new adult will remain in the seed for 3 to 4 days while it hardens and matures. The lifecycle is completed in 40–45 days. As it is an internal feeder, both adults and larvae attack the grains and feed voraciously. In case of heavy infestation only pericarp of the kernel is left behind, while rest of the mass is eaten up. The insect can infest crop at maturing stage in the field.

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Fig 1. Egg **Fig 2. Grub** **Fig 3. Adult**

Fig 4. Egg plugs laid by *S. oryzae* **Fig 5. *S. oryzae* feeding on maize kernel**

2. Angoumois grain moth *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechidae)

The alternate hosts are paddy, wheat, sorghum and bajra. Eggs are cylindrical, cigar-shaped laid singly or in small clusters on the surface of the grain which look white at an early stage but later changes to bright red. Caterpillar is white in colour with yellow head. Larva undergoes 4 instars after about six days each at optimum temperature. The adult moth measures 8-10 mm with buff coloured front wings. Hind wings are margined with long hairs, their tips are elongated. The life cycle is completed in 30-32 days.

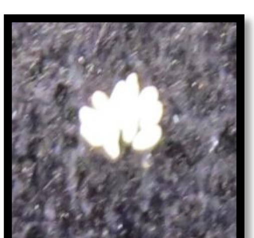

Fig. 6. Eggs **Fig 7. Adult** **Fig 8. Damage symptoms**

Only larvae damage grains, adults being harmless. The larva after hatching, begins to feed on endosperm. As a result, grains are hollowed out resulting into loss of viability. On damaged grains, a circular hole with a characteristic flap or trap door appears. Pest attack is both in fields and stores. In stored bulk grain, infestation remains confined to upper 30 cms depth only.

3. Rice moth *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae)

Rice moth is known to infest severely in unhygienic storage situations. The alternate hosts are rice, jowar, barley, millets, soybean and oil seeds. Adult has a wingspan of 12-15 mm, with greyish brown forewings. The female lays up to 150 eggs within a few days of emergence. The young larva is creamy white with prominent light brownish yellow head. The adults live for 1-2 weeks and drop their eggs in the produce. At maturity, they construct white silken cocoons for pupation. The pupal period lasts for 7-9 days. The adult lives for 7-15 days. Young larva feeds on the broken grains make webbings resulting in grain pollution with large quantities of frass and silken cocoons.

Fig 9. Larva **Fig 10. Adult** **Fig 11. Larva feeding on broken grains**

4. Red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae)

The alternate hosts are cereals, millets, flour, starchy material, nuts and prepared cereal foods. Adults are flat brown, 5-6 mm in length and reddish brown in colour. Eggs are whitish colour, sticky and are laid on the grain/ debris of grains. They are small, cylindrical in shape, rounded at both ends. The larvae are very active, cylindrical and pupate after 3-4 weeks. The pupal stage lasts for 5-9 days. The adult has 4-5 months longevity and feeds through out the life. The life cycle is completed in 3-4 weeks. It feeds on broken grains resulting in dust formation. Infested flour emits sour and pungent smell which is due to secretions of beetles. The presence of larval stage, dead and live adults and odour represent damaged material.

Fig 12. Larva **Fig 13. Adult** **Fig 14. Adult feeding on maize flour**

5. Lesser grain borer *Rhyzopertha dominica* (Fab) (Coleoptera: Bostrichidae)

The alternate hosts are wheat and rice. The full grown larva is dirty white with light brown head and curved abdomen covered with tiny hairs. The larval period varies from 25-28 days. The pupal stage lasts for 7-8 days. It completes its life cycle in 6-8 weeks. Heavily attacked grains become hollowed out and only thin shell remains. After severe infestation adults produce frass and spoil more than what they eat. Profuse powdery substance is the characteristic of its damage.

Fig 15. Adult

6. Khapra beetle *Trogoderma granerium* (Everts.) (Coleoptera: Dermestidae)

The alternate hosts are wheat, barley, oats, cotton seed and dry fruits. The larva is brownish white in colour, body covered with bundles of long reddish brown movable and erectile hairs on the posterior segments and forming a sort of tail in the posterior end. The larval period extends up to 20-25 days. Pupal period is for 4-8 days. The life cycle completes in 33-45 days.The grub feeds on internal part of grain. Adults are harmless. Visible mould occurs. Shed skins and faeces can also contaminate grain and cause allergic reactions.

Management strategies for storage pests

- Cleanliness and sanitation is the most important and first step towards prevention of insect infestation. Dusts, grain, and chaffs should be removed from transport system, storage area as well as threshing yard before using them for new produce after harvest.
- The crop should be harvested at the proper time to prevent egg laying by storage pests.
- The moisture content of grain should be less than 10%.
- Newer grains should not be mixed with older ones.
- Seed stored gunny bags should be kept few inches above the ground.
- Walls and floor of the storage area should be painted/ white washed or sprayed with solution of deltamethrin 2.8EC@1.5ml/l of water/100sqm.
- Malathion 50 EC @ 15ml /4.5 litres of water or 5%NSKE should be sprayed as a thin film on bags before use.
- Through mechanical devices monitoring and mass trapping of stored product insects can be done.
- Staggered sun drying with short exposure to sun spread reduces insect infestation
- By modified atmospheric storage, insects can be controlled by decreasing O_2 or increasing Co_2 or N_2.
- Use of plant products such as *Adathoda vasica*, *Azadirachta indica*, *Vitex negundo*, *Catharanthus roseus* @ 2% w/w (20g /kg seed) have been found to be effective against storage pests.

- Storing of maize in double layered bags is advisable. Application of leaf powder of *Tinospora cordifolia* as water-based paste between the layers of double layered storage bags provide protection against *Sitophilus oryzae* for a period of five months (LakshmiSoujanya *et al*.2018).
- Hermatic control (complete air tightness) is a simple, cheap and effective method of insect management. In this method metabolic activities of insects and microflora act as bio generators that alter the oxygen and carbondioxide composition of the intergranular atmosphere so that insects development is arrested.

Conclusions

Right execution of pre-storage activities will help farmers by reducing the risk of insect pests infestation from field to storage. Preventative measures such as right time of harvest, maintaining optimum moisture content, sanitation in storage area, proper storage structures are essential for effective protection of maize under storage conditions. Utilization of botanicals alone and in combination with different packaging materials reduce rice weevil infestation and its associated losses. Also, application of botanicals through novel methods protects the stored grain with out any adverse effects. Implementation of preventative measures and appropriate use of botanicals in hermetic storage help in strengthening food security and higher returns to small scale farmers.

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Fall armyworm- Status and initiatives taken for its sustainable management in maize

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1. Introduction

Maize (*Zea mays* L.) is a potential crop for doubling farmer's income and is one of the most important cereals consumed as food, feed, fodder and industrial purposes. In India maize is grown in 9.2 mha with production of 28.75 mt. The country represents 4% of global maize area and 2% of global production. Maize was a rainy season (Kharif) crop predominantly in India. It was largely grown in northern India in the states of Uttar Pradesh, Bihar, Rajasthan and Madhya Pradesh. After 1980s a significant shift in area towards peninsular region was noticed. Currently this region represents nearly 40% of the total area under maize and over 52% of production. The major maize growing states are Karnataka (14.8%), Maharashtra (10.9%), Madhya Pradesh (10.8%), undivided Andhra Pradesh (10.4%), Rajasthan (10.6%), Uttar Pradesh (8.3%), Bihar (7.9%), Gujarat (5.0%) and Tamil Nadu (3.6%), accounting for nearly 80% of the total maize area of the country.

2. Distribution and Spread of FAW

Fall armyworm (FAW), is native to tropical and subtropical Americas and known as a pest in the United States since 1797. FAW moths were reported to fly 100 km per night (Johnson 1987), making it potential to invade large swath of land and large area. Simulations based on nightly flight activity of FAW combined with the time gap in the starting and stopping point of migratory path in the USA suggest the pest is aided by regional air transport systems (Westbrook et al. 2016). Outside Americas FAW first invaded Africa, reported from Sao Tome, Nigeria, Benin and Togo during 2016 (Goergen et al. 2016). Subsequently it spread to sub-Saharan Africa invading 44 countries by 2018 (www.cimmyt.org). In the absence of any control measures, FAW is predicted to cause 21-53% loss in annual maize production in Africa (Day et al. 2017). In 2018, the pest invaded Asia probably from Yemen due to its proximity to Africa. In India, its presence was confirmed in May 2018. Since then it has spread within the country and moved eastwards to countries bordering India, *viz.*, Sri Lanka, Bangladesh, Myanmar (December 2018, https://www.ippc.int), China (January 2019, https://www.ippc.int) and Nepal; and to Thailand (December 2018, https://www.ippc.int), South Korea and Japan by July 2019 according to the latest report (https://www.cabi.org/isc/datasheet/29810#todistribution).

The incidence of FAW in India was first observed in Shivamogga district of Karnataka on 18th May, 2018 (by UAHS, Shivamogga). Since then FAW gradually spread to various states. Rakshit et al. (2019) have documented the temporal spread of FAW within India since its report from the state of Karnataka in May 2018. By July, 2018 it was reported from Tamil Nadu and parts of Telangana and Andhra Pradesh (reported by State Agricultural Universities, SAUs). By August and September 2018, it further spread to Maharashtra, Chhattisgarh, and Madhya Pradesh and by September it reached Gujarat (reported by SAUs and DAC). By October 2018, FAW was reported from Bihar and West Bengal in east and from Rajasthan in West (reported by AICRP on Maize) (Fig. 11). It was observed in Kerala by December 2018 (reported by SAU).

By March 2019, it reached in the NEH zone in Tripura and Mizoram (reported by DAC), and by April 2019 it spread to Nagaland (reported by AICRP on Maize). By May 2019, it was recorded in Manipur, Meghalaya, Arunachal Pradesh and Sikkim (reported by ICAR Complex for NEH). Assam, Jharkhand and Uttar Pradesh reported FAW in June 2019 (reported by DAC). FAW incidence was reported in Uttarkhand (reported by AICRP on Maize) and Delhi (reported by ICAR-IIMR) on 31st July and by 6th August in Haryana (reported by AICRP on Maize) and 15th August in Punjab (reported by ICAR- IIMR). Till date, fall armyworm had spread to almost all states except Himachal Pradesh and Jammu and Kashmir.

3. Host Range

FAW is a highly polyphagous pest. Montezano et al. (2018) reported 353 host species for FAW belonging to 76 plant families. Maximum number of host taxa (106) belongs to Poaceae family, followed by 31 taxa each to Asteraceae and Fabacea families. Hardke et al. (2015) reported that though the pest can attack large number of cultivated species, it can cause maximum damage to maize and sorghum. Early et al. (2018) recorded FAW to feed on 182 plant species from 42 families. However, it is primarily a pest of grasses, *i.e.* prefers plant species of Poaceae family, in which maize, rice, sorghum, millets, wheat, oat, fodder and pasture grasses are damaged economically. Non-graminaceous crops, *viz*., soybean, alfalfa and cotton are also economically affected by FAW (Murua et al. 2006, Nagoshi et al. 2018). FAW consists of two strains, *viz.*, corn strain “C” which feeds predominantly on maize, sorghum and cotton; and rice strain “R” which prefers rice and turf grass dominated habitats (Juarez et al. 2014, Nagoshi and Meagher 2016). In India, FAW damage has been documented in sorghum, sugarcane and other millets etc. However, maize is its first preference.

4. Damage by FAW

FAW attacks all crop stages of maize from seedling emergence (V2) to ear development (R6). The young larvae of FAW feed on the opened leaves by scraping and skeletonizing the upper epidermis leaving a silvery transparent membrane resulting into papery spots. The damage also results in pinhole symptoms on the leaves. Later on the larva enters the whorl and start feeding between the leaves. The damage by late instars (3rd instar onwards) result in extensive defoliation of leaves and presence of large amounts of faecal pellets in whorls. Damage during vegetative stage leads to leaf damage but if damage happens during reproductive stage it may infest tassels or may bore inside the cob and eat away the grain. The whorl damage by FAW results in significant yield losses while ear feeding results in both quality and yield reduction.

5. **Initiatives for the management of fall armyworm**

Soon after the report of FAW in India, ICAR mainly through its two institutes, *viz.*, ICAR-Indian Institute of Maize Research (ICAR-IIMR), Ludhiana and ICAR-National Bureau of Agricultural Insects Resources (ICAR-NBAIR), Bangalore, took pro-active measures to contain the damage by FAW. ICAR coordinated with Department of Agricultural and Cooperation, Ministry of Agriculture and Farmers Welfare, Govt. of India towards development of policy interventions to contain the spread and damage by FAW. ICAR-IIMR through its AICRP on Maize network took comprehensive steps to create awareness among the stakeholders as well as policy makers to control the spread and damage by FAW. ICAR-NBAIR and its AICRP on Bio-control partners took extensive measures to control the damage by FAW through biological means. Various modules developed by ICAR-IIMR and ICAR-NBAIR together being implemented through the above two AICRP networks and the network of KVKs under ATARI, Hyderabad, Zone X.

Since the conformation of fall armyworm attacking maize in India, ICAR has undertaken several initiatives to strengthen capacity of the country to respond to fall armyworm attack through ICAR–IIMR, ICAR-NBAIR, AICRP centres. Major initiatives by ICAR-IIMR are given below.

Date	**Action**
Aug 3, 2018	Preliminary management schedule of FAW prepared and sent by Director ICAR-IIMR to Mandya and Coimbatore centres
Aug 7, 2018	Director ICAR-IIMR issued FAW alert to AICRP on Maize Centres and advised to start surveillance
Aug 9, 2018	Meeting in Bengaluru with state agriculture department officials and scientists of CIPMC, ICAR-IIMR and ICAR-NBAIR to discuss management options for FAW under the chairmanship of Joint Director (PP), DPPQ&S
Aug 10, 2018	Management schedule finalized and communicated by Director ICAR-IIMR to DAC&FW
Aug 20,2018	Meeting in Delhi to discuss the outbreak of FAW under chairmanship of Secretary DARE and DG, ICAR
Aug 26, 2018	Fresh management schedule of FAW issued by Director ICAR-IIMR to AICRP on Maize centres adding more chemicals
Aug 28, 2018	Pre-Rabi advisory on FAW management was prepared by ICAR-IIMR for DAC&FW–ICAR interface 2018-19
Sep 26, 2018	CABI – ICAR meeting in Delhi for collaborative Project Proposal (2018-2020) on deployment of proven IPM technologies against FAW
Oct 1, 2018	IPM for rabi season was prepared by ICAR-IIMR with inputs from NBIAR and sent to ADG PP&B
Oct 3, 2018	FAW alert was issued to Director, Agriculture of Bihar govt. and SAU/CAU in Bihar by Director ICAR-IIMR
Nov 2, 2018	Integrated pest management (IPM) schedule for FAW was developed by ICAR-IIMR in collaboration with NBAIR and circulated to AICRP centres
Nov 5, 2018	Director ICAR-IIMR issued FAW alert with IPM schedule to Directors of Agriculture of Zone I, II, III and V
Nov 11, 2018	FLDs on management of FAW were initiated. Two hundred fifty pheromone traps and 800 lures for mass trapping and monitoring of FAW were distributed in Telangana by ICAR-IIMR
Nov 16, 2018	Director ICAR-IIMR conducted meeting on management of FAW with Director, Agriculture and district officials in West Bengal
Nov 29, 2018	Director ICAR-IIMR attended meeting on management of FAW with district agriculture officers of Bihar at Patna
Jan 8, 2019	FAW management package of practice was supplied to DAC, which was adopted in office memoranda dt. May 6, 2019, updated August 16, 2019
Jan 30, 2019	Director ICAR-IIMR issued FAW alert for spring maize for AICRP centres
Feb 10, 2019	To monitor entry of FAW in spring maize pheromone traps were supplied to AICRP Maize centers of NWPZ
Feb 27, 2019	An alert on the possible incidence of FAW was issued to Mizoram Govt. by

	Director, ICAR-IIMR
March 1,2019	ICAR-IIMR organized an interactive session on FAW awareness and management with 26 AICRP on Maize centres at WNC, ICAR-IIMR, Hyderabad
March 12, 2019	FAW management trials at WNC IIMR, Hyderabad was visited by DDG(CS), ICAR and Joint Director (PP), DPPQ & S
April 10, 2019	The incidence of FAW was confirmed in Mizoram by ICAR-IIMR team and documents on FAW identification and management schedule was sent to the state by Director, ICAR-IIMR
April 24, 2019	A quick action strategy as well as integrated pest management module was sent to Director of Agriculture Research and Education, Govt. of Mizoram by Director ICAR-IIMR
May 7, 2019	Director ICAR-IIMR sent advisory on the management of FAW to Director of Agriculture of all the NE states
May 24, 2019	Director ICAR-IIMR sent advisory on the management of FAW and forwarded links of SAWBO Video on "How to identify and scout for fall armyworm" to Director Agriculture and Horticulture of all states. Also sent folder on "Identification and management of Fall armyworm" developed by ICAR-IIMR.
June 20, 2019	For FAW monitoring in Kharif maize, pheromone traps were supplied to all AICRP centres
July 25, 2019	Management strategies for FAW were reviewed under the Chairmanship of Agriculture Commissioner. Biopesticides were distributed by ICAR-IIMR to AICRP Entomology Centres under Peninsular Zone for the management of FAW
Aug 5, 2019	Revised Package of practices for FAW management with inclusion of few new interventions by DAC&FW
Aug 15, 2019	Punjab Agricultural University was alerted regarding detection of FAW at Ludhiana fields
Aug 17, 2019	Survey of maize fields in Punjab by team of ICAR-IIMR and AICRP on Maize, PAU was conducted. Director ICAR-IIMR issued alertness on scouting and control of FAW to Director of Agriculture Bihar, Director of Research, Samastipur and Bhagalpur, Bihar

6. Information Education and Communication Initiatives against FAW

As soon as the pest was reported, the network research system of All India Co-ordinated Research Project (AICRP) on Maize and Bio-control were alerted to scout for the pest and pictures of damage symptoms and pest were shared on android platforms. Regular surveys, surveillance and monitoring were conducted by the Central Integrated Pest Management Centres (CIPMCs) in collaboration with the State Department of Agriculture, SAUs and ICAR institutes.

A. Interphase Meetings with State Government

AICRP centres functioning under various SAU's held consultative interphase meetings with State Government officials to ensure coordinated response for effective action in response to the rapid out break of fall armyworm. Survey of the existence of fall armyworm in maize crop was conducted by constituting State Level Teams comprising of Scientists from different AICRP Centres, CIPMC and Plant Protection Officers of DDA (PP) and State Govt. Officials. Teams visited the fall armyworm infested plots immediately after getting the information about the incidence. All the AICRP centres constituted survey team for different districts and reported to Government.

B. Training programmes

IIMR in coordination with its AICRP centres sensitized towards information dissemination in different training programmes. Campaigning and awareness programmes are being conducted in different states. Awareness was also created by field functionaries in the village level by conducting group meetings. Further efforts are also going on for proper monitoring, awareness and sustainable management of fall armyworm following IPM strategies. Till now ICAR institutes with its coordinating networks have organized 589 major training programmes across the country, where 100 programmes were organized by ICAR-IIMR and/or its AICRP on Maize partners benefitting 11564 personals, 24 by ICAR-IIMR and ICAR RC for NEH benefitting 1782 personals and 30 programmes were organized by ICAR-NBAIR and AICRP Biocontrol centres benefitting 1770 personals, respectively. In addition to this, ICAR-KVKs have been actively involved with state functionaries and NGOs in organizing awareness programmes on FAW management. A total of 407 training programmes were conducted on awareness of FAW by KVK's in Zone X under ATARI, Hyderabad benefitting 33,132 personals.

C. Extension Folders/Leaflets/Pamphlets

IIMR and its AICRP Maize centres have prepared folders/leaflets/pamphlets on the identification and management of fall armyworm and issued advisories. Advisory has been developed based on ICAR-IIMR advisory from the side of the State Department and sent to all concerned authorities for necessary action for the management of fall armyworm. ICAR -IIMR prepared extension folder titled "Identification and management of fall armyworm (*Spodoptera frugiperda*)" in English and translated to Hindi and Punjabi languages.

D. Radio/TV talks

AICRP centres on Maize and Biological Control actively participated in 21 radio/TV talks on FAW in various languages which helped in dissemination of the awareness and information on FAW.

E. Awareness through mass media

Tremendous efforts have been made by IIMR and its AICRP centres in collaboration with State Government officials towards creating awareness of fall armyworm to the maize growing community. The information has been disseminated in big way through media/ news papers.

7. Research Initiatives

On the research side, ICAR-Indian Institute of Maize Research (ICAR-IIMR), Ludhiana and ICAR-NBAIR started a collaborative action where IIMR is working on mass awareness, pest forecasting and management of fall armyworm, whereas NBAIR is working on identification and mass production of biological control agents and microbial pesticides. Integrated pest management schedule was prepared by ICAR-IIMR and ICAR-NBAIR. The same was updated from time to time and circulated through a hierarchy of stake holders through DAC. Cultural techniques, life cycle studies and response of existing lines and land races against FAW has been worked out. Six multi location trials have been constituted by ICAR-IIMR based on the inputs from both ICAR-IIMR and ICAR-NBAIIR, where monitoring the pest in 32 AICRP-Maize centres using ICAR-NBAIR slow releasing dispensor is the notable one, which was aimed at developing a forecasting model for the pest.

8. Collaborations

1. ICAR-IIMR is in collaboration with ICAR-NBAIR to evaluate biocontrol technologies in maize. It is also in collaboration with ICAR-National Centre on Integrated Pest Management (ICAR-NCIPM) to validate and deploy the IPM technologies.
   ICAR-IIMR is also in collaboration with private partners to evaluate chemical pesticides, mating disruption techniques using FAW pheromone and development for FAW forecasting model.
2. ICAR-IIMR is in constant touch with international organizations, especially CIMMYT to share the experiences, germplasm exchange etc. ICAR-NBAIR is in collaboration with CABI in deploying biological control technologies.
3. ICAR-IIMR collaborated with the University of Michigan and SAWBO, to translate SAWBO animated video on FAW identification, scouting and management into different Indian languages (Hindi, Punjabi, Gujarati, Telugu, Kannada, Tamil, Odiya, Bengali, Marathi, Manipuri, Mizo, Nagamese, Malayalam). These are available online in the following links. Apart from this, Malayalam and Marathi translations of the same were co-ordinated by ICAR-KVK and 6 Grain corp. respectively.

- Hindi - https://youtu.be/LlNDUhFCBTs
- Bengali- https://youtu.be/FjIF43ViQEw
- Gujarati- https://youtu.be/s7CcvyaxX7g
- Punjabi- https://youtu.be/4twy79A0Tcc
- Tamil- https://youtu.be/6P2NvZBNDb0
- Telugu- https://youtu.be/DU2lDjnTDLY
- Kannada- https://youtu.be/FwNe4Q-BZT8
- Odia- https://youtu.be/jqE1esjE5_4
- Manipuri- https://youtu.be/_kkbOOxdQxI
- Mizo- https://youtu.be/w0r8j--ZEzo
- Marathi - https://youtu.be/fprog39tUmM
- Malayalam- https://youtu.be/PIZCDvq7kNI
- Nagamese- https://youtu.be/rR81gTgquzc

It can be concluded that fall armyworm has spread all over India except Himachal Pradesh and Jammu and Kashmir and has potential to stretch to other crops such as wheat, rice, sugarcane, sorghum, cotton, pigeon pea and vegetables. Intensive studies, rapid and coordinated action, enormous awareness creation, technological innovation, national, regional and international collaborations are required to tackle the intensity of fall armyworm.

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Identification, Biology, Symptomatology, Monitoring and Scouting for Management of Fall Armyworm

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Introduction

Maize is infested by over 130 insects from sowing till harvest, of which three insect pests, *viz*., spotted stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia inferens* Walker) and shoot fly (*Atherigona* spp.) were of major consequences (Sarup *et al*., 1978, Reddy and Trivedi 2008) till the report of the invasive pest fall armyworm (*Spodoptera frugiperda* J. E. Smith) in May 2018. Fall armyworm (FAW) is native to Americas and is known as a pest in the United States since 1797. It invaded Africa in 2016, where in a span of two years it has spread to 44 countries (www.cimmyt.org). Since its invasion in May 2018 in India, its rapid spread to more than 90 % of maize growing area of diverse agro-ecologies in a span of 16 months presents a major challenge to small holder maize farmers, maize based industry, as well as food and nutritional security. There is no single tool available for controlling FAW, but Integrated Pest Management (IPM) is mooted as a crop protection package to keep FAW population below economic threshold level. Regular monitoring of a pest is the basis of IPM decision making, where, information on identity, current stage in the life cycle of a pest and severity of its damage is gathered. This will help to decide the IPM tool to be used for the time. The chapter elaborate on identification, biology, symptomatology, monitoring and scouting for management of FAW in maize.

Identification

The larvae of fall armyworm appear in shades of green, olive, tan and grey with four black spots in each abdominal segment (Fig. 2) and has three creamy yellow lines running down its back (Fig. 2 d, e & f). It is easily identified from any other armyworm species by its tail end, where the black spots are bigger and arranged in square pattern on abdominal segment 8 (Fig. 2 a) and trapezoid on segment 9 (Fig. 2 b). The head has a predominant white, inverted Y - shaped suture between eyes (Fig. 2 c). Male moth has two characteristic markings, *viz*., a fawn colored spot towards the centre and a white patch at the apical margin of forewing (Figure 3A). Forewing of female is dull with faint markings (Figure 3B).

Fig. 2. Fall armyworm larva with characteristic identification marks, *viz*., four bigger spots arranged in square on abdominal segment 8 (a) and trapezoid on abdominal segment 9 (b), white Y- shaped suture on head (c) and three prominent lines on back (d, e & f).

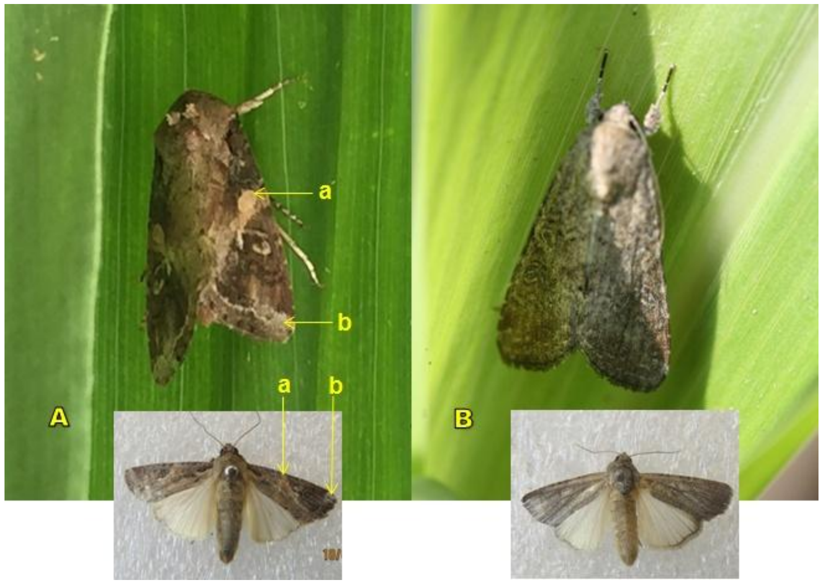

Fig. 3. Fall armyworm Male moth (A) has fawn coloured spot (a) and white a patch (b) at the apical margin of the wing. Female (B) is dull with faint markings

Fall armyworm's life cycle

A female moth lays over 1000 eggs in single or multiple clusters, covered with hairs (Figure 3A a). Incubation period varies from 4.30±0.57 to 5.67±0.58 days. New born larvae in groups disperse from the hatching site and reach to feed on epidermal layers of lower surface of young leaves. Larvae undergo 6 stages called instars (Figure 4 B 1st to 6th) in its growth of 14.33±0.58 to 17.60±0.57 days and then undergo pupation. Pupa is reddish brown in colour (Figure 4 A c) and takes 7.33±0.58 to 8.30±2.30 days to emerge into adult moth (Figure 4A d). Adult moth can survive 3.67±0.58 to 6.30±1.52 days. The total life-cycle takes 30.67±1.15 to 34.60±2.88 days (Figure 4 A) as observed from August to January under natural rearing conditions in ICAR-IIMR Winter Nursery Centre, Hyderabad. Only the larval stage of FAW damages maize.

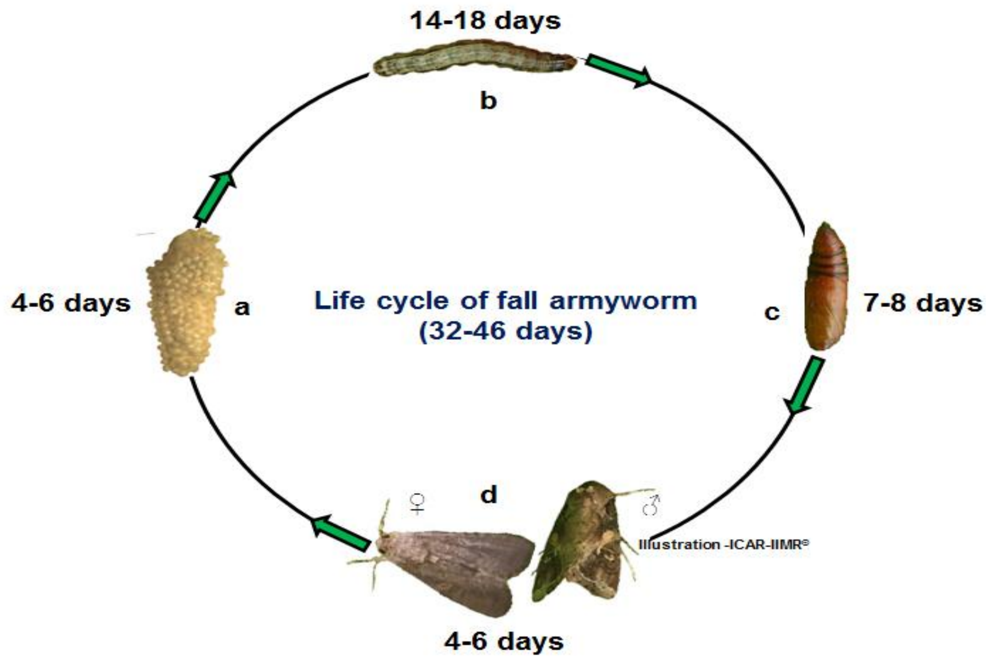

Fig. 4 A Life-cycle of fall armyworm a. Egg mass; b. Larva; c. Pupa; d. Adult female (♀) and male (♂) moths.

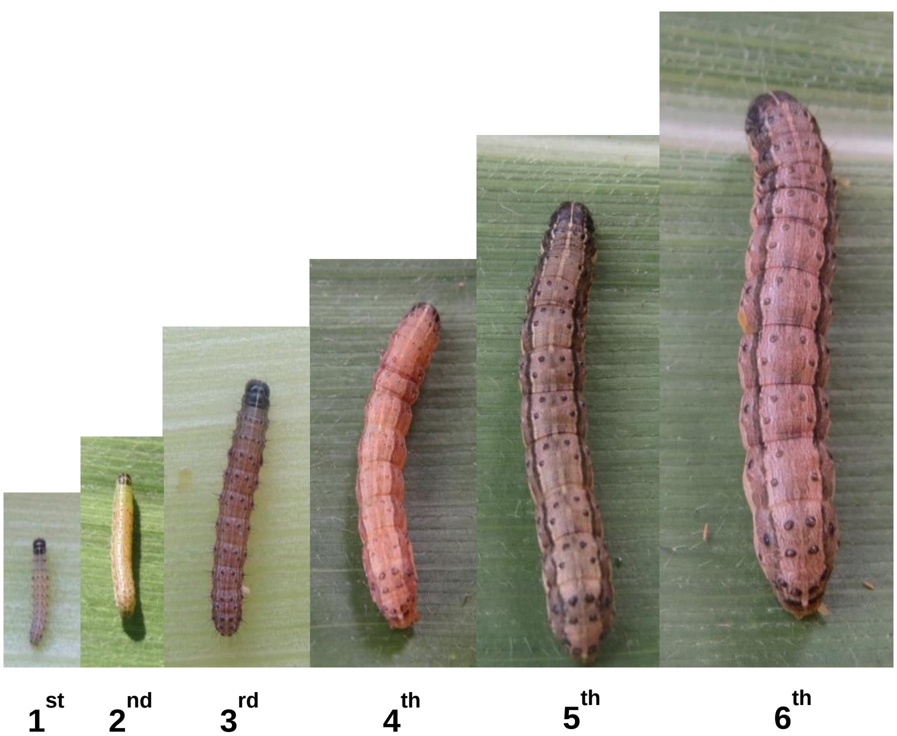

Fig. 4 B. First (1st) to sixth (6th) larval instars of fall armyworm

Symptomatology

FAW attacks all crop stages of maize from seedling emergence to ear development. First and second instar larvae of FAW feed on the opened leaves by scraping and skeletonising the upper epidermis leaving a silvery transparent membrane resulting into papery spots (5 A). The damage by third instar results in shot hole symptoms on the leaves (5 B). The size of the holes increases as the larva grows and damage by late instars results in extensive defoliation of leaves and presence of large amounts of faecal pellets in whorls (5 C, D & E). If infestation continues during reproductive stage, it may damage tassels (Fig. 6 A) or may bore inside the developing ear (Fig. 6 B) and eat away the grain (6 C). The whorl damage by fall armyworm result in significant yield losses while ear feeding results in both quality and yield reduction.

Fig. 5 Progression of symptoms of FAW infestation a. 1st and 2nd instar, b. 3rd instar c. 4th instar d. 5th instar e. 6th instar

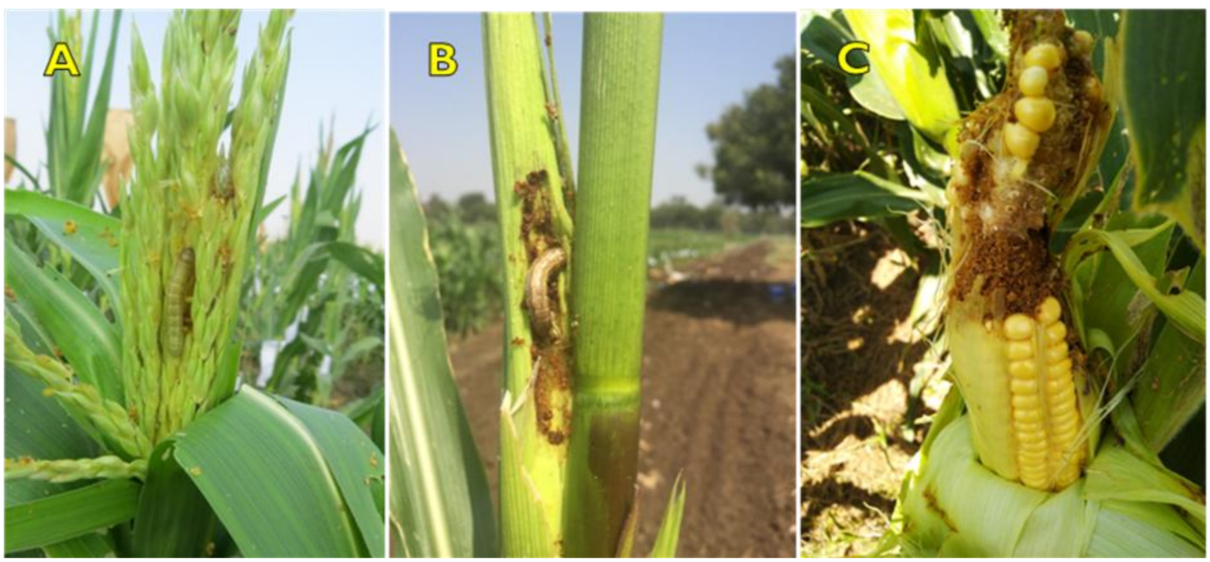

Fig. 6 Damaged Tassel (A) and developing ear (B) and sweet corn (C) by FAW larvae

Monitoring

Early detection and adoption of control measures at the earliest is the motto of FAW management. This is because first to third instar larvae of FAW are quiet small and eat less than 2% of the total foliage consumed in its life cycle, while as it grows to 6th instar, it devours 77% of the total consumption (Sparks 1979) in a span of 2-3 days. Since the severity of damage depends upon size of larvae, the choice of pest control intervention is chosen upon the prevailing symptom. Thus for early detection, monitoring the arrival of moths and its current population is done by installation of pheromone traps @ 4/ac before germination of the crop. On observation of one moth/trap/day or 5% FAW infestation on crop, spray with 5% neem seed kernel extract

(NSKE) or azadiractin, 1500 ppm (1 litre/acre) @ 5ml /litre is recommended as the first intervention since it reduce egg hatchability, harm early instar larvae by antifeedant action and direct mortality, and repel gravid females for sometime from egg laying.

Scouting

A few plants showing FAW damage need not warrant pesticide application; it would not be economical. Also, the threshold level of infestation for deciding control measures increases with crop growth, since the foliage compensation ability of maize increases with growth. Action threshold is determined by 'scouting' which is closely observing/ sampling plants by walking in such a way to cover entire filed. A simple method is by walking in "W" pattern in the field after leaving 4-5 outer rows. Observe 10 plants at each stopping point representing the corners of "W" (Figure 7) and record the number of damaged plants.

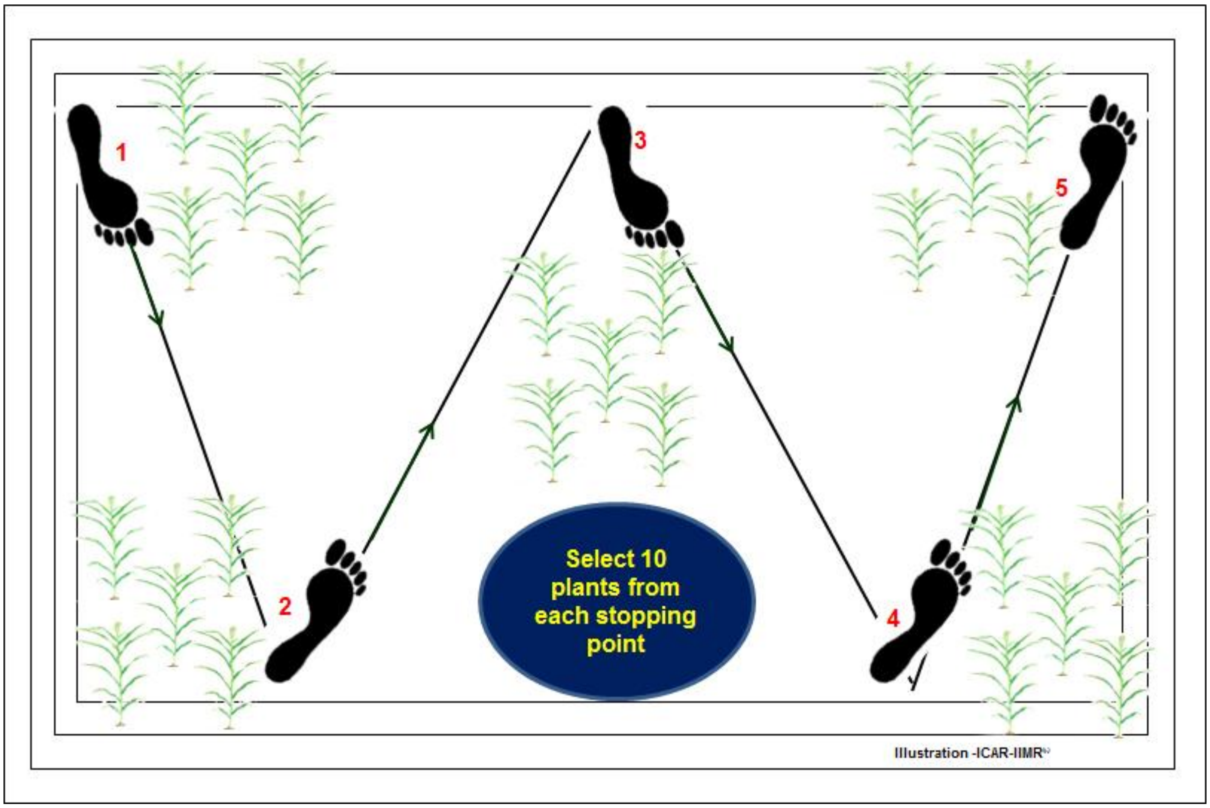

Fig. 7 Scouting methodology to determine action thresholds for management of fall armyworm

Derive the percent infested plants at each stopping point. For instance, if one plant is infested out of ten plants sampled, the percent infestation is 10%. Derive average percent infestation of all stopping points. It warrants a pesticide spray if the average percent infestation is 10% at seedling to six leaf stage, but 20% if the six leaf stage stage is crossed. Scouting should begin as soon as plants germinated or by indication of arrival of FAW by pheromone trap. Scouting should be conducted every week and should continue until the crop is harvested or the risk of pest pressure has passed as in harsh winter and summer months of North India.

Conclusion

The most reliable, but challenging aspect of FAW IPM is early detection of symptoms and determination of action thresholds. For this, scouting must be stressed in extension programmes. The information on the same has been disseminated through various media. However, the most potential one is the animated video at https://youtube.com on FAW identification, scouting and management by Scientific Animations Without Borders (SAWBO), University of Michigan. SAWBO made it available in Hindi, Punjabi, Gujarati, Telugu, Kannada, Tamil, Odiya, Bengali, Manipuri, Mizo and Nagamese in collaboration with ICAR-IIMR and in Malayalam and Marathi in collaboration with ICAR-KVK and 6Grain corp., respectively.

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Management of Fall Armyworm in Maize through Integrated Pest Management

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Introduction

Maize is infested by over 130 insects from sowing till harvest, of which the native insect pests, *viz*., spotted stem borer (*Chilo partellus* Swinhoe), pink stem borer (*Sesamia inferens* Walker) and shoot fly (*Atherigona* spp.) and the invasive pest fall armyworm (*Spodoptera frugiperda* J. E. Smith) pose major consequences. Fall armyworm (FAW), a native of Americas, invaded Africa in 2016, and subsequently entered Asia in May 2018 in India. FAW is considered the most destructive invasive pest in recent times owing to its rapid spread and threatening livelihoods depended on maize, the most remunerative grain crop globally. There is no single tool available for controlling FAW, but Integrated Pest Management (IPM) as a crop protection package is recommended to keep FAW population below economic threshold level. IPM is an eco-friendly approach that focuses on long-term management of pests through a combination of techniques such as deployment of resistant varieties, modification of cultural practices, habitat manipulation and biological control.

In this chapter, tools of IPM and its integration, and guides on action threshold based management is discussed.

Tools of Integrated Pest Management

- **Monitoring**: Installation of pheromone traps @ 4/acre in the current and potential area of spread in crop season and off-season.
- **Scouting:** Start scouting as soon as maize seedlings emerge. Action thresholds and interventions are discussed in Table 1.
- **Cultural Measures:** Cultural measures include tillage and other agronomic practices like intercropping, trap cropping, clean cultivation, balanced use of fertilizers, etc. .
- **Mechanical control:** Hand picking and destruction of life stages of the pest, application of abrasive substances like sand, dry sand, mass trapping of male moths using pheromone traps, etc. are options under this category.
- **Bio Control:** *In situ* protection of natural enemies, and erection of bird perches etc. are conservation biocontrol options. This is complemented with augmentative release of parasitoids and applications of microbial and botanical pesticide formulations.
- **Chemical Control:** This encompasses seed treatment, foliar spray and poison baiting etc. with recommended chemical pesticides

Integration of different tools in pest management based on crop stage

IPM encompasses different tools logically integrated in synchrony with crop phenology. It starts well before sowing.

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible

- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing
- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth $
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Intercrop maize with legumes *viz.*, pigeonpea, cowpea, black gram, kidney bean etc. in 2:1 to 4:1 ratio
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches#
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- Application of sand or soil mixed with lime in 9:1 ratio into whorl of maize plants
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (1 litre/acre) @ 5ml /litre after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 50,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]
- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water is recommended
- If infestation is more than 10%, whorl application of anyone of the recommended insecticides with label claim , *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre or Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre or Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre

Seven leaf stage to flowering

- Monitoring of FAW using pheromone traps @ 4/acre should be continued#
- Spray 5% NSKE^ or azadiractin, 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water is recommended
- If infestation is more than 20%, spray with anyone of the recommended insecticides with label claim *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre or Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre or Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre

- Poison baiting is effective for late instar larvae and is optional. Mix 10 kg rice bran + 2 kg jaggery with 3 litres of water. Keep the mixture for 24 hours to ferment. Add anyone of the recommended insecticides mentioned above at their recommended dosages and 1 kg of sand just half an hour before application. Make into small pellets and apply into whorls of infested plants only. [Use hand gloves during mixing and application]

Flowering to harvest

- Hand picking and destruction of larvae boring into ears
- At 10% ear damage, application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water is recommended

Guides on action threshold based management

Bio-pesticides are recommended for initial symptoms and low infestation rates, while chemical pesticides are recommended at higher infestation levels considering its quick and efficacious control. However, chemical pesticides are the last resort in IPM owing its non-target effects, thus to be used only after monitoring/scouting indicates that they are needed according to action thresholds. Determining action threshold is elaborated in a different chapter in these manual, while choosing a pesticide based on action threshold is given below.

Table 1 Guide on action thresholds and management intervensions in grain corn

Crop stage	Action threshold	Intervention options
Sowing to six leaf stage	One moth/trap/day or 5% infestation on trap or main crop	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water
	One moth/trap/day caught in traps kept for monitoring	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action] **[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 50,000/acre. Two releases of parasitoids at weekly interval should be done. [**Release of parasitoids should not be opted if mass trapping is followed**]
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water is recommended

	>10% infestation	Whorl application of anyone of the recommended insecticides with label claim , *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre or Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre or Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre
Seven leaf stage to flowering	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^{8} cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water
	>20% infestation	Whorl application of anyone of the recommended insecticides with label claim, *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre or Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre or Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre
Flowering to harvest	10% ear damage	Application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^{8} cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @10g/litre of water

[$]**Seed treatment -** as given as per Department of Agriculture and Farmers Welfare (DAC&FW) recommendation dated 16th August, 2019.

[#]**Pheromone traps**– Funnel trap with FAW lure should be installed at a height adjusted each week matching with crop canopy. Traps should be separated by a minimum distance of 75 feet. Observe traps for number of moths caught twice or once in a week and work out the catch/day. FAW lures should be changed once in 30 days in case of monitoring and no lure change is required for mass trapping.

^ Preparation of Neem Seed Kernel Extract (NSKE) for one acre– 10 kg of need seed kernel is required for one acre. Grind 10 kg of need seed kernels to make powder. Soak the powder in 50 litres of water overnight. Stir and filter the contents using cotton cloth. Add 200 g detergent powder or 200 ml of soap solution to the filtered solution. Make up the volume to 200 litres by adding water.

Caution upon release of egg parasitoids - Minimum one week interval should be there between parasitoid release and application of neem or chemical insecticides

Precautions for pesticide use: Not more than two chemical sprays are to be used in entire crop duration. Same chemical should not be chosen for second spray. Sprays should always be directed towards whorl and applied either in early hours of the day or in the evening time. Use protective clothing, facemask and gloves during preparation and application of pesticides. Enter the field only 48 hours after spraying pesticide. Interval between application of chemical insecticide and harvest of corn should be minimum 30 days.

Conclusion

Success of FAW control through IPM depends upon community based and area-wide approach for implementing management strategies. This requires capacity building and mass awareness created in key stake holders through various media.

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Fall army worm (FAW) *Spodoptera frugiperda* (J.E.Smith) in Millets

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Fall Army worm, *Spodoptera frugiperda* (J.E.Smith) is native to Americas and is distributed throughout the Western Hemisphere from Southern Canada to Chile and Argentina. FAW is polyphagous feeding on over 100 recorded plant species belonging to 27 families (Goergen et al. 2016). However, it prefers plants from Gramineae family including many economically important plants such as maize, sorghum, sugarcane, rice, wheat etc.

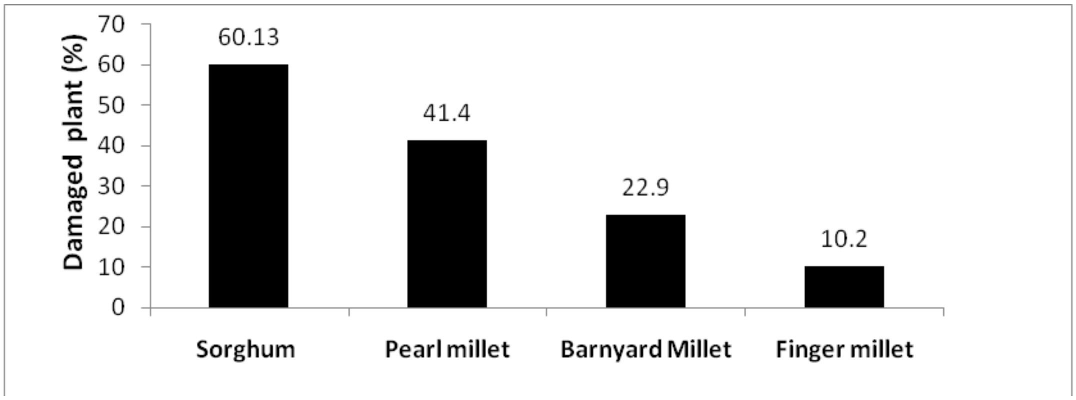
Spread of fall armyworm

A severe outbreak of FAW on corn and millets was documented in 1912 (Walton and Luginbill 1916, Sparks, 1979It invaded Africa in 2016, first reported from Sao Tome, Nigeria, Benin and Togo (Goergen et al. 2016) and subsequently spread to sub-Saharan Africa invading 44 countries by 2018 (www.cimmyt.org). In 2018 it invaded Asia probably in Yemen first due to its proximity to Africa; however its presence was confirmed in July 2018. In India, its presence was conformed in May 2018. Since then it has spread eastwards to countries bordering India viz., Sri Lanka, Bangladesh, Myanmar (December 2018, https://www.ippc.int), China (January 2019, https://www.ippc.int) and Nepal; and beyond it to Thailand (December 2018, https://www.ippc.int), South Korea, and Japan the latest report in July 2019 (https://www.cabi.org/isc/datasheet/29810#todistribution). In India by July 2019, it has covered all maize growing states except the northern states of India viz., Haryana, Punjab, Uttarakhand, Himachal Pradesh, and Jammu & Kashmir. FAW presents a major challenge to small holder maize farmers and the feed and processing industry sectors, the largest consumers of maize. However, to add to the problem sporadically FAW has been reported affecting millet crops as well. Thus, threatening the food as well as nutrition security of the country as whole.

Host preference and economic damage

In Latin America, FAW was observed to cause upto 73% yield losses in maize (Hruska and Gould 1997, Murúa *et al.* 2006). In the absence of any control measures, FAW was predicted to cause 21%-53% loss of the annual maize production in Africa (Day et al. 2017). The pest was closely monitored in sorghum, Pearl millet and small millet (Barnyard, finger millet) and the damage ranged from 1-2 % during kharif, 2018 and it was sporadic. But the rabi sown crop during i.e September – October has experienced medium to severe damage during October – November, 2018.

Fig 1. Incidence of Fall army worm in Millets (Rabi, 2018, IIMR, Hyderabad)



The observations recorded indicated that among them millets sorghum was most preferred followed by Pearl Millet, Barnyard millet and Finger millet suggesting that the severity of infestation was due overlapping generations as evident from presence of first, third, fourth, fifth instars and adults. The sudden outbreak of the pest is also attributed to the vacation of maize crop present in the vicinity. However, multiple management options tried to contain the pest, which were found to be very effective. However, the second damage assessment after management measures revealed reduction in crop damage on sorghum crop in the range of 18 to 40 per cent (Fig 1). It was observed that with the panicle initiation in sorghum ie by 50 – 60 days of seedling emergence the FAW abandons crop and migrates to younger crop or alternate host, thereafter the crop recovers if care is taken by providing irrigation. No damage to panicles was observed in sorghum and other millets.

Symptoms:

Treatments based on the symptoms are the main line of management of FAW as the progression of the damage symptoms gives clue about larval stage and the choice of toxicant based on the larval stage.

Papery patches on leaves: These symptoms are caused by young larvae upto 2^{nd} instar. The young larvae of FAW feed on the opened leaves by scraping and skeletonising the upper epidermis leaving silvery transparent membrane. The larvae scrape both surfaces of leaf leaving papery patches on leaves in seedling to early whorl formation stage. At this stage it is very easy to manage pest by applying neem based insecticide (5 % NSKE) or 1500 ppm azadiractin. Or using fungal pathogen, *Nomurea rileyi* (1 x 10^8 cfu@ 3 grams per liter of water.

Ragged edged holes: These are caused by 3^{rd} instar larvae, the larvae enter the whorl and inflict ragged edged oblong holes on leaf lamina.

Extensive leaf damage: Once the larvae reaches fifth instar it feeds voraciously causing extensive defoliation of the whorl and large amount of soggy fecal matter can be seen. On an average 1-2 larvae were found in each whorl.

Scouting of field: To ascertain the crop damage by FAW in Sorghum, periodically scouting need to done at weekly basis. It is done by entering into the field leaving outer 3-4 rows and moving in “W” pattern stopping at 5 points. At each point access damage in 10 plants. Count the damaged plants in proportion to total plants from all 5 points. Based on scouting insecticidal managements need to be taken if 10 % damage is observed at seedling stage (7 – 20 day old crop); 10- 20 % damage is observed in early whorl stage (20 – 40 day old crop) and > 20 % damage is observed in late whorl to booting stage (40 – 65 day old crop).

Management: Following are the management options suggested to manage the pest:

General management measures:

- Deep ploughing of the field exposes the FAW larvae and pupae to sunlight and natural enemies
- For synchronous planting sow the crop within the sowing window so that single stage of crop is available.
- Deploy pheromone traps @ 12 traps / ha for monitoring the FAW.
- Collect and destroy egg masses/ larvae during scouting
- Erect bird perches @ 25/ha. soon after sowing as it facilitates movement of insectivorous birds viz., black drongo and swallows which predate on flying moths as well as caterpillars.

Early instars (I – II):

- Treat the millet seed with mixture of Cyantraniliprole 19.8 % + Thiomethoxam 19.8% @ 6 ml/ kg of seed as it protects the crop up to three weeks which in turn helps the crop to establish with good initial plant vigour (Based on results of adhoc trials at IIMR, Hyderabad, Kharif, 2019)
- When incidence is low or at early instar stage (7- 30 day old crop), spray Azadirachtin 1500 ppm @ 5ml/liter or 5% Neem seed Kernel extract (NSKE).
- Spray with fungal pathogen, *Nomurea rileyi* (1 x 10^8 cfu@ 3 grams per liter of water

In case of severe infestation (> 10% damage) as a last resort spray crop with Spinetoram 11.7 % SC @ 0.5 ml/l water or Chlorantraniliprole 18.5 @ 0.3 ml/lit of water. Alternate the chemical in subsequent sprays.

Mid instars (III – IV)

- Collect egg masses and larvae and destroy
- Apart from insecticides application of mixture of sand (10kg) and lime 50 grams into the whorls harms the larvae protecting the crop. This was observed at farmers field.
- In case of severe infestation (10 – 20 % damaged plants) as a last resort spray crop with Spinetoram 11.7 % SC @ 0.5 ml/l water or Chlorantraniliprole 18.5 @ 0.3 ml/lit of water. Alternate the chemical in subsequent sprays. Spray using high volume sprayer (Knapsack) preferably in the morning or evening with nozzle directed towards the whorls.

Late instarts (V- VI)):

- The late instar larvae are very difficult to manage using chemicals. In case of presence of late instar larvae baiting is suggested with fermented mixture of rice bran (50 kg), jiggery (4 kg), water (8 liters) and Chloropyriphos 20 EC (500 ml)

    - ➢ Spread 50 kg of rice bran on the floor, to that add 4 kg of jaggery dissolved in two litres of water and sprinkle on the bran evenly.
    - ➢ The required quantity of insecticide is dissolved in two litres of water and sprinkled on the bran.

- Pour, 4 litres of water into the mixture and mix properly wearing gloves.
- Transfer mixture to a gunny bags and hold for 48 hours for fermentation.
- Thereafter apply the prepared bait as small balls during evening hours into the plant whorls where possible and sprinkle on the ground. The fermenting mixture attracts larvae which in turn feed and succumb.

- In case of severe infestation (> 20% damaged plants) as a last resort spray crop with Spinetoram 11.7 % SC @ 0.5 ml/l or Chlorantraniliprole 18.5 @ 0.3 ml/lit of water. Spray using high volume sprayer, the nozzle directed towards the whorls for better control. The subsequent spray may be taken up after 10 -15 days depending on the intensity of infestation avoiding the previously sprayed chemical.

Integrated Pest Management Modules for Fall Armyworm Management in Maize

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Introduction

Integrated Pest Management (IPM) modules are the package of practices for management of fall armyworm (FAW) in maize. Different modules have been developed for different kinds of maize crops viz., grain corn, sweet corn, baby corn, fodder and silage maize. Since FAW infests maize crop as early as two leaves stage to development of corn ears, different measures are adopted as the crop grows. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems so as to encourage natural control mechanisms.

Package of Practices for Management of Fall Armyworm in Grain Corn

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible
- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing
- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth **$**
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Intercrop maize with legumes *viz.*, pigeonpea, cowpea, black gram, kidney bean etc. in 2:1 to 4:1 ratio
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches**#**
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- Application of sand or soil mixed with lime in 9:1 ratio into whorl of maize plants
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (1 litre/acre) @ 5ml /litre after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]

- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 10%, whorl application of any one of the recommended insecticides for FAW, *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended

Seven leaf stage to flowering

- Monitoring of FAW using pheromone traps @ 4/acre should be continued[#]
- Spray 5% NSKE^ or azadiractin, 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 20%, whorl application of any one of the recommended insecticides for FAW, *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended.
- Poison baiting is effective for late instar larvae and is optional. Mix 10 kg rice bran + 2 kg jaggery with 3 litres of water. Keep the mixture for 24 hours to ferment. Add anyone of the recommended insecticides mentioned above at their recommended dosages and 1 kg of sand just half an hour before application. Make into small pellets and apply into whorls of infested plants only. [Use hand gloves during mixing and application]

Flowering to harvest

- Hand picking and destruction of larvae boring into ears
- At 10% ear damage, application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended

Guide on Action Thresholds & Management Of Fall Armyworm On Grain Corn

Crop stage	Action threshold	Intervention options
Sowing to six leaf stage	One moth/trap/day or 5% infestation on trap or main crop	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water
	One moth/trap/day	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action]

	caught in traps kept for monitoring	**[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [**Release of parasitoids should not be opted if mass trapping is followed**]
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>10% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Seven leaf stage to flowering	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>20% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Flowering to harvest	10% ear damage	Application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water

Package of Practices for Management of Fall Armyworm in Sweet Corn

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible

- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing
- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth [$]
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches[#]
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- Application of sand or soil mixed with lime in 9:1 ratio into whorl of maize plants
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (1 litre/acre) @ 5ml /litre after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]
- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 10%, whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended

Seven leaf stage to flowering

- Monitoring of FAW using pheromone traps @ 4/acre should be continued[#]
- Spray 5% NSKE^ or azadiractin, 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended

Flowering to sweet corn harvest

- Hand picking and destruction of larvae boring into ears
- At 10% ear damage, application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended

Guide on Action Thresholds & Management Of Fall Armyworm On Sweet Corn

Crop stage	Action threshold	Intervention options
Sowing to six leaf stage	One moth/trap/day or 5% infestation on trap or main crop	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water.
	One moth/trap/day caught in traps kept for monitoring	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action] **[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [**Release of parasitoids should not be opted if mass trapping is followed**].
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>10% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Seven leaf stage to flowering	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
Flowering to sweet corn harvest	10% ear damage	Application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water

Package of Practices for Management of Fall Armyworm in Baby Corn

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible
- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing
- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth **$**
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches**#**
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- Application of sand or soil mixed with lime in 9:1 ratio into whorl of maize plants
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (1 litre/acre) @ 5ml/litre after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop.
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]
- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 10%, whorl application of any one of the recommended insecticides for FAW, *viz.*, Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended

Seven leaf stage to baby corn harvest

- Monitoring of FAW using pheromone traps @ 4/acre should be continued**#**
- Spray 5% NSKE^ or azadiractin 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- Hand picking and destruction of larvae boring into ears

Guide on Action Thresholds & Management Of Fall Armyworm On Baby Corn

Crop stage	Action threshold	Intervention options
Sowing to six leaf stage	One moth/trap/day or 5% infestation on trap or main crop	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water.
	One moth/trap/day caught in traps kept for monitoring	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action] **[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [**Release of parasitoids should not be opted if mass trapping is followed**]
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>10% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Seven leaf stage to baby corn harvest	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water

Package of Practices for Management of Fall Armyworm in Maize for Silage

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible

- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing
- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth **$**
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Intercrop maize with fodder legumes such as cowpea, horsegram, rice bean etc. in 2:1 to 4:1 ratio
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches**#**
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (1 litre/acre) @ 5ml /litre after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]
- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 10%, whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended

Seven leaf stage to fodder harvest for silage

- Monitoring of FAW using pheromone traps @ 4/acre should be continued**#**
- Spray 5% NSKE^ or azadiractin, 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation.
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended

Guide on Action Thresholds & Management Of Fall Armyworm On Maize For Silage

Crop stage	Action threshold	Intervention options
Sowing to	One	Application of 5% neem seed kernel extract (NSKE) or

six leaf stage	moth/trap/day or 5% infestation on trap or main crop	azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water
	One moth/trap/day caught in traps kept for monitoring	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action] **[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.*,*Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done [**Release of parasitoids should not be opted if mass trapping is followed**]
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>10% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Seven leaf stage to fodder harvest for silage	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water

Package of Practices for Management of Fall Armyworm in Fodder Maize

Pre-planting practices

- Deep plough the fields to expose pupae to sun light and predatory birds
- Add neem cake @ 200kg/acre to the fields when maize is grown with zero tillage or wherever possible
- Maintain field bunds clean and plant flowering plants such as marigold, sesame, niger, sunflower, coriander, fennel etc. to attract natural enemies

Sowing to six leaf stage

- Timely and uniform sowing over larger area
- Follow ridge and furrow planting method instead of flat bed sowing

- Apply only the recommended dosage of NPK as basal dose
- Seed treatment: Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6 ml/kg of seed offers protection for 15-20 days of crop growth **$**
- Plant 3-4 rows of napier grass/hybrid napier as trap crop around maize fields
- Intercrop maize with fodder legumes *such as* cowpea, horsegram, rice bean etc. in 2:1 to 4:1 ratio
- Erect bird perches @10/acre to encourage natural FAW predation by birds
- Install pheromone traps @ 4/acre soon after sowing and monitor moth catches**#**
- Adopt clean cultivation to eliminate possible alternate hosts
- Destruction of egg masses and larvae by crushing
- First spray should be with 5% neem seed kernel extract (NSKE)^ or azadiractin, 1500 ppm (one litre/acre) @5ml /l after observation of one moth/trap/day or 5% FAW infestation on trap crop or main crop
- If monitoring indicates more than one moth/trap/day install pheromone traps @ 15/acre for mass trapping [*Note: For success of mass trapping go for community action*] **OR** release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [*Note: Release of parasitoids should not be opted if mass trapping is followed*]
- At 5-10% infestation whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/l or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended
- If infestation is more than 10%, whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre is recommended

Seven leaf stage to fodder harvest

- Monitoring of FAW using pheromone traps @ 4/acre should be continued**#**
- Spray 5% NSKE^ or azadiractin, 1500 ppm (one litre/acre) @5 ml /l after observation of one moth/trap/day or 5% of fresh FAW infestation.
- If infestation is more than 10%, whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600ml/acre) @3ml/ litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water is recommended.

Guide on Action Thresholds & Management Of Fall Armyworm On Fodder Maize

Crop stage	Action threshold	Intervention options
Sowing to six leaf stage	One moth/trap/day or 5% infestation on trap or main crop	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/litre (1 litre/acre) of water

	One moth/trap/day caught in traps kept for monitoring	Install pheromone traps @ 15/acre for mass trapping of male moths [For success of mass trapping go for community action] **[Mass trapping should not be an option if parasitoid releases are planned]**
		Release egg parasitoids *viz.,Telenomus remus* @ 4000/ acre or *Trichogramma pretiosum* @ 20,000/acre. Two releases of parasitoids at weekly interval should be done. [**Release of parasitoids should not be opted if mass trapping is followed**]
	5-10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water
	>10% infestation	Whorl application of any one of the recommended insecticides for FAW, *viz.,* Chlorantraniliprole 18.5 SC (80 ml/acre) @ 0.4 ml/litre; Thiamethoxam 12.6 % + Lambda cyhalothrin 9.5% ZC (50ml/acre) @ 0.25 ml/litre; Spinetoram 11.7 % SC (100ml/acre) @ 0.5 ml/litre; Emamectin benzoate 5% SG (80g/acre) @ 0.4g/litre
Seven leaf stage to fodder harvest	5% infestation	Application of 5% neem seed kernel extract (NSKE) or azadirachtin 1500ppm @ 5ml/l (1 litre/acre) of water
	>10% infestation	Whorl application of *Bacillus thuringiensis* v. *kurstaki* formulations (400g/acre) @ 2g/litre or *Metarhizium anisopliae* or *Beauveria bassiana* with spore count of 1×10^8 cfu/g (1 kg/acre) @ 5g/litre or SfNPV (600 ml/acre) @3ml/litre or entomopathogenic nematode (EPN) (4kg/acre) @20g/litre of water

$ **Seed treatment** - as given as per Department of Agriculture and Farmers Welfare (DAC&FW) recommendation dated 16th August, 2019.

Pheromone traps– Funnel trap with FAW lure should be installed at a height adjusted each week matching with crop canopy. Traps should be separated by a minimum distance of 75 feet. Observe traps for number of moths caught twice or once in a week and work out the catch/day. FAW lures should be changed once in 30 days in case of monitoring and no lure change is required for mass trapping.

^ **Preparation of Neem Seed Kernel Extract (NSKE) for one acre**– 10 kg of need seed kernel is required for one acre. Grind 10 kg of need seed kernels to make powder. Soak the powder in 50 litres of water overnight. Stir and filter the contents using cotton cloth. Add 200 g detergent powder or 200 ml of soap solution to the filtered solution. Make up the volume to 200 litres by adding water.

Caution upon release of egg parasitoids - Minimum one week interval should be there between parasitoid release and application of neem or chemical insecticides

Precautions for pesticide use: Not more than two chemical sprays are to be used in entire crop duration of grain corn. Same chemical should not be chosen for second spray. **Not more than one chemical sprays is to be used in sweet corn, baby corn, fodder and silage maize.** Sprays should always be directed towards whorl and applied either in early hours of the day or in the evening time. Use protective clothing, facemask and gloves during preparation and application of pesticides. Enter the field only 48 hours after spraying pesticide. Interval between application of chemical insecticide and harvest of corn should be minimum 30 days. Note: The label claim/extension of Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS and Emamectin benzoate 5 SG is subjected to CIBRC, Govt. India.

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Screening techniques for Fall armyworm *Spodoptera frugiperda* (J. E. Smith)

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Introduction

Fall armyworm *Spodoptera frugiperda* (J. E. Smith) has become the most destructive insect pest of maize since its invasion in May 2018. It is a polyphagous pest that attacks more than 100 plant species including maize, sorghum, sugarcane, vegetable crops etc. FAW attacks maize at all stages of its growth right from from seedling emergence to ear development stage resulting in yield reduction of 14.3 to 22.7% (Harrison 1984). Though use of insecticides result in effective management of FAW but have many adverse effects such as development of resistance, human health hazards, toxic to non target organisms and environmental pollution. In this context, Host Plant Resistance based approaches are the best alternatives. Utilizing diverse crop genetic resources that confer insect resistance has long been one of the most effective strategies for the integrated pest management programme in maize. More over as the attack of FAW starts from seedling stage of maize, it is necessary to develop and test the resistance/ susceptibility at an early stage. The success of breeding programmes including Marker Assisted Selection, development of insect resistant genotypes depends upon the precision of screening techniques. Screening of maize germplasm against fall armyworm can be done both under natural and artificial conditions. Even though germplasm screening can be taken under high natural infestation of FAW, screening through artificial infestation provides most precise and accurate data in classification of genotypes. This ensures that pest escapes or feeding preferences do not lead to errors in evaluation of resistance.

For classifying Host Plant Resistance to insects, Painter (1951) proposed three categories namely Preference (antixenosis), antibiosis, and tolerance. Antixenosis refers to the host plant effect on insect behavior that deters oviposition and/or feeding. Natural field infestations, caged field plots, and greenhouse experiments that give insects a choice of plants to feed on are used to identify antixenosis (All et al. 1989; Hill et al. 2004; Rowan et al. 1991). Antibiosis refers to the adverse host plant effect on the physiology and life history of the insect. The adverse effect can be measured as increased mortality, slowed development, or decreased fecundity. No-choice experiments, which restrict the insect to feed on a single genotype, are used to measure antibiosis. These assays are usually conducted in controlled environments, such as growth chambers or greenhouses (Hill et al., 2004; Zhu et al., 2008).

For measuring antibiosis, newly hatched FAW caterpillars are to be separated into individual petri dishes 9 cm in diameter with humidified filter paper and corn leaves (30 days old), which will be then closed using a polyethylene film. Fresh food will be provided daily. The following biological parameters are to be evaluated. (a) Larval stage: the viability of the larval stage and weight of larvae at ten days and (b) pupal stage: the viability and weight of pupae at 24 h of age. After emergence of moths the longevity of the adults will be evaluated without food (Paiva et al. 2016).

Simplified visual foliar damage ratings and indices facilitate quick and easy screening of lines against FAW that does not require tedious counts throughout the growing season. The protocols for natural and artificial infestation of FAW and also the visual rating scales based on foliar and ear damage under field conditions have been mentioned in detail.

Natural infestation

Natural infestation is usually conducted by selecting an area with a predictable, high level of FAW infestation, commonly referred to as a "hot spot" area. Natural infestation may be used effectively by adjusting planting dates so that the desired growth stage for infestation coincides with peak periods of pest incidence. However, natural infestation makes it difficult to achieve sufficient uniformity in the distribution of the infestation, or to control the level of infestation among the screening materials. This is because the insects are prone to escape, or there may be excessive infestation or differential attraction. The susceptible check is to be planted at periodic intervals to ensure the required insect pressure. Screening under natural infestation should be done under conditions where insect population is nearly stable across the seasons. The degree of leaf feeding damage are visually rated at 25-30 DAG using a modified scale of 1–9 described by Ni et al. (2011) based on the rating scale described by Davis et al. (1992) and Smith et al. (1994). Further data on total number of damaged plants and total number of damaged leaves/ plant will also be taken for considering resistance/susceptibility criteria.

Artificial infestation

The most reliable method of screening maize genotypes against FAW is through artificial infestation technique. During screening under artificial conditions, 15–20 neonate larvae per plant (Davis et al. 1996) will be released manually or with modified bazooka insect applicator (Wiseman and Gourley 1982) into the whorls of each maize plant at 10-12 DAG. Precalibrations of the 'bazooka' will be made in the laboratory prior to infestations on each seedling test. Neonate larvae to be released early in the morning (between 7 and 10 am) or late afternoon (after 4 pm), to avoid exposing the neonates to harsh, sunny conditions that could desiccate the larvae before they are conditioned to the micro climatic conditions. Rating scales are commonly used to quantify the performance (resistant or susceptible) of the plant(s) after infestation in a screen/ net-house conditions.

The degree of leaf feeding damage are visually rated twice *i.e.* at 7^{th} and 14^{th} day after infestation using a modified scale of 1–9 described by Ni et al. (2011) based on the rating scale described by Davis et al. (1992) and Smith et al. (1994). Further data on total number of damaged plants and total number of damaged leaves/ plant will also be taken for considering resistance/susceptibility criteria.

Plate 1. Egg mass of FAW

Plate 2. Neonates of FAW

Germplasm rating based on foliar damage (Ni et al. 2011)

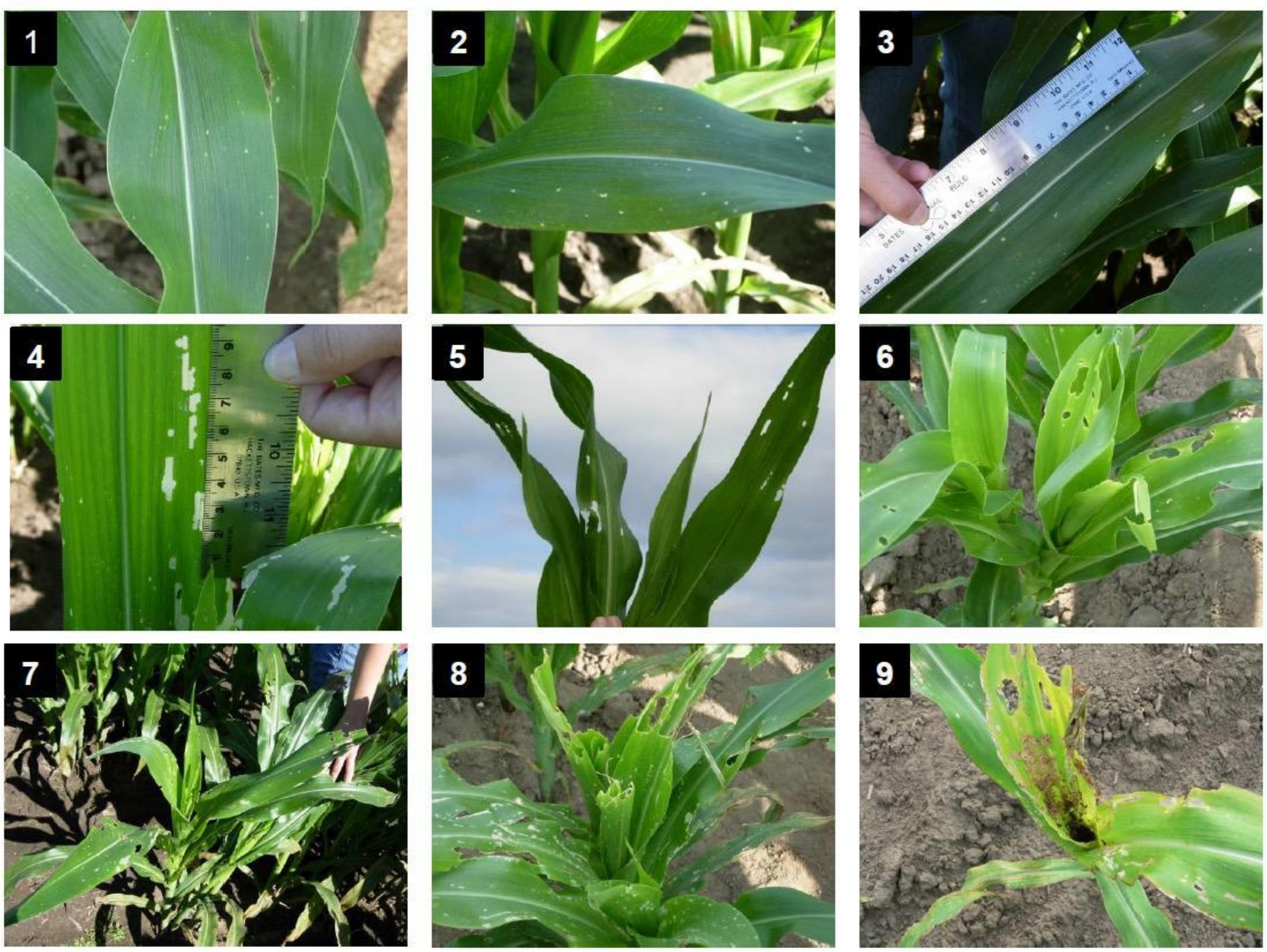
Score	Damage symptoms/ Description	Response
1	No injury or few pinholes	Resistant
2	Few short holes (also known as shot holes) on several leaves	Resistant
3	Short holes on several leaves	Resistant
4	Several leaves with short holes and a few long lesions	Resistant
5	Several holes with long lesions	Moderately Resistant
6	Several leaves with lesions <2.5 cm	Moderately Resistant
7	Long lesions common on one half of the leaves	Susceptible
8	Long lesions common on one half to two thirds of leaves	Susceptible
9	Most leave with long lesions, and complete defoliation was observed	Susceptible

Germplasm rating based on foliar damage (Modified from Davis and Williams 1992)

Score	Damage symptoms/ Description	Response
1	No visible leaf feeding damage	Highly resistant
2	Few pinholes on 1-2 older leaves	Resistant
3	Several shot-hole injuries on a few leaves (<5 leaves) and small circular hole damage to leaves	Resistant
4	Several shot-hole injuries on several leaves (6–8 leaves) or small lesions/pinholes, small circular lesions, and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves	Moderately Resistant
5	Elongated lesions (>2.5 cm long) on 8-10 leaves, plus a few small- to mid-sized uniform to irregular-shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves	Moderately Resistant
6	Several large elongated lesions present on several whorl and furl	Susceptible

	leaves and/or several large uniform to irregular-shaped holes eaten from furl and whorl leaves	
7	Many elongated lesions of all sizes present on several whorl and furl leaves plus several large uniform to irregular-shaped holes eaten from the whorl and furl leaves	Susceptible
8	Many elongated lesions of all sizes present on most whorl and furl leaves plus many mid- to large-sized uniform to irregular-shaped holes eaten from the whorl and furl leaves	Highly Susceptible
9	Whorl and furl leaves almost totally destroyed and plant dying as a result of extensive foliar damage	Highly Susceptible

Wiseman and Widstrom (1980) reported release of 20-40 FAW larvae per plant was the most efficient technique to screen maize germplasm. Hershey (1978), Wiseman et al. (1980) and Smith (1982) concluded that time(s) of rating is critical for detecting differences in resistance or susceptibility. In addition to categorizing the amount and type of damage (antibiosis type resistance reaction) to maize plants by FAW, CIMMYT has been using the yield differential technique of Hershey (1978) to try to capitalize further on tolerance type resistance. In this technique, yield comparisons between paired infested and protected plots or progeny rows are made and selection criteria include selecting progenies which are able to yield reasonably well in spite of the FAW damage sustained. However, results from using this technique to date (Hershey, 1978; Smith 1982) have not been encouraging.



Visual guide of Davis scale

Source: www.irac-online.org

FAW is able to cause significant ear/kernel damage when the larvae gain entry into the developing ears along with extensive foliar damage on susceptible germplasm. Therefore, germplasm rating under natural/artificial infestation must also consider potential damage caused by the insect on the ears and kernels. Individual ears for each of the germplasm entries are scored at the time of harvest, and the average ear damage score for a germplasm entry is then computed.

Germplasm rating based on ear damage (Davis and Williams, 1992)

Score	Damage symptoms/ Description	Response
1	No damage to the ear	Resistant
2	Damage to a few kernels (<5) or less than 5% damage to an ear	Resistant
3	Damage to a few kernels (6-15) or less than 10% damage to an ear	Resistant
4	Damage to 16-30 kernels or less than 15% damage to an ear	Moderately Resistant
5	Damage to 31-50 kernels or less than 25% damage to an ear	Moderately Resistant
6	Damage to 51-75 kernels or more than 35% but less than 50% damage to an ear	Susceptible
7	Damage to 76-100 kernels or more than 50% but less than 60% damage to an ear	Susceptible
8	Damage to >100 kernels or more than 60% but less than 100% damage to an ear	Susceptible
9	Almost 100% damage to an ear	Susceptible

Source: CIMMYT unpublished protocol

Conclusion

Visual assessment of plants using scales or indices is the most common type of resistance evaluation. In this chapter, comprehensive criteria of resistance including foliar damage at vegetative stage, ear damage at harvest have been described for effective screening of maize germplasm against FAW. These techniques will help in the identification of resistance sources and phenotyping studies in breeding programmes for the development of resistant maize genotypes.

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Agro-technique for management of FAW

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FAW is a polyphagous pest. Hardke et al. (2015) reported that though the pest can attack large number of cultivated species, maximum damage it can cause is to maize and sorghum. Early et al. (2018) recorded FAW to feed on 182 plant species from 42 families. However, it is primarily a pest of grasses, *i.e.* prefers plant species of Poaceae family, in which maize, rice, sorghum, millets, wheat, oat, fodder and pasture grasses are damaged economically. Non-graminaceous crops, *viz*., soybean, alfalfa and cotton are also economically affected by FAW (Murua et al. 2006, Nagoshi et al. 2018). Montezanoet al. (2018) reported 353 of host species for FAW larvae belonging to 76 plant families. Maximum number of host taxa (106) belongs to Poaceae family, followed by 31 taxa each to Asteraceae and Fabacea families. FAW consists of two strains, *viz.*, corn strain “C” which feeds predominantly on maize, sorghum and cotton; and rice strain “R” which prefers rice and turf grass dominated habitats (Juarez et al. 2014, Nagoshi and Meagher (2016). Prevalence “R” was reported in Africa, damaging maize as much as the “C” strain (Srinivasan et al. 2018), but the infestation pattern was typical to C strain *i.e.* damaging maize and sorghum only (Nagoshi 2019). Molecular genetic diversity studies suggests that the genetic stock in India belong to “R” strain (Swamy et al. 2018), but under laboratory conditions, it fed on cabbage, tomato, groundnut and sugarcane, but not on rice (Sharanabasappa et al. 2018).

The above reports suggest rice-feeding strain is not present in India and further studies are needed to confer “R” status or redefining the haplotypes in non-pan American context. In spite of these conflicting reports, to the best of our understanding FAW in India and Indian sub-continent prefers to attack maize the most followed by sorghum and other millets. However, isolated reports of FAW on sugarcane and rice are available from India but they are not found to cause economic damage or complete life cycle on these alternate crops.

Governments and other stakeholders in their haste to limit the damage caused by the pest, governments in affected regions may promote indiscriminate use of chemical pesticides,” say the authors of a recent study on fall armyworm management. “Aside from human health and environmental risks,” they explain, “these could undermine smallholder pest management strategies that depend largely on natural enemies.”

Agro-ecological approaches offer culturally appropriate, low-cost pest control strategies that can be easily integrated into existing efforts to improve smallholder incomes and resilience through sustainable intensification. Researchers suggest these should be promoted as a core component of integrated pest management programs in combination with crop breeding for pest resistance, classical biological control and selective use of safe pesticides.

However, the suitability of agro-ecological measures for reducing fall armyworm densities and impact must be carefully assessed across varied environmental and socioeconomic conditions before they can be proposed for wide-scale implementation(Agro-ecological options for fall armyworm (Harrison et al., 2019).

Zero-tillage and FAW:

Surface crop residue retention helped in conservation of natural enemies of FAW and result in enhanced pest predation and parasitism (Murrell, 2017). Maize crop with frequent weeding and practicing zero-tillage had lower incidence of FAW, while intercropping of pumpkin was found to promote its incidence in Eastern Zimbabwe (Baudron et al. 2019). FAW damage was found to be significantly reduced by frequent weeding operations and by minimum- and zero-tillage (Baudron et al. 2019). FAW damage was found to be lower for maize crops established through zero-tillage compared to maize crops established through conventional tillage in all three models. Minimum-tillage was also found to decrease FAW damage in two models. Similar results were reported in Florida and Mexico, with lower FAW damage hypothesized to be due to higher densities of general predators (e.g., carabid beetles, rove beetles, spiders, ants) in minimum-tillage plots (Clark et al., 1993; Rivers et al., 2016).

The higher density of general predators in zero- and minimum-tillage plots may be attributed to an increase of alternative prey due to the organic mulch left on the soil surface when tillage is reduced or foregone (Landis et al., 2000). The lower FAW damage found in two of the three models when manure or compost were applied may be explained by similar mechanisms i.e., organic material on the soil surface leading to higher densities of alternative prey for general predators (Landis et al., 2000; Thomson and Hoffmann, 2007). On the other hand, Kumar and Mihm (2002) have found that zero-tillage combined with mulching tended to significantly increase damage by FAW on maize hybrids. It has been suggested that this might be due to the retention of moisture in the mulch, which provides optimum conditions for larval feeding. In addition, moisture retained in the mulch was reported to attract ovipositing moths for some other lepidopteran species (Kumar, 1994).Crop nutrition also plays an important role in managing FAW damage and needs standardization in Indian conditions. By improved crop nutrition and soil health, plants develop well before the pest significantly affects yield components; and also invest more in defense (Chapin 1991).

Intercropping with legumes

Cropping systems and cultivation practices can change the FAW incidence in various agro- ecologies. Inter-cropping with legumes reduces pest damage by improving soil health and fertility, preventing female moths from laying eggs probably by olfactory disruption, inhibiting movement of larvae among from plant to plants and provide habitat for natural enemies (Harrison et al. 2019). Also intercropping with repellent plants such as *Tephrosia*and *Desmodium* repel the adult female FAW moths and reduce the number of eggs laid on host plants (Harrison et al. 2019). Legume species intercropped with maize viz., cowpea, groundnut, and common beanfound to have lower incidence of FAW due to repelling effect. Intercropping of pigeonpea in strips of alternate row found to be effective for decreasing FAW incidence in India.

Identifying the location specific intercropping/mixed cropping systems suited to varied agro-ecological region for India could be the most sustainable technology especially for small holder farmers as it is based on locally available plants and not depending upon expensive external inputs. It is a core component of integrated pest management programs in combination with breeding for pest resistance, biological control and safer pesticides. Manipulating the time of host plant development relative to pest pressure including early planting, crop rotations works well for FAW management.

Conversely, pumpkin intercropping was found to significantly increase FAW damage (Baudron et al. 2019). Pumpkins (*Curcubita* spp.) are known to be FAW host plants (https://www.cabi.org/isc/datasheet/29810) but in our study, only maize plants were scouted. Pumpkins may provide better shelter habitat than maize for FAW moths during the day. The closed canopy leaves of pumpkins may also offer 'bridges' to larvae which fall short of their 'landing zones' when ballooning from the maize plants where they hatched (Zalucki et al., 2002).

Best weed management:

FAW damage was found to be significantly reduced by frequent weeding operations, as graminaceous weeds, which are dominant in the agroecologies considered, are likely to host FAW.Frequent weeding tended to decrease FAW damage in all three models. This may be explained by the fact that the weed flora in the study areas tends to be dominated by graminaceousspecies that may be FAW hosts. Similarly, the fact that FAW damage tended to be higher for maize crops following a fallow – in all three models – may be due to the dominance of graminaceous species in short-term fallows. However, we should be cautious with this finding as native grasses and weeds may also host natural enemies of FAW (e.g., Hay-Roe et al., 2016). Conversely, they may also host other crop pests like stemborers (*B. fusca* and *C. partellus*) with which FAW shares the same habitat (Le Rü et al., 2006; Moolman et al., 2014; Van den Berg, 2017). If research confirms that graminaceous weeds attract FAW, it could be recommended to avoid having graminaceous plants mixed with maize within the field, but graminaceous plants could be planted around the field as a trap crop. This is one of the key principles of the push-pull technology, originally developed to control lepidopterousstemborers (Khan et al., 1997). Midega et al. (2018) recently demonstrated the effectiveness of the push-pull technology in controlling FAW as well.

Push-pull technology:

Midega et al. (2018) reported that farmers who implemented the Push-Pull approach reduced FAW infestation and crop damage by up to 86%, with a 2.7-fold increase in yield relative to neighboring fields that did not implement the approach. In this approach, pest repelling legumes like *Desmodium*spp. or *Tephrosia*plants intercrop for push the insect outside crop areas while on the border pest-attractive trap plant species such as napier grass (*Pennisetumpurpureum*Schumach.) or *Brachiaria*spp planted to 'PULL' the pest towards them. Hence, the pest will deter from main field due to volatile produced from these legume intercrops and will move to border for attractive crop. Such systems are characteristic of subsistence agriculture and smallholder farmers in India.

In addition to a trap crop, the push-pull technology is based on the use of a repellent crop – generally *Desmodium* spp. or another legume – intercropped with maize (Khan et al., 1997).However, and although this was not demonstrated for FAW, Kebede et al. (2018) found common bean to be as effective as *Desmodium* spp. in repelling *B. fusca*. Thus, although the potential to control FAW through push-pull appears high in sub-Saharan Africa, further research is needed to determine which companion crops (trap crops and repellent crops) would be the most efficient in controlling FAW and the most acceptable to smallholders.

So, agroecological practices such as intercropping, conservation agriculture, agro-forestry improve the health of the crop, provide shelter and alternative food sources to natural enemies and ultimately reduced the ability of FAW larvae to move between host plants (Thierfelder et al. 2015). Some of the promising practices identified are given in Table 1.

Table 1. Cultural and landscape management options for control of FAW

S. No.	Method	Description	Reference
1.	Planting at recommended/optimal time	Planting to be done with the first effective rains, as FAW populations build up later in the crop season.	Vanden Berg and Van Rensburg (1991)
2.	Plant Nutrition	Adequate nutrient supply through mineral fertilizer, use of fertilizer trees and nitrogen-fixing legume crops, organic manures, or compost support healthy plant growth.	Altieri and Nicholls (2003)
3.	Intercropping with compatible companion crops or fertilizer trees	Planting of additional crops in strips, rows, or stations between the main crop (e.g., pigeonpea, cassava, sweet potatoes, cowpea, beans, pumpkins, or fertilizer trees [e.g., *Tephrosia, Gliricidia*]	Landis et al. (2000); Pichersky and Gershenzon (2002)
4.	Conservation Agriculture	Combined use of no-tillage, residue retention, and rotation increases and diversifies biological activity of macro-(spider, beetles, ants), meso- (fungi), and microfauna(bacteria). These practices also lead to improvement of soil health, which contributes to more vigorous growth of the crop.	Rivers et al. (2016)
5.	Increased ground cover	Cover crops like mucuna, lablab beans, jack bean, sunnhemp, *etc.*, contribute to plant species diversity that enhances biological activities and provides shelter for natural enemies (spiders, beetles, ants).	Altieri et al. (2012)
6.	Hedge rows and live fences	Complex cropping systems influence interactions of biota and increase effectiveness of parasitoids. Provides extra-field diversity and habitats for natural enemies to proliferate and contribute to control of the pest (birds, spiders, ants). Planting of live fences or hedgerows, maintenance of uncultivated areas, reduced weeding in part or all of the crop, planting of other crops or fruit trees in neighbouring fields.	Veres et al. (2013)
7.	Enhance agroforestry systems at landscape level	Plant trees/shrubs between maize especially neem, *Tephrosia*, *Gliricidia*etc., to enhance diversity for natural enemies (beneficial insects and birds).	Hay-Roe et al. (2016)

Source: CABI Evidence Note (2017)

Principal agro-ecological components of IPM module of FAW management in maize are as follows:

- Selection of Single cross maize hybrids with tight husk cover, especially for sweet corn.
- Planning of sowing time at community level to follow synchronous planting.
- Planting of crop before arrival of monsoon in kharif season for seedling stage escape from crop damage.
- Deep ploughing after harvest of crop to expose FAW pupae to sun light and predators. Under zero-tillage, application of neem cake @ 500kg/ha to be done. Fields to be kept weed free and balanced fertilizer application to be followed.
- For maximizing plant diversity, intercropping of maize with suitable pulse crops of particular region is advisable. Eg: Maize + pigeon pea/black gram /green gram. Planting of Napier grass in the border rows to act as FAW trap crop.
- Pest repelling legumes like *Desmodium*spp. or *Tephrosia*plantedas intercrop push the insect outside crop areas while on the border pest-attractive trap plant species such as napier grass (*Pennisetumpurpureum*Schumach.) or *Brachiaria*spp planted to 'PULL' the pest towards them.
- Hill planting of maize is to be avoided; one plant should be maintained per hill by thinning.
- Application of nitrogen and irrigation after control measures will boost up the crop growth.

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Bio rational integrated pest management modules and on-farm biorational inputs production techniques for better crop health in maize crop

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A pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economically unacceptable damage or loss (FAO,1967). Thus, IPM is the best combination of cultural, biological and chemical measures that provides the most cost effective, environmentally sound and socially acceptable method of managing diseases, insects, weeds and other pests. IPM is a knowledge intensive sustainable approach for managing pests by combining compatible cultural, biological, chemical, and physical tools in a way that minimizes economic, health, and environmental risks with the help of pest scouts. IPM relies heavily on knowledge of pests and crop interaction to choose the best combination of locally available pest management tools. Therefore, IPM is not a single product that can be stored on shelves like pesticide, and it does not rely on single method to solve all our pest problems. Pests also co-evolve and adapt very quickly to single control tactics through natural selection, and that multiple methods used simultaneously, or an "integrated" approach, is the most effective for long-term, sustainable management programs.

IPM is neither organic nor it rely solely on biological control to achieve the desired sustainable outcomes. It does often try to assist and augment the effectiveness of natural enemies by limiting the impact of pesticide on their populations and provide clean and safe niche. It seeks to conserve balance between the crop and the natural environment. The World Bank policy (OP 4.04 - Natural Habitats) also promotes the conservation of natural habitats, and enhancement of the environment for long-term sustainable development. In the IPM concept, use of pesticides involves a trade-off between pest control and the risks of adverse effects on non-target organisms, such as natural enemies, pollinators, wildlife, and plants, contamination of soil and water.

Insect Pest of Maize

More than 130 insect pests have been recorded causing damage to maize in India, among these about half a dozen insect pests are of economic importance, major and minor insect pests of Maize are:

Major insect pests of Maize			
Pests	**Scientific Name**	**Family**	**Order**
Fall Aryworm	*Spodoptera frugiperda*	Noctuidae	Lepidoptera
Maize shoot fly	*Atherigona varia soccata*	Muscidae	Diptera
Stem borer	*Chilo partellus*	Pyralidae	Lepidoptera
Pink stem borer	*Sesamia inferens*	Noctuidae	Lepidoptera
Maize cut worm	*Mythimna separata*	Noctuidae	Lepidoptera
Cob worm/ Earworm	*Helicoverpa armigera*	Noctuidae	Lepidoptera
Aphid	*Rhopalosiphum maidis*	Aphididae	Hemiptera
Shoot bug	*Peregrinus maidis*	Delphacidae	Hemiptera

Minor insect pests of Maize			
Maize leaf hoppers	*Cicadulina sp.*	Cicadellidae	Hemiptera
Sugarcane Leafhopper	*Pyrilla perpusilla*	Lophopidae	Hemiptera
Red headed Hairy Caterpillar	*Amsacta albistriga*	Arctiidae	Lepidoptera
White Grubs	*Holotrichia serrate*	Scarabaeidae	Coleoptera
Chaffer beetle	*Chiloloba acuta*	Scarabaeidae	Coleoptera
Termites	*Odontotermes obesus*	Termitidae	Isoptera

Integrated pest management for Major pest of Maize

Cultural Practices: Deep summer ploughing followed by fallowing helps in exposing resting stage of pests, inter-cropping with legume reduces borer incidence, maize-soybean/Maize-Cowpea/ Maize-Green gram are some of the good examples, use of well decomposed farm yard manure (FYM) reduces termite attack, plant spacing 75 cm x 20 cm in Kharif and 60 cm x 20 cm in Rabi is recommended, balanced use of fertilizers (NPK 120:60:40) kg/ha and supplement of micronutrient are the some of the key cultural practices recommended.

Mechanical control: For effective management for insect pests various practices like removal of dead hearts will help to reduce second generation infestation, use of bird scarer prevents seed damage, manual collection and destruction of white grub and chaffer beetle during adult emergence period reduces the pest population, use of pheromone traps @5/ha and light traps @ 1 per ha. are recommended.

Biopesticides: Soil application of neem cake @ 200 kg /ha is effective an effective biopesticides option suggested for control of nematode and chaffer beetle

Parasitoids: For the management of lepidopteron pest in maize crops, use of egg parasitoids like *T. chilonis* @ 2 cc/ release and *Cotesia flavipes and Campoletis chlorideae* larval parasites @ 2000 to 3000/ acre are recomented accordingly dominant stage of the insect pests. The larval and pupal parasitoid *Sturmiopsis parasitica* also recommended for pest management in maize crops.

Predators: *Chrysoperla carnea* @ 5000 first instars grub/acre for two releases for 15 days to control maize aphids, *Rhopalosiphum maidis* and conserve predators such as mirid bug, lady birdbeetles, lacewing, wasp, dragonfly, spiders, robber fly, reduviid bug, praying mantis, fire ants, big eyed bugs, pentatomid bug, earwigs, ground beetles, rove beetles etc.

Flowering plants that attract natural enemies/ repel pests: Cosmos, Sunflower, Okra, Hibiscus, Marigold, Fennel, Coriander, Mustard, Radish, Tridax, Ageratum *sp*., Alfalfa, Chrysanthemum, Carrot.

Fall Armyworm (FAW) and its management

The Fall Armyworm (FAW) *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is native to the tropical and subtropical region of America. It has invaded many African and Asian countries and caused huge economic losses. Fall Armyworm has infested crops in over 50 countries across two continents in just over two years. Incidence of FAW reported in India during May 2018 and the phylogenetic analysis has revealed that Indian Maize FAW clustered with Florida (rice strain), Ghana, Nigeria, Uganda on maize.

The techniques and options involved for FAW management are detailed below

***Monitoring*:** Installation of pheromone traps @ 5/acre in the current and potential area of spread in crop season and off-season. Fix the traps to the supporting pole at a height of one foot above the plant canopy. Change of lures should be made at 2-3 week interval (regular interval). During each week of surveillance, the number of moths/trap should be counted and entered.

Scouting: Start scouting in **'W'** manner as soon as maize seedlings emerge. At seedling to early whorl stage (3-4 weeks after emergence) action need to be taken if 5% plants are damaged and at Mid whorl to late whorl stage (5-7 weeks after emergence) action need to be taken if 10% whorls are freshly damaged in mid whorl stage and 20% whorl damage in late whorl stage. At tasseling and post tasseling (Silking stage) no pesticide spray is advised however, if the ear damage exceed 10% damage that may needs action provided the crop is planted in sufficient wider spacing for any spray interventions.

***Cultural control*:** Cultivation of maize hybrids with tight husk cover will reduce ear damage by FAW and during off season deep ploughing is recommended before sowing to expose FAW pupae to predators and solarisations. In order to achieve uniform crop growth stage timely sowing is advised and staggered sowings is not recommended as the late sowing crop may invite infestation by migrating broods. Intercropping of maize with suitable pulse crops of particular region (eg. Maize + pigeon pea/black gram /green gram) is also a ecological engineering concept that helps in minimising FAW damage. To attract the action of erection of bird perches @ 10 /acre during early stage of the crop (up to 30 days) is advice. Sowing of 3-4 rows of trap crops (eg. A sustainable napier grass) around maize field and spray with 5% NSKE or azadirachtin 1500 ppm as soon as the trap crop shows symptom of FAW damage. Clean cultivation and balanced use of fertilizers including use of VAM is also important for better crop health.

***Mechanical control*:** Hand picking and destruction of egg masses and neonate larvae in mass by crushing or immersing in kerosine water is most effective in early crop stages. Application of dry sand in to the whorl of affected maize plants soon after observation of FAW incidence in the field.

***Biological control*:** In *situ* protection of natural enemies by habitat management: Increase the plant diversity by intercropping with pulses and ornamental flowering plants which help in build-up of natural enemies. Augmentative release of *Trichogramma pretiosum* or *Telenomus remus* @ 5 cc per acre at weekly intervals or based on trap catch of 3 moths/trap.

Biopesticides: Biopesticides like *Metarhizium anisopliae, Nomuraea rileyi, Bacillus thuringiensis* are effective at 5% damage in seedling to early whorl stage and 10% ear damage. The entomopathogenic fungal formulations *Metarhizium anisopliae* talc formulation ($1x10^8$ cfu/g) is affective when applied @ 5g/litre whorl application at 15-25 days after sowing. Another 1-2 sprays may also be given at an interval of 10 days depending on pest damage (or) *Nomuraea rileyi* rice grain formulation ($1x10^8$ cfu/g) @ 3g/litre whorl application at 15-25 days after sowing. Another 1-2 sprays may also be given at an interval of 10 days depending on pest damage. The bacterial formulation of *Bacillus thuringiensis* var *kurstaki* @ 2g/litre (or) 400g/acre is also effective in managing FAW in the early stages of the crops.

On-Farm Production Techniques for Biorational Inputs

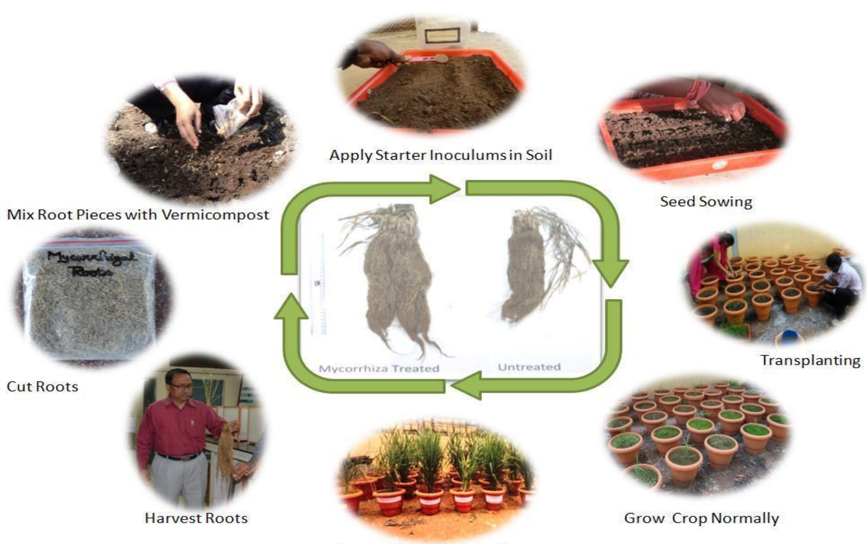
For on-farm production of biocontrol agents, biopesticides and biofertilizers like VAM, NIPHM is facilitating custom made on-campus and off-campus capacity building programme for official and farmers on continues basis. The on farm production protocol for the bio-rational inputs for plant health management in maize crop are as follow:

1. On-farm production of VAM:

The maize crop removes large quantity of nutrients from soil, particularly NPK. Among these major nutrients, the efficiency of applied P through chemical fertilizers is very low i.e. 15 to 20 percent. This is because of the fixation of applied phosphorous in the soil into unavailable form. Therefore, there is need to enhance the phosphorous availability by using phosphorous solubilizing microorganisms (PSM) and their by increasing the health and vigor of the plant to fight against invading pest and diseases. Among PSM, different species of mycorrhizal fungi have been reported to be effective in increasing growth and uptake of phosphorous by different plant species. Mycorrhiza filaments extend from the roots into the soil, reaching several times beyond the root hairs. Efficient species of mycorrhiza (VAM &AM) are symbiotic endophytic soil fungi, which colonize the roots of approximately 80% plants. Nutrients are taken up by the hyphae and carried to the plant. This results into rhizosphere improvement through efficient mobilization & uptake of phosphorous and other nutrients by plants. VAM soil root based culture 10 kgs to be mixed with 1000 kgs of vermicompost or FYM. It is applied along with seed sowing in the main field in a directly sowing crops or applied two days prior to transplanting of seedling in transplanted crops.

No infrastructure like equipments, specific equipment's, machines are not required for mycorrhiza production at farm level. The multiplication of VAM can be done at farmers field with materials like Plastic Pots or Poly bags, Soil, Vermicompost, Starter Inoculum and Seed Material (Sorghum/Mize/Ragi/Rice, etc). Mycorrhiza can be produced at farm level by farmers after undergoing a few days training and hands on practice. For this purpose, following steps have to be followed sequentially.

Sterilize soil by heating for 2-4 hours using a big metal pan or by drying under intense heat of the sun for 2-3 days, place the sterilized soil in thoroughly cleaned and dry clay pots, after cooling the soil, place a pinch of root starter inoculants then cover with a thin layer of soil, sow 3-5 seeds in each pot, grow the plants for three months under normal conditions, protect the plants from pest and diseases, stop watering the plants after 3 months, do not use chemical fertilizer/ fungicide in pots/ seedbed before sowing if VAM is to be applied, cut the plants or stalks when they are completely dried, allow the soil in the pot to dry further, remove the plant from pot and remove soil adhering to the roots, cut the roots finely and save some root inoculants for future use, mix the finely cut roots with the soil from the pot to produce VAM soil inoculants or 5% of cut roots mix with vermicompost for products, store the root and soil inoculants in sealed plastic bags in a dry and cold place



2. On-Farm Production of *Trichogramma* (Egg Parasitoids):

Rearing basins: The host rearing containers (basins) are made of materials which are non-toxic, cheap and optimum sized to permit mating and host searching and amenable to easy cleaning. The basins (16 or 18dia) used for Corcyra multiplication are thoroughly cleaned with.5% detergent wash and rinsing in tap water followed by wiping with dry, clean – used towel and shade drying. Whenever the trays are emptied after a cycle of rearing, they have to be cleaned preferably to 2 per cent formaldehyde and returned to storage until further use. On reuse the cleaning steps are repeated.

Preparation of feed material: The requisite quantum of sorghum is milled to make 3-4 pieces of each grain. Sorghum grains are heat sterilized in oven at 100◦C for 30 minutes and the grains are sprayed with 0.1% formalin. This treatment helps in preventing the growth of moulds as well as to increase the grain moisture to the optimum (15-16%), which was lost due to heat sterilization. Then grains are air dried.

Preparation of Corcyra eggs: The primary source of Corcyra eggs is reputed laboratories, commercial producers for bulk preparation. If it is intended to begin the production with nucleus colony, the adult moths can be collected from warehouses where the food materials are stored. The eggs used for building up the colony of Corcyra have to be free from contaminants like the moth scales and broken limbs and not exposed to UV light. The collections of overnight laid eggs are measured volumetrically to ascertain the number of trays that can be infested with eggs. One cc of eggs is known to contain approximately 16000 18000 eggs.

Corcyra charging: The overall production scheme involves initial infestation of the Sorghum medium with Corcyra eggs in desired quantities. This is accomplished by sprinkling the freely flowing eggs on the surface of the medium in individual basins. Per basin 0.5 cc eggs of Corcyra is infested. The basins are then covered with clean khada cloth and held tightly with rubber fasteners. Yeast, groundnut kernel and streptomycin is added to enhance egg laying capacity of the adult moths and for enriching the diet. The basins are carefully transferred to the racks.

Handling the trays: The larvae that hatch out in 3-4 days begin to feed the fortified Sorghum medium. At this stage, light webbings are noticed on the surface. As the larvae grow up they move down. During this period the larvae are allowed to grow undisturbed in the trays.

Collection of moths: After about 35-40 days of charging, moths start emerging and the emergence continues for two months. 10 to 75 moths emerge daily with the peak emergence being between 65th and 75th day. Adults are either aspirated with mechanical moth collector or collected with specimen tubes. The whole operation is carried out in a tent of mosquito net. This prevents the large-scale escape of the moths, which if uncontrolled can migrate to the storage area and spoil the grains stored by laying eggs. Workers involved in the collection of moths should wear face moths continuously to avoid inhalation of scales. Collect the moths daily and transfer to the specially designed oviposition cages. The adults are provided feed containing honey solution. The adult feed is prepared by mixing 50 ml honey with 50 ml water and 5 capsules of vitamin E (Evion). The feed is stored in refrigerator and used as and when required. Piece of cotton wool tied with a thread is soaked in the solution and inserted into the drum through the slot at the top. From a basin, moths can be collected up to 90 days after which the number of moths emerging dwindles down and keeping the basins is not economical for the producer.

Preparation of Trichocards: The parasitisation of *Trichogramma* spp., in laboratory condition on one cc eggs of *Corcyra cephalonica,* which are uniformly spread and pasted on a card measuring 15 cm x 10 cm is called as Tricho card. The card has 12 demarcations (stamps). About 12,000 *Trichogramma* adults emerge out from this card in 7-8 days after parasitisation. To delay the emergence of *Trichogramma,* these cards can be stored in refrigerator at 5-100C for 10-15 days. On removing the cards to room temperature, the parasitoids emerge normally. Trichocards have a shelf life of 2-3 days. However, these can be stored in a refrigerator for a period of 1 month without any spoilage. Label information on the manufacturer, species of the parasitoid, date of parasitization and expected date of emergence are given in the left over spaces. A coat of 10% gum arabic is applied on the grids and the eggs are sprinkled uniformly in a single layer with the aid of a tea strainer. The excess eggs pasted are removed by gently passing a shoe brush over the card after sufficient air drying under fan. The egg cards are placed into polythene bags of suitable size and the nucleus card of *Trichogramma* are introduced in it. The easiest way to accomplish this is to place a piece of ‗Tricho egg card' containing parasitized eggs (i.e. pharate adults) that are ready to yield the adults and to hold them in subdued light for 2 to 3 days. The emerging parasites readily parasitize the fresh eggs.

3. On-Farm Production of Green lacewing for Managing Sucking Insect Pests:

Mass Production procedure: In mass production, the adults are fed on various types of diets. The larvae are either reared in plastic tubes or empty injection vials or in groups in large containers or in individual cells. The adults are collected daily and transferred to big glass jars. The rearing jars are covered with perforated brown sheet which act as egg receiving card. About 25 adults (60% females) are allowed into each trough and covered with white nylon or georgette cloth secured by rubber band. On the cloth outside three bits of foam sponge (2 $inch^2$) dripped in water is kept. Besides an artificial protein rich diet is provided in semisolid paste form in three spots on the cloth outside. This diet consists of one part of yeast, fructose, honey, Proteinex R and water in the ratio 1:1:1:1. The adults lay eggs on the brown sheet. The adults are collected daily and allowed into fresh rearing jars with fresh food. From the old troughs, the brown paper sheets along with *Chrysopa* eggs are removed. The first larvae are either taken for culture or for recycling or for field release.

Individual rearing of grubs: In the first step of larval rearing, 120 three day old chrysopid eggs are mixed with 0.75 ml of *Corcyra* eggs (the embryo of *Corcyra* eggs are inactivated by keeping them at 2 ft distance from 15 watt ultraviolet tube light for 45 min) in a plastic container (27x18x6 cms). On hatching, the larvae start feeding. On 3^{rd} day the larvae are transferred to 2.5 cm cubical cells of plastic louvers @ one $cell^{-1}$. Each louver can hold 192 larvae. *Corcyra* eggs are provided in all the cells of each louver by sprinkling through the modified salt shaker. Feeding is provided in two doses. First feeding of 1.5 ml *Corcyra* eggs for 100 larvae and second feeding of 2 ml for 100 larvae with a gap of 3-4 days is done. Total quantity of *Corcyra* eggs required for rearing 100 chrysopid larvae is 4.25 ml. The louvers are secured on one side by brown paper sheet and after transfer of larvae covered with acrylic sheet and clamped. Brown paper is used for facilitating pupation and clear visibility of eggs. The louvers are stacked in racks. One 2m x 1m x 45 cm angle iron rack can hold 100 louvers containing 19,200 larvae. Cocoons are collected after 24 hr of formation (when they get hardened) by removing paper from one side. The cocoons are placed in adult oviposition cages for emergence (Adults are sometimes allowed to emerge in louvers and released on glass window panes from where they are collected using suction pumps).

Field release: 1-3 days old larvae are released on plants along with dust or dropped from the corrugated paper strips. paper strip with stalked *Chrysoperla* eggs stapled on the lower surface of leaf. *Helicoverpa armigera*, *Earias* spp., *Pectinophora gossypiella* 50,000 ha^{-1} twice during the season with a gap of 15 days. Aphids - 50,000 ha^{-1} or 6 larvae $plant^{-1}$ twice during the season with a gap of 15 days

4. On-farm Production of Entomopathogenic Viruses for Lepidopteran Insects:

Details of mass production:

Diet preparation: The larvae of Gram pod borer and Tobacco caterpillar can be multiplied by using chick pea based semi-synthetic diet. The composition of the diet for rearing larvae is as follows:-

	Item	**Quantity**
'A' fraction:	Chickpea (Kabuli chenna) flour	105.00 gm
	Methyl para-hydroxt benzoate	2.00 gm
	Sorbic acid	1.00 gm
	Streptomycin sulphate	0.25 gm
	10% formaldehyde solution	2.00 ml
'B' fraction:	Agar-agar	12.75 gm
'C' fraction:	Ascorbic acid	3.25 gm
	Yeast tablets	25 tablets
	Multivitaplex	2 capsules
	Vitamin E	2 capsules
	Distilled water	780.00 ml

390 ml of water is mixed with fraction 'A' of the diet in the blender which is run for two minutes. Fraction 'A' and 'C' are mixed and the blender is run again for 1 minute. Fraction 'B' is boiled in the remaining 390 ml water, added to the mixture of A and B and the blender is run for a minute. Formaldehyde solution is added at the end and the blender is again run for a minute.

***Production of Helicoverpa armigera NPV (Ha NPV) and Spodoptera litura NPV (SI NPV)*:** For Ha NPV and SINPV production, the synthetic diet prepared is poured at 4gm/cell in the multi-cavity trays and the diet surface is uniformly sprayed with virus prepared in distilled sterilised water at 18 x 106 POBs / ml. Eighty percent of the total 5-7 day old larvae are utilised for Ha NPV and SINPV production. The trays are incubated at 260C for 7 days. In case of virus infected larval trays, the diseased larvae dies after attaining its maximum size of 6th instar, where the dead caterpillar will have 2-6 billion poly occlusion bodies (POB) which is in terms of larval equivalent (LE). 1 LE of *H.armiegera* NPV = 6 x 109 POBs; 1 LE of *S. litura* = 2 x 109 POBs. The dead larvae have to be harvested, macerated in distilled/sterilised water and filtered through muslin cloth to get the crude suspension of the virus. The extraction is centrifuged to further clarify the solution.

Field application and dosage: Ha NPV is used for controlling H. armigera attacking cotton, redgram, bengalgram, tomato, okra, sunflower, groundnut, chillies, maize, sorgram etc., whereas, SI NPV is used for controlling tobacco caterpillar attacking tobacco, groundnut, soyabean, sunflower, cotton, cabbage, beetroot, cauliflower etc.

Directions for use of NPV: The recommended dosage is 200 ml of NPV/acre or 500 ml/ha containing 100 and 250 larval equivalent (LE) of NPV respectively as active infective material (one LE = 6 x 109 POBs). 100 ml of NPV could be diluted in 200-400 litres of water when high volume sprayer is used and in 50-70 litres of water in case of power sprayers. Preferable to spray using high volume knap-sack sprayer. Virus should be sprayed during evening hours. Spray should be initiated as soon as some newly hatched larvae are observed or three to five days after a trap catch of 5 moths per pheromone trap. Subsequent sprays should be made at 7-10 days intervals depending upon the pest population.

Compatibility with other insecticides: The viral pathogen seems to be less sensitive to chemical pesticides. When the combination of pathogen and pesticide is used, sometimes synergistic action is noticed. But is recent years mixing of NPV with insecticides is not advisable due to cross resistance problem.

5. On-farm Production of of Entomopathogenic Nematodes for Lepidopteran Insects:

In vivo culture method*:* The approach consists of inoculation, harvest, concentration, and (if needed) decontamination. Insect hosts are inoculated on a Petri dish or tray lined with absorbent paper or another substrate conducive to nematode infection such as soil or plaster of Paris. Inoculation process is similar to the way explained in chapter except that you may need to use large number of laboratory host (may be hundreds and thousands). After approximately 2-5 days, infected insects are transferred to the White traps; if infections are allowed to progress too long before transfer, the chances of the cadaver rupturing and harm to reproductive nematode stages will increase. White traps can be prepared using circular or square plastic box (24 x 9 cm) with a perforated aluminum sheet having a slight slope towards one end. The blotting paper should be placed on aluminium sheet in such a way that the paper towards the lower end of the sheet should always be in contact with water. Now transfer the dead cadaver on the blotting paper. Distilled water containing formalin (0.1%) with not more than one cm height should be maintained in the plastic box. Incubate such traps in B.O.D at 25^{o}C. The nematodes will start emerging and collecting at the bottom of the container after 10 days. Harvest the nematodes daily thereafter, repeatedly clean them with distilled water, and concentrate to a required density and store.

Production and formulation: Entomopathogenic nematodes are currently mass -produced by different methods either in vivo or in vitro (solid and liquid culture) (Shapiro-Ilan and Gaugler, 2002). In vivo production is also arguably the most appropriate technology for grower cooperatives and for developing countries where labor is less expensive (Gaugler and Han, 2002). In vivo production is a simple process of culturing specific EPNs in live insect hosts which requires less capital and technical expertise. In vivo production system based on the White trap (White, 1929), which take advantage of the IJ‘s natural migration away from host cadaver upon emergence. The most common insect host used for in vivo production is the last instar of the greater wax moth (Galleria melonella), because of its high susceptibility to most nematodes, ease in rearing, wide availability and ability to produce high yields. Insect hosts are inoculated on a dish or tray lined with absorbent paper. After approximately 2-5 days, infected insects are transferred to the White are inoculated on a dish or tray lined with absorbent paper. After approximately 2-5 days, infected insects are transferred to the White

Application methods: Production and application technology is critical for the success of EPNs in biological control. Infective juveniles of EPNs are usually applied using various spray equipment and standard irrigation systems. Nematodes require a film of water around soil particles to move through the soil profile in search of a host. Therefore, it is important to ensure adequate agitation during application. Enhanced efficacy in EPN applications can be facilitated through improved delivery mechanisms (e.g., cadaver application) or optimization of spray equipment. Substantial progress has been made in recent years in developing EPN formulations, particularly for above ground applications, e.g., water-dispersible granules, nematodes on gel, micronized vermiculite, and an aqueous suspension of nematodes. Bait formulations and insect host cadavers can enhance EPN persistence and reduce the quantity of nematodes required per unit area. Finally, superior bio control applications with EPNs can also be achieved through strain improvement. Improved strains may possess enhanced levels of various beneficial traits such as environmental tolerance, virulence, reproductive capacity, etc. Methods to improve EPNs include strain or species discovery or genetic enhancement via selection, hybridization or molecular manipulation. Many researchers were reported that EPNs can be applied in combination with insecticides and other bio control agents.

On-farm production of *Trichogramma* parasitoid

On-farm production of *Trichoderma* and *Pseudomonas*

On-farm production of *Bracon* parasitoid

On-farm production of EPN

On-farm production of insect predators and parasitoids

Mrs. Mariswari, Farmer has got **Entrepreneurship Award-2018** from Honourable Central Minister of Agriculture on the occasion of International Rural Women day

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Protocols for mass rearing of fall armyworm *Spodoptera frugiperda* (J. E. Smith)

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Introduction

Fall armyworm *Spodoptera frugiperda* (J. E. Smith) is an invasive lepidopteran pest which feeds on maize causing substantial damage. FAW is polyphagous pest originated from the tropical and subtropical regions of America. FAW has the potential to cause maize yield losses in a range from 8.3 to 20.6 m tonnes per annum, in the absence of any control methods which represents a range of 21%–53% of the annual production of maize (Day et al. 2017). Pest populations are being controlled through pheromones, host plant resistance, mechanical control and also through chemical insecticides. The effectiveness of these methods is determined by evaluating biological parameters of test insects using bioassays. For running successful bioassays availability of healthy insects in substantial numbers is essential to meet the requirements. Vanderzant (1966) reported that mass rearing of insects can either be achieved by growing them on their respective host plants or by providing a suitable and nutritionally adequate medium to support their growth and development. Despite the several artificial diets suitable for FAW, its larval cannibalistic behavior is considered as a challenge for most rearers. Efficient mass rearing is possible with the addition of slightly more space and equipment. Basic requirements include a separate diet preparation area, a larval rearing room, and an adult emergence/oviposition room. The rearing and oviposition rooms require controlled temperature (18-30^{0}C), humidity (50-95% R.H.) and photoperiod. FAW can be reared in many types of containers including glass vials or cups, ice cube trays (Bailey and Chada, 1968), and "jelly cups" (Burton and Cox, 1966; Burton, 1967).

Diet Ingredients and Preparation

The mass rearing of fall armyworm can be done both under natural and artificial diets. The detailed protocols are mentioned below.

Natural diet

To raise the initial culture of fall armyworm in the laboratory, minimum number of 100 larvae to be collected from maize fields. Field collected larvae were reared in plastic jars (1 L capacity) containing tender cut baby corn pieces. The baby corn is to be washed with Sodium hypochlorite and rinse with water to prevent contamination before used as feed. The larvae from third instar were transferred to multi-well (50) tissue culture plates (length-26 cm; width-13.5 cm) due to cannibalistic behaviour in mature larvae of fall armyworm. Every day sufficient amount of cut baby corn pieces are to be provided to fall armyworm larvae as a food. All the pupae obtained were collected and kept in separate jars for adult emergence. Newly emerged moths from pupae were carefully removed and released in oviposition cage containing 5-8 day old potted maize plants (BML 6) (Lakshmi Soujanya 2018, Un published data). Honey solution

(10% W/V) was provided as food to the moths by soaking 3 cm cotton plug in the solution. The portion of leaves bearing egg masses were carefully removed, transferred to petri-plates with tender portion of baby corn and can be utilized for further studies. However, rearing FAW on their natural host may not be feasible every time for several reasons, such as seasonal availability, excessive costs, and variable quality. Therefore, artificial diets that bear little resemblance to their natural host may provide satisfactory growth and development of insects.

Plate 1a. Egg masses

Plate 1b. Mature larvae

Plate 1c. Pupae

Plate 1 d. Adults

Plate 1. Egg masses (1a), larvae (1b), pupae (1c) and adults (1d) obtained in the laboratory when reared under natural diet-Babycorn

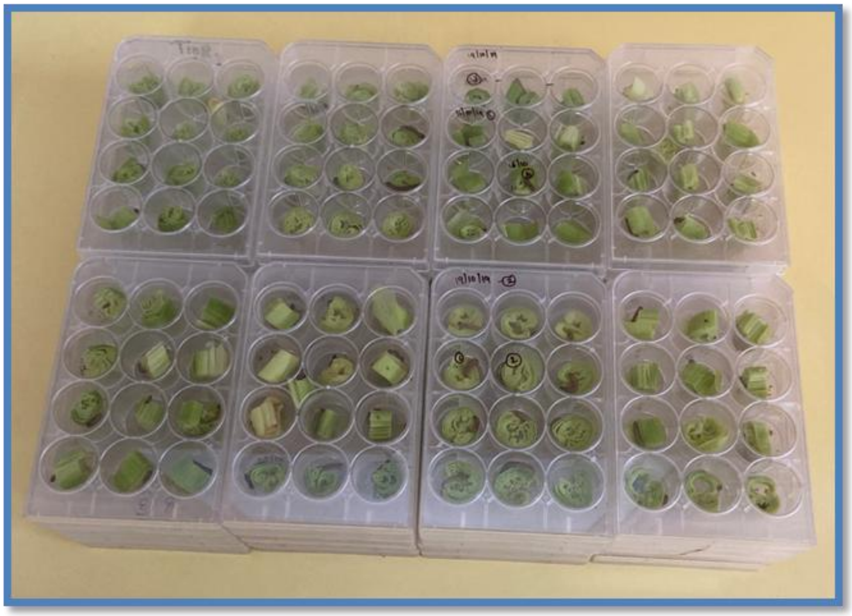

Plate 2: Rearing of FAW larvae in multi-well tissue culture plates

Plate 3: Oviposition cage with 5-8 day old potted maize plants

Artificial/Synthetic diet

The use of artificial diets to rear insects promotes knowledge about the biology, behavior, and nutritional requirements of insects, which is fundamental for the development of efficient integrated pest management programs. Several diets have been successfully used to rear FAW in the laboratory. Because of the FAW's polyphagous nature, it can be reared on many diets that have been developed for other species. One of the first artificial diets used to rear FAW was the wheat germ diet developed for the European corn borer, *Ostrinia nubilalis* (Hubner), where first instar larvae were started on corn and transferred to artificial diet in the second instar (Revelo and Raun 1964). Burton (1967) was the first to develop mass rearing techniques for the FAW solely on an artificial wheat germ diet. The more economical modified pinto bean diet, developed for rearing the corn earworm, *Heliothis zea* (Boddie) (Burton 1969), was subsequently used for rearing the FAW. Numerous modifications of the rearing procedures have been made to more efficiently rear the FAW, but the modified pinto bean diet remains the standard diet of choice (Perkins 1979). The FAW has been reared in the laboratory for over 360 generations on the modified pinto bean diet.

Diet Ingredients for fall armyworm (Modified Pinto bean diet -Burton 1969)

S.No	Ingredient	Quantity
1.	Pinto beans	111 g
2.	Torula Yeast	33.8 g
3.	Ascorbic acid	3.4 g
4.	Wheat germ	52.8 g
5.	Methyl-p-hydroxy benzoate	2.1 ml
6.	Sorbic acid	1.1 g
7.	Formaldehyde (10%)	8.4 ml
8.	Water (For mixing above ingredients)	490 ml
9.	Agar	13.5 g
10.	Water (For Agar solution)	338.0 ml

To prepare the diet, beans can be ground to the fineness of 35 mesh with a commercial grinder. Beans can also be soaked overnight in water plus a small amount of formaldehyde.
FAW can also be successfully mass-produced on maize stem borer diet, as practiced by CIMMYT in Africa. Several synthetic diets have been optimized by various institutions, including International Centre for Wheat and Maize Improvement Centre (CIMMYT), International Institute of Tropical Agriculture (IITA), International Centre of Insect Physiology and Ecology (ICIPE), and the Agricultural Research Council (ARC)-South Africa, based on local availability of ingredients. The synthetic insect diet is a combination of nutritive substances including carbohydrates, proteins, fat, minerals, and vitamins. Each fulfills a specific function in the development of the insect and influences the safe shelf life of the constituted diet.

a) CIMMYT Diet

Fraction A: Mix all the powdered ingredients except methyl-p-hydroxybenzoate from Fraction A using a plastic spoon, in a clean container under a fume hood. Boil the distilled water, cool it to 60°C, and then mix with the pre-mixed ingredients using a blender for 1 minute. Add methyl-p-hydroxybenzoate (dissolved in 20ml of absolute ethanol) to the mixture in the blender, and then blend for a further 2 minutes.

Fraction B: Weigh agar powder in a separate container and then add to cold distilled water in a separate saucepan. Boil while stirring periodically, and then cool to 60°C. Add the ingredients of Fraction B to Fraction A and blend for 3 minutes.

Fraction C: Finally, add 40% formaldehyde to the ingredients of Fractions A and B in the blender and then mix for 3 minutes at room temperature.

b) ICIPE diet

Prepare Fractions A-C as described for the CIMMYT diet, using the ingredients and quantities listed for the ICIPE diet (Table 1).

c) ARC-RSA diet

Fraction A: Mix all dry ingredients in Fraction A well with 1,500ml distilled water in a container.

Fraction B: Boil 1,000ml distilled water, add 7.5g sorbic acid, and stir periodically until the sorbic acid is dissolved. In a separate container, add agar to 1000ml water and mix well. Add agar mix to sorbic acid mix. Boil for 10 minutes. Let Fraction B cool down to 70°C, then add it to Fraction A and mix well with a blender.

Fraction C: Add formaldehyde (40%) to the mix of Fraction A and B. Dissolve Nipagen (3g) in 75ml ether. Add to the mix of Fraction A and B. Dispense an appropriate volume of the diet into plastic trays, jars, or vials.

Table 1. Three potential diet ingredient options used presently for rearing FAW

S.No	**Ingredients**	**CIMMYT Quantity g or ml per 3 L diet**	**ICIPE Quantity g or ml per 3 L diet**	**ARC-RSA Quantity g or ml per 3 L diet**
Fraction A				
1.	Maize leaf powder	75.6 g	75.0 g	-
2.	Common bean powder	265.2 g	187.5 g	-
3.	Chickpea	-	-	250 g
4.	Wheat germ	-	150.0 g	225 g
5.	Brewer's yeast	68.1 g	-	45 g
6.	Torula yeast	-	32 g	-
7.	Milk powder	-	57 g	45 g
8.	Ascorbic acid	7.5 g	9 g	-
9.	Sorbic acid	3.9 g	4.5 g	-
10.	Methyl-p hydroxybenzoate	6.0 g	7.5 g	-
11.	Vitamin E capsules	6.3 g	-	-
12.	Multivitamin drops	-	3.0 ml	-
13.	Sucrose	105.9 g	-	-
14.	Distilled water	1,209.3 ml	1350 ml	1500 ml
Fraction B				
1.	Agar (Tech No.3)	37.8 g	34.5 g	50 g
2.	Distilled water	1,209.3 ml	1200 ml	1000 ml
3.	Sorbic acid	-	-	7.5 g
Fraction C				
1.	Formaldehyde 40%	6.0 ml	6.0 ml	1.0 ml
2.	Suprapen p	-	7.5 g	-

	(Tetracycline)			
3.	Nipagen	-	-	3 g
4.	Ether	-	-	75 ml

Sources: CIMMYT diet – adapted from Tefera et al. (2011); ICIPE diet – Sevgan Subramanian (ICIPE, Kenya), personal communication; ARC-RSA diet – Erasmus Annemie (ARC-Grain Crops, RSA), personal communication.

Surface-disinfested black-head eggs or neonate larvae are to be released into the prepared diet. Several FAW neonates can be introduced into the same container. However, at the third instar, the larvae need to be transferred to multiwell tissue culture plates because of their cannibalistic nature. Keep the multiwell tissue culture plates containing the larvae on shelves in the larvae-rearing room under controlled environmental conditions (27±1°C; 65±5% RH; 12:12 light:dark photoperiod).

The larval and pupal development has to be monitored daily to identify problems such as contamination with fungi or insects, and discard any affected diet containers immediately. Begin close monitoring for pupal harvesting 14-20 days after diet infestation, and daily thereafter to avoid moth emergence within rearing jars. Harvest pupae at once when at least 50% of the larvae have pupated. Clean the pupae with a gentle spray of distilled water, and place on tissue paper to drain excess moisture. Transfer the pupae to clean vials lined with moist tissue paper. Keep the vials at room temperature (25±1°C); 12:12 light:dark photoperiod; and a relative humidity of 75±5%. Newly emerged moths from pupae were carefully removed and released in oviposition cage (Plate 2) containing 5-8 day old potted maize plants (BML 6). On a daily basis, check each oviposition cage and collect eggs that have been oviposited on plant leaves. Surface-disinfect the eggs by dipping them in 10% formaldehyde for 15 minutes, rinsing them thoroughly using distilled water, and then drying them on filter paper. Transfer the surface-disinfested egg batches on waxed paper into clean plastic containers.

Several other larval diets were evaluated and modified by various researchers. Silva and Parra (2013**)** reared FAW larvae since the second instar to pupation in rectangular plastic containers containing 40 individuals and observed 90% larval survivorship with below mentioned diet.

Diet Ingredients for fall armyworm (Greene et al. 1976; Silva and Parra 2013)

S.No	**Ingredient**	**Quantity**
1.	Water	3400 ml
2.	Gelcarin	46 g
3.	Pinto beans	250 g
4.	Wheat germ	200 g
5.	Soybean Protein	100 g
6.	Casein	75 g
7.	Torula Yeast	125 g
8.	Ascorbic acid	12 g
9.	Vitamin mixture (Vanderzants NBC)	20 g
10.	Tetracycline	250 g
11.	Formaline (40%)	12 g
12.	Methyl-p-hydroxy benzoate	10 g
13.	Sorbic acid	6 g

Combine ingredients 1 and 2 at room temperature in a 4-liter pyrex beaker and mix thoroughly. Sequentially add ingredients 3-7 while heating the solution to 75°C.Continue mixing while the temperature cools to 68°C. Add ingredients 8-13, blend at high speed for one minute and pour into rearing containers.

Pinto et al. (2019) evaluated three types of artificial corn based diet for rearing FAW including standard diet based on beans (D_1), a diet with corn flour as substitute for wheat germ (D_2), and a diet replacing beans with green corn (D_3). Results showed that the most adequate diets for rearing FAW in the laboratory are D_1 and D_3.

Diet Ingredients for fall armyworm (Pinto et al. 2019)

S.No	Ingredient	Quantity		
		D1	D2	D3
1.	Bean	240 g	240 g	-
2.	Green Corn	-	-	60 g
3.	Wheat germ	120 g		120 g
4.	Corn Flour		240 g	
5.	Brewer's Yeast	72 g	72 g	72 g
6.	Ascorbic acid	7.3 g	7.3 g	7.3 g
7.	Sorbic acid	2.4 g	2.4 g	2.4 g
8.	Methylparahydroxy benzoate (Nipagin)	4.4 g	4.4 g	4.4 g
9.	Vitamin solution	10.0 ml	10.0 ml	10.0 ml
10.	Formaldehyde (40%)	6.0 ml	6.0 ml	6.0 ml
11.	Agar	20.0 g	20.0 g	20.0 g
12.	Distilled water	1.0 ml	1.0 ml	1.0 ml

Composition of the vitamin solution used for artificial diets

S.No	Component	Amount
1	Niacinamide	4 mg
2	Calcium pantothenate	4 mg
3	Thiamine HCl	1 mg
4	Riboflavin	2 mg
5	Pyridoxine Hcl	1 mg
6	Folic acid	1 mg
7	Biotin	0.08 mg
8	Vitamin B12	0.008 mg
9	Distilled Water	400 ml

Precautions

Insect artificial diets are also suitable for growth of some microorganisms, including bacteria, fungi and viruses. Most of these microorganisms are pathogenic to insects and may cause an outbreak in laboratory, and other contaminating organisms may cause spoilage of the artificial diet. Sources of microbial contamination can include field-collected insects; improper handling of the insects; an insufficiently clean insectary environment; or inadequate sterilization of the containers and diets during preparation, storage, and use. Immediate removal and disposal of contaminated diets and infected insects; proper sterilization of diets, working areas, and utilities; good personnel hygiene; and following recommended occupational safety guidelines will minimize microbial contamination in an insectary. Moth scales and toxic fumes during sterilization can cause respiratory problems and allergies. Therefore, all insectary personnel must wear a laboratory coat, hand gloves, and face-mask in the laboratory.

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Mass production protocols for important bio pesticides

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PRODUCTION PROTOCOLS FOR *Trichoderma viride* and *Pseudomonas fluorescens*

Maintenance of Mother Culture:

- Maintain on specific media (*Trichoderma/Pseudomonas fluorescens* media) in test tubes/ Petri plates.
- Maintain 10-20 mother culture tubes and store them in refrigerator (alternatively store in sterile glycerol)
- For long term storage, fill with sterilized mineral oil and store at -20^{0}C.

Mass multiplication of mother culture:

Trichodema viride

- *Trichodema* is generally mass multiplied on molasses yeast broth medium (30 g molasses; 5g yeast powder;1L distilled water)/ Jaggery/Soy
- Mix the ingredients in distilled water and pour in conical flasks/ horlicks bottles.
- Plug and cover the flask and keep them for sterilization in autoclave for 15 minutes at 121^0 centigrade with 15 lbs pressure.
- Cool them at room temperature.
- Inoculate with mycelial disc of *Trichoderma* from 5-6 day old cultures grown on PDA.
- Incubate the flask containing sterilized molasses yeast broth inoculated with *Trichoderma* by keeping in rotary shaker at 140 rpm for 3-5 days.
- Estimate the population in the Broth for each batch (cfu/ml)

Pseudomonas fluorescens

- *Pseudomonas* requires adequate nutrient supplements and hence King's B medium/ Tryptic soya broth/ nutrient broth should be used.
- Multiply *pseudomonas* using rotary shakers in 5 litre flask by incubating at 25-28^0 C for 48 hrs.
- Ensure that the harvested bacteria are in active phase.
- Do not continue shaking beyond 4 days and do not use Broth incubated for more than 4 days).

Mass multiplication for making talc based formulation:

- Mass multiply the culture in nutrient broth (*Pf*)/PDB or SDB (*Tv*).
- Homogenize the Bio Mass produced in a mixer.
- Sterilize the fermentor along with in nutrient broth (*Pf*)/PDB or SDB (*Tv*)..
- Incubate mass multiplied culture Broth at the rate of 1lit for 35 lit of media Broth (Kings B media Broth/Tryptic Soya Broth/Nutient Broth for *Pseudomonas*)/PDB or SDB (*Tv*).

- Run the fermentor for 4 days.
- Take a sample from the fermentor and retest the cfu.
- Mix the Broth @ 1:3 with talc powder and air dry it.
- Add CMC (Corboxy Methyl Cellulose) or Gum Arabic @ 0.5 % to the formulation
- Use Blender for mixing.
- Store in polythene bags of required sizes.

PRODUCTION TECHNOLOGY FOR PSEUDOMONAS FLUORESCENS

Prepare 200 ml of Kings B broth and sterilize at 121^0 C for 15 min.

↓

Inoculate a loopful of inoculam at luke warm temperature and keep under shaker for 24 hrs at 120 rpm

↓

Check the purity of the culture by following serial dilution and spread plate method

↓

After confirmation of the purity, the 200 ml broth is aseptically transferred to 10 L King's broth and the same procedure for incubation and purity check is followed

↓

The 10 L broth is aseptically transferred to pilot plant Fermenter containing 50 L of Nutrient broth

↓

The parameter for the pilot plant fermenter are set at temperature = 30^0 C, aeration = 5 to 6 L/hour, pH = 7, stirrer = 150rpm and incubation time up to 24 hrs.

↓

The purity of the culture was checked similarly

↓

500 L of Nutrient broth was prepared and sterilized in large scale fermenter using boiler at 121^0 C for 30 minutes and cooled to room temperature using cooling towers.

↓

50 L of actively grown culture broth was aseptically transferred to large scale fermenter using peristaltic pump.

↓

The growth conditions in fermenter was set as temp = 30^0 C,aeration = 5 to 6 L/hour, pH = 7, stirrer = 150rpm and incubation time up to 36 hrs.

↓

Check the purity.

DOWNSTREAM PROCESS:

Harvest the whole fermented broth after 36 hrs.

↓

Check the viable population in the broth using plate and haemocytometeric methods.
Formulate the broth with Talc powder in a clean and sterile mechanical blender at the ratio of 1:3 (broth: talc).

↓

Ensure uniform mixing.

↓

Allow the formulated culture to cure in the sterile trays in an aseptic room at room temperature.

↓

Sieve the cured formulation in a mechanical siever of 300 mesh size

↓

Transfer the sieved material into the milky white LDPE pouches not less than 20 micron in size.
Store the packed product in cool condition

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Different types of media used for the production of Bio Pesticides & their composition:

1. **Kings B medium**

Peptone	:	10 g
K_2HPO_4	:	1.5 g
$MgSO_4$	:	1.5 g
Glycerol	:	10ml (15 ml for Seed Culture)
Dis. Water	:	1000 ml
pH	:	7.0

2. **Nutrient broth**

Peptone	:	5 g
Beef extract	:	2 g
Yeast extract	:	3 g
Nacl	:	5 g
Water	:	1000 ml
pH	:	7.0

3. **Potato Dextrose broth**

Potato Infusion	:	200g
Dextrose	:	20 g
Dis. Water	:	6.5 g
pH	:	6.5 g

4. SDB

Dextrose	:	40 g
Pepton	:	10 g
Dis. Water	:	1000 ml
pH	:	6.5 g

Molasses/ Jagary	:	30 g
Yeast extract	:	3 g
Dis. Water	:	1000 ml
pH	:	6.5 g

PRODUCTION PROTOCOLS FOR *Ha* NPV and *Sl* NPV

Spodoptera litura nuclear polyhedrosis virus (*Sl* NPV)

- From the stock culture of *S.litura* 90 percent of 7-9 day old larvae (4th instar) are used for *Sl*NPV production and the remaining 10 percent for continuation of laboratory culture. The larvae are collected and starved for 8 hours. *Sl*NPV suspension is prepared in 250 ml of water in a bottle. The larvae are exposed to *Sl*NPV infection by dipping the clean Castor leaves in *Sl*NPV suspension, drying them under shade for 15-20 min and providing them to the larvae for 2 consecutive days. Thereafter, the larvae are fed on healthy (not treated with *Sl*NPV) leaves for the remaining part of their life. Fresh leaves are provided every day for the larvae. The larvae could also be exposed to *Sl*NPLV infection by transferring them on to a semi-synthetic diet treated with *Sl*NPV suspension.

- The virosed larvae show characteristic symptoms with in 4-5 days infection they start dying from the 7th day onwards and are placed @ 300 per container containing drinking water and are allowed to putrify for 3 days. The *Sl*NPV infected larvae could be easily distinguished by the pinkish color on the under surface of their skin which turn to white with the accumulation of POBs (on death of infected larvae).The skin ruptures and the white liquefied body contents ooze out. In that stage, the larvae are ground and filtered through muslin cloth. The virus is allowed to settle in sufficient water for about a week. The supernatant is now carefully removed and the polyhedra are suspended in water. Further purification can be done by centrifugation at 500 rpm for 5-10 min and the pellet containing only tissue debris is discarded. The collected POBs are further purified by high speed centrifugation at 2500rpm 15-20mins. The white preparation of POBs is finally obtained as sediments. The pure POBs suspended in water are counted through modified Neubauer haemocytometer. The count is expressed on larval basis as well as on per unit of larval weight basis. The POBs are dried over Calcium chloride or by Acetone precipitation and formulated by adding permitted spreaders/ wetting agents.

Helicoverpa armigera nuclear polyhedrosis virus (*Ha* NPV)

- For *Ha* NPV production, the diet used for rearing *H.armigera* is poured at 4gm/ cell and the diet surface is uniformly sprayed with virus prepared in distilled sterilized water at $18x10^6$

POBs/ml. 80 percent of the available 5-7 day old larvae are utilized for *Ha* NPV production and the remaining 20 percent are transferred into trays where 6gms diet/larva is provided (for continuation of the host culture).

- The trays are incubated at 26^0C for 7 days. In case of virus infected larval trays, the diseased/dead larvae harvested after 7 days and subsequently macerated in mixtures /blenders in distilled/ sterilized water.

- The other procedure pertaining to harvesting of POBs is same as given in Sl NPV production protocol.

- The product is standardized with regard to the number of POBs per ml in terms of LC_{50} with 95 percent fiducial limits. The POBs can be restored in distilled water and packed in plastic cans/bottles with proper instructions provided on the container. One larval equivalent is equal to $6X10^9$ POBs or their equivalent in activity. The cost of production of one Ha NPV infested larva comes to Re 1 (overheads included) which could be further reduced when the production is increased. Ha NPV can be stored in a cool/dark place at room temperature without exposing to direct sunlight or in an ordinary refrigerator, up to 6 months to 2 years.

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