



# Startup of Climate-Smart Integrated Pest Management Against Corn Earworm *Helicoverpa zea* (Boddie) in Maize (*Zea mays* L.) for Altering Insect Risk

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## Abstract:

Climate and environment changes can cause spreading of harmful insects into new areas and change their seasonal phenology, resulting in faster development and increased food consumption in ecosystem. Basically, corn earworm *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), is a well-known established global pest of corn (*Zea mays* L.), and causes leaf injury by feeding in vegetative stage giving ragged appearance, and preferentially forages on silk tissue, ear tip and kernels of plant. An elevated CO<sub>2</sub> can increase levels of simple sugars in leaves and lower their nitrogen content resulting an increase in damage caused by insect to consume more leaves for meet metabolic requirements. Higher temperature from global warming, lowers effectiveness of some pesticides and a greater number of pests may survive during winter season leading to spread of insect in both hemispheres. The dislodgement of earworm eggs is resulted from plants by the action of rain and wind, and these conditions influence on caterpillars that pupate into soil. Climate-smart pest management options are grow corn early to escape peak egg laying period, develop corn hybrids with silk comprising antibiotic chemical against larvae and having husks tightly fitting around ear, implement pest scouting, use economic threshold level, adopt transgenic corn hybrids, initiate *Bacillus thuringiensis* Berliner and nucleopolyhedrovirus sprays to target early instars of pest's population, predators and parasitoids applications, and insecticide usage as last resort. As climate change exacerbates pest problem, future management strategies include monitoring climate and pest populations, modified integrated pest management strategies, and use of modelling prediction tools.

*Keywords: Helicoverpa zea, Global warming, Climate change, Crop-pest interactions, Transgenic crop, Integrated Pest Management*

## INTRODUCTION

Around the world, maize (**corn**) *Zea mays* L., in Family Poaceae is the tertiary utmost imperative cereal crop afterward to rice and wheat, grown for human and animal nourishment, and also used as biofuel. Maize and maize sauce are used in general diet stuffs, for instance, soft drinks and cereals, along with being used as forage for cattle. World's rising population and ethanol manufacture are growing desire for corn. Extension of pest's choices might have considerable influences by increased costs and reduced produces for pest management and seed production (Shah et al., 2015).

More than 250 insect's species have been observed, which are accompanying with maize in storage and field situations. Among these, corn earworm *Helicoverpa zea* (Boddie), is the utmost imperative limitation to corn creation. Its larva is a polyphagous and key agricultural pest, and immature attack more than 182 species of plants, including chickpea, cotton, peas, cowpea, pigeonpea, sorghum, sunflower, groundnut, tobacco, tomato, maize, field beans, and a wide

range of fruits, vegetables and even tree species. This pest looks to be an important hazard to harvest harm and a key task for pest managing in corn, which is an essential diet crop (Bibi et al., 2018).

Additional vegetables, this pest will devour comprise cabbage, beans and soybeans. This is stated to as tomato fruit worm while originates on tomato, and cotton bollworm whenever originate on that crop. Characteristically, the 'worm' in sweet corn is known as corn earworm that chooses corn, nevertheless, once corn plants are not as attractive late in the season, it might harm to snap beans and tomatoes through consumption of the pods or fruits. There are several non-crop plants on which the earworm may grow initially in the season earlier to gardens and crops are planted. Cultivated hosts comprise field corn, sweet corn, rice, snap beans, green beans, eggplant, peppers, lettuce, sweet potato, strawberry, grapes and several others. Corn earworm is likewise an important pest in cannabis or hemp production, and it is not infrequent to observe larvae devouring leaves and buds (Capinera, 2001; Sarwar, 2015).

This pest species is vigorous during the whole year in subtropical and tropical environments, nevertheless progressively becomes extra limited to the hotter months by cumulative latitude. It is dispersive highly, and spreads routinely from southerly united states to northerly states and Canada. Accordingly, these zones have hibernating, both hibernating and migrant, or migrant densities, dependent on weather and location. Change in climate is creating easier things for a damaging pest, which effects maize and further crops, and corn earworm is the costliest insect and thrives in warmer weather (Fitt, 1989).

Population of earworm might boost and develop to a fresh region as worldwide climate change carries milder winters and warmer summers. Climate model repetitions suggest that wintertime will be slighter further frequently far ahead in the future, whereas hotter rising seasons will be warmer and longer more frequently than they are nowadays. Basically, in projected future climates, the number of days enough warm for the pest to breed and the number of days enough cold to die the pest. Favorable temperature and precipitation are helpful to farmers generating a good corn. However, changes to climate of the state including rising levels of carbon dioxide (CO<sub>2</sub>), changes in precipitation amounts and patterns, and increasing temperatures in the air will upshot in numerous straight and incidental effects to the corn livelihood (DeLucia et al., 2008).

This article describes and focuses on results from studies on how expected changes in climate of a state will disturb the population of corn earworm pest and its pressure for agricultural production of maize statewide.

### **Life Cycle of Corn Earworm**

Corn earworm is too recognized as cotton bollworm, sorghum headworm, tomato fruitworm and vetchworm. Adults moth in wingspan measure 32- 45 mm, forewings are usually yellowish brown, centrally hold a minute dark spot and distally a wide dark diagonal band, nevertheless wing border is not dark. Hind wings are basally creamy white and distally blackish, and centrally bear a minute dark spot. Adults are stated to live for 5- 15 days, however, under optimum situations might survive for above 30 days (Mitter et al., 1993). Principally, the moths are nightly, generally hide in shrubbery throughout daylight hours, however, occasionally seen eating on nectar and go on vigorous during the dark period. Nearly, 3 days afterward to emergence, oviposition starts and continues till death. For oviposition, fresh-silking maize is attractive highly, however, ears with dry silk can even have eggs (Archer et al., 1994).

Eggs are pale green, usually laid singly on corn silk and leaf hairs, and with time become yellowish and then gray prior to hatch. Their outline differs from a little dome shaped to a firm sphere, and measure around 0.5 mm in height and 0.5- 0.6 mm in diameter. Fecundity per female, varies 500- 3000 eggs and each female might give up to 35 eggs per day that hatch in around 3-4 days (Terry et al., 1987)]. Fresh caterpillars are not cannibalistic, initially quite a lot of larvae might forage together and as larvae develop, they turn out to be very hostile. But older larvae become aggressive, killing and cannibalizing other larvae, ensueing 1 or 2 larvae at each feeding spot, and habitually one mature larva in each ear of corn is found only (Braswell et al., 2019).

Customarily, earworm comprises 6 instars and lasts for 12- 15 days in the hotter portion of the growing period, and bears saddle on 4<sup>th</sup> segment of body. Mean widths of head capsule are 0.29 and 3.10 mm for 1 and 6 instars, while larvae lengths 1.5 and 24.8 mm, respectively. Development times average 3.7 and 2.9 days for instars 1 and 6, correspondingly. Once larva is matured, in the side of ear it bores a small earhole to leave ear and drops on soil, where pupation takes place. Fully grown, 6<sup>th</sup> instar larvae leave the feeding site of host plant, make a pupal cavity 5- 10 cm beneath to ground and enter to pupal stage, which lasts for 10 to 15 days in summer. The pupae are reddish brown in hue, and measure 5.5 mm in width and 17- 22 mm in length. Adult moths appear from ground, consume liquids and nectar as food, mate and disperse to lay eggs (Herbert et al., 2003).

Overall, larva varies in color, body is green, brown, pink or occasionally yellow otherwise generally black, head has a propensity to be light brown or orange by a white net-like outline and thoracic plates are black. Usually, larva laterally holds a wide dark strip over the spiracles and a white to light yellow strip under the spiracles. A couple of thin dusky strips occurs often along the middle of the back and body bears numerous black thorn-like microspines (Figure 1). The occurrence of light-colored head and spines help to differentiate corn earworm from European corn borer *Ostrinia nubilalis* (Hubner) and fall armyworm *Spodoptera frugiperda* (Smith). Both these later commonly corn infesting species, have dark heads and lack the spines. A closely related species, tobacco budworm *Heliothis virescens* (Fabricius), has the late instar larvae, which bear microspines also. Larvae of tobacco budworm have spines on tubercles of first, second and eighth abdominal segments that are around half the height of tubercles, however in corn earworm spines are equal to one-fourth the height of tubercle (Storer et al., 2001).



**Figure 1: Different color patterns of corn earworm larvae**

### **Crops Attacked by Corn Earworm**

Adults of corn earworm assemble fluid or other plant exudations from a huge number of flowering trees, plants and bush species. Along with corn, its utmost favorite vegetable hosts are asparagus, artichoke, collard, cantaloupe, lima bean, cucumber, okra, melon, pumpkin, potato, squash, spinach, broccoli, watermelon and cantaloupe. Further crops injured comprise clover, alfalfa, millet, oat, flax, sugarcane, wheat and vetch. Ornamental plants and fruits might be invaded,

together with ripening peaches, plum, pear, avocado, raspberry, geranium, carnation, rose, nasturtium, snapdragon, gladiolus and zinnia (Sarwar, 2014a; 2014b).

Weeds, like crown vetch, common mallow, hemp, horse nettle, fall panicum, lambs' quarters, lupine, pigweed, prickly sida, morning glory, ragweed, purslane, Spanish needles, velvetleaf and toadflax, have been described to assist as larval hosts, along with winter vetch and crimson clover that might be equally weeds or crops, particularly cranesbill (wild geranium) species are significant weed hosts, and mostly vital wild hosts are deergrass and toadflax (Stadelbacher, 1981).

### **Nature of Damage by Corn Earworm**

Afterward to hatching, larvae walk round the plant till an appropriate nourishing site is encountered, generally the reproductive bodies of the host plant. At what time earworms are existing, sweet corn entirely by visible new silk is vulnerable to injury. Corn during tassel phase needs not to be protected from earworms, however, crop might be invaded at that time through other pests. Anywhere, successive plantings are situated together adjacently, field having the freshest silk will possibly take the majority of egg laying, however, other fields are *not* invulnerable. Earworm is generally hard to manage if it internally feeds on reproductive bodies of plant (Terry et al., 1989; Rachel et al., 2017).

Normally, earworms only forage on kernels of sweet corn, commencing through eating at tip of ear and as they grow move downside to ear. Nearly, eating is continuously restricted to the topmost third portion of the ear. Fecal material as big soaking pills is originated in silk duct and at the tip of ear. As per fall armyworms and European corn borers occasionally do, earworms do not bore into the cob. Although earworms harm to a minor proportion of the kernels only, their droppings and presence to most of consumers are very distasteful. Wherever, control measure in the field has been fewer than perfect option, farmers are required to checkered ears at harvest and discard the injured ones. Sometimes, earworm-infested ears can be still sold if their tips are detached, though this exercise meaningfully decreases the shelf life of corn. Sweet corn intended for processing plant might be capable to withstand some damage by earworm at ear tips, because tips are not used in the finished produce (Braswell et al., 2019).

The earworm might be existing all over the season, however is abundant mostly throughout August and September. Larvae feed on leaves, whorl, tassels and within ears, nevertheless, ears are the favorite spots for attack of corn earworm. Ear injury is categorized by a widespread filth at the tip of ear. Early instar larvae forage on corn silks by cutting these off. Just afterward, larvae forage their way inside to ear, where they persist by eating in tip zone till, they exit for pupation in earth. When disturbed, they will either fight or curl into a C-shape style (Zalucki et al., 2002).

On corn, corn earworm generally feeds on every part of host, initially, younger larvae have a tendency to forage on silks and hinder in pollination, however they habitually gain entree into kernels eventually. They might forage at the tip only, or damage might spread to half the dimension of ear prior to development of larva is completed. Such type of eating likewise increases growth of plant pathogenic molds. If the ears yet have not formed silk, larvae might tunnel into the ear directly. Usually, they continue their eating within single corn ear, however, occasionally abandon the eating spot and look for another. Larvae likewise can harm to whorl-stage corn through eating on the younger, emerging leaf tissue. Nevertheless, persistence is well on more progressive development plant stages. On tomato, larvae might forage on greenery and

tunnel into stalk, however, maximum of eating happens on tomato fruit. Commonly, larvae start to tunnel into a fruit, forage for a brief time only and then depart to invade one more fruit. When corn is not silking, tomato is extra vulnerable to damage, but in the existence of corn, moths will oviposit preferentially on fresh silk. Further crops, for instance, pumpkin, cucumber, bean, squash and cantaloupe might be harmed in a style analogous to tomato, but are also less possible to be wounded if silking corn is adjoining (Bilbo et al., 2018).

When larvae forage on silk and move down into kernels, this injury stops pollination and presents entry for several fungi, diseases and molds into ear. As a result, yearly produce losses range from 5-7% in field and 10-15% corn for humanoid ingesting. Besides direct injury, earworms also can hasten the crop to invasions by other pests. Afterward to earworms start eating on sweet corn grains, sap beetles will be attracting to the odor of fermenting sugars. In field corn, ear molds evolving in the injured grains can originate harmfulness complications for livestock. While larvae feed in tips of ears, consuming seeds and infecting ear, even invasions injury of the kernels less than 10% amounts, is sufficient to origin stern financial fatalities of fresh marketable sweet corn owing to customer refusal, and of hybrid dent seed corn owing to high worth of produce (Olivi et al., 2019). Larvae start eating on seeds after they have gotten third instar and enter 9-15 cm into ear, through deeper diffusion taking place as grains toughen. Larvae do not feed on tough grains, however take on chews of several seeds, thus dropping value of corn for processing (Waldbauer et al., 1984).

### Impacts of Climate Change on Insect Pests

Climatic change and global warming could profoundly affect insects' life histories, favor quick establishment and development, increase both the number and appetite, expand area, and create a spare generation of progenies, which could pose a serious threat leading to a boom in pest's population. Milder winter and hotter rising season temperatures can let some of the pests to enlarge their region and create a superfluous offspring. Growing hotness increases both the appetite and number of insect and these will abolish nearly 30% further maize than they do nowadays through a rise of 2°C, but new increasing damage by pest will origin as a minimum of another 4-8% to be missing (Bale, 2002). Just by 2°C increase of worldwide warming, the global four top creators of maize will drop faraway additional to pests (Figure 2).

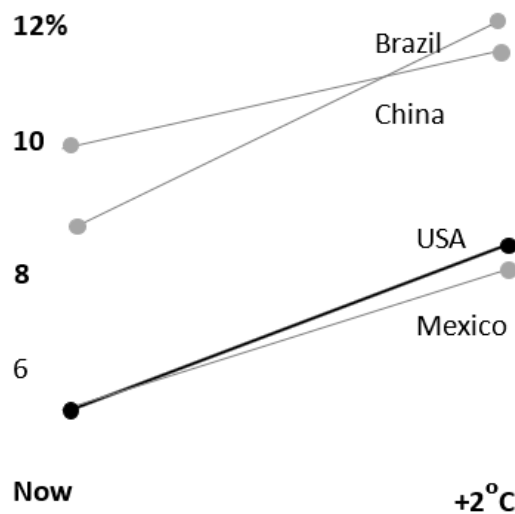


Figure 2: Percent of yield lost in Maize due to field pests - top producer country in dark color

The variation in yield is owing to expected upsurges in temperature, changes in rainfall forms and higher concentrations of surface carbon dioxide from human caused emissions of greenhouse gas, creating hard to produce more maize in the tropics. General, fatalities by 20-50% are initiate to rise for 2°C of heating above pre-industrial stages and 40%-100% for 4°C. The general photograph is that in a temperate area, if farmers are rising lots of diet, they will be going to be success toughest. Europe's breadbasket is amongst the stiffest success, by 11 countries projected to get an upsurge in pest fatalities of 75% or extra (Baker et al., 2000).

Direct environment influences on pests (life history behaviors) are well understood than indirect impact (crop-pest relations, biological control) resultant in a gap among discipline of management options and predicting changes (Furlong and Zalucki, 2017). There are some cases of transformation in topographical dispersal of few species of corn insects on account of climate change (Table 1).

**Table 1: Few cases of variations in geographical spreading of insect pests because of climate change.**

Insect pest	Plant host	Effect on insect/ behavior comeback	Reference
Old world Bollworm <i>Helicoverpa armigera</i> (Hubner)	Maize	Enlarged occurrence in southern Europe and epidemics, and extension of geographical expanse in northern Asia	Cannon (1998)
European corn borer <i>Ostrinia nubilalis</i> (Hubner)	Maize	Northward movement by per season an extra generation	Porter et al. (1991)
Corn earworm <i>Helicoverpa zea</i> (Boddie)	Maize	Range extension to high elevations, USA and northern Europe, and amplified hibernating	Diffenbaugh et al. (2008)

It has been speculated that worldwide warming will upsurge the occurrence of insect pests in several agroecosystems. This is very expected that the chief drivers of environment change (higher temperature, higher atmospheric CO<sub>2</sub> and reduced soil moistness) significantly can disturb density dynamics of insect pests and consequently the proportion of crop fatalities (Kocmankova et al., 2010).

#### INFLUENCE OF CLIMATE CHANGE ON CORN EARWORM

There are three diverse geographic regions crossways to southern expanse, where corn earworm subsists winter; transitional zone, where it might subsist winter; and northern limits, where it is usually incapable to subsist winter for the reason of earth temperatures fall under cold. The hotter winter soil intended for insects, which live in earth are further expected to subsist (Sandstrom et al., 2007)].

The biological thresholds for an insect species joined with models of growth to determine in what way would each respond to predictable climate change circumstances, are used. For instance, pupal phase of corn earworm hibernates and cannot resist further than 5 days at temperatures under 14°F. For completion of development, it likewise needs 6 days at a temperature of around 55°F. Through including of these parameters in the climate model, an expert is capable to plan forthcoming temperature-based dispersals of pest. Corn earworm is of specific concern for the reason that it is migrant, pesticide resistant and established worldwide pest, and has particularly

recognized hard to manage. The adult moth is able of being transportation lengthy distances in jet stream to invade new crops (Meola et al., 1983).

Corn earworm is well-thought-out to be amongst the maximum common farmhouse pests, destroying crops together with maize. The comfortable cold restraint can enlarge the expanse of past's taxonomic group, together with a considerable range extension in case of corn earworm, which is cold intolerant insect. Since, corn earworm is a global nuisance, it suggests that this expansion could also threaten other crops. For management of noteworthy further burden from such set of recognized insects, would necessitate an extra pest managing efforts, predictable reductions in cold limitation and upsurges in heat buildup having the potential to alter pest's management significantly. Additionally, these range extensions might have considerable financial influences by bigger insecticide and seed prices, reduced produces, and downstream effects of changes in crop harvest changeability (Dovely et al., 2016).

There are three serious foundations upsetting extent and timing of corn earworm movement; emergence period of corn earworm adult, obtainability of maturing maize as host, and obtainability of appropriate atmospheric situations for transference. Information on corn earworm movement will be useful especially in inventing and applying new control strategies in states anywhere pesticides are extensively applied to manage migrant corn earworm in seed corn, sweet corn, snap beans *Phaseolus vulgaris* L., and further crops of high value. It is important particularly to geographical range, abundance and managing of corn earworm in relation to possible climate change and usage of transgenic crops tolerant of heat and drought situations (Westbrook et al., 2010).

### **Response of Earworm to Increased Temperature**

Physiology of insects is very delicate to variations in temperature and their metabolic degree have a tendency to nearly twofold through an upsurge of 10°C. An amplified temperature inclines to hasten insect's development, movement and consumption that can distress population dynamics through persuading geographic range, fertility, generation time, survival and density magnitude [33]. So, insect densities in tropical regions are projected to practice a reduction in growing degree on account of climate warming owing to the present temperature level that is already near to optimal for pests growth and development, despite the fact insects in temperate regions are predictable to practice an intensification in growing degree (Deutsch et al., 2018).

Hotter temperatures exponentially upsurge insects' metabolic rates and intensify propagative rates, have more insects and they will eat extra. Under a continuous vapor pressure scarcity of 8.41 mm Hg, a holding temperature of 30°C generates the utmost quick growth of corn earworm. But fertility and oviposition are more after pupae and larvae are detained at lesser temperatures (25.6 and 22.2°C) in comparison to those detained at 28.9 and 18.9°C, while a higher temperature of 32.2°C in an adjustable temperature schedule lowers egg hatching. The intermediate temperature (25°C) looks to be optimal for detection of development variances between susceptible and resistant plant matters irrespective of silk concentration. In warmer conditions, larval activity intensifies, and larval feeding and activity finish once temperatures fall under 12°C (Wiseman et al., 1989).

### **Response of Earworm to Higher CO<sub>2</sub> Concentration**

Raised CO<sub>2</sub> and worldwide warming will disturb insects development and growth that will alter relations among insect pests and their plant hosts. Raised concentrations of atmospheric CO<sub>2</sub>

may disturb abundance, performance and distribution of herbivore insects. Such intensifications can disturb fertility, growth rates, consumption rates and population densities of insect pests (Fuhrer, 2003). Amplified levels of CO<sub>2</sub> are expected to disturb plants physiology through increasing photosynthetic action, resultant in healthier development and progressive plant production. Indirectly, it would in turn disturb insects through altering both the quality and quantity of vegetation and plants. In the insect's body, nitrogen is the vital component for its growth and hence bigger concentration of CO<sub>2</sub> leads to upsurge plant feeding amount in some sets of pests (Bezemer et al., 1998).

Climate change is an inevitable and imminent state of affairs, driven largely by rise in temperature and CO<sub>2</sub>. Adversative climate situations [increased temperatures (29, 31, 33 and 35± 1°C) and increased CO<sub>2</sub> (550 ppm)] are simulated in temperature and carbon dioxide gradient compartments for development and growth of *Helicoverpa* species, wherein relative growth rate of pest increased with elevated CO<sub>2</sub> and temperature (Srajan et al., 2021).

Both tolerance and resistance that are two tactics used by plants to bound biotic stress, which are disturbed through abiotic atmosphere including tropospheric levels of CO<sub>2</sub>. The results showed that raised CO<sub>2</sub> reduces simultaneously the tolerance and resistance of plants to herbivore insect through lessening level of jasmonic acid, and actions of lipoxygenase polyphenol oxidase, and proteinase inhibitors in host infested with *Helicoverpa* pest (Guo et al., 2012). Thus, farmers face plague of pests as a rise in concentrations of atmospheric CO<sub>2</sub>.

### **Response of Earworm to Changeable Precipitation Pattern**

Variations in frequency, intensity and amount of rainfall are very vital pointers of climate change. Such kind of precipitation form has favored the incidence of floods and droughts. Species of insects, which hibernate in earth are affected directly through lapping precipitation. Significant precipitation may cause flooding and lengthy water stagnation. Such kind of occurrence impends to insect endurance and as a minimum disturbs their diapause. Besides, larvae and eggs of insects may be splashed away through flooding, heavy rains and wind (Shrestha, 2019). Insects are affected by drought because dry environments might deliver appropriate ecological surroundings for growth and development of insects, drought hassled plants attract some species of insects and are further vulnerable to insects' outbreak for the reason that of a reduction in creation of secondary metabolites having a protection role (Yihdego et al., 2019).

The limit of corn earworm's migration appears to fluctuate largely depending on temperature and precipitation during the winter. Their rate and direction of spread during the summer are expected to be affected through weather conditions. Rainfall and temperature appear to be primary limiting factors, with the probability that durations of low temperature as well as minimum temperature determine the hibernation points of corn earworm. Likewise, excessive winter rainfall has been observed to prevent hibernation, especially in the soils of low permeability. The amount of rainfall during the summer may also affect earworm populations, in that excessive amounts destroy eggs on corn silks and leaves, drown the pupae or prevent emergence of adults from soil. Conversely, the length of pupal stage may be greatly increased where drought conditions exist (Kearney et al., 2010).

While rainfall will certainly hamper migration possibilities further to west, a combination of south to southwest winds along with more scattered precipitation may lead to isolated moth flights especially into the eastern corn-growing and southern regions overnight. Fields from



eastern region will be at risk of some additional isolated moth flights as southerly winds return along with potential precipitation chances leading to isolated drop zone regions. In many areas of the northern corn-growing region, there have been corn earworm moth flights. So, growers should continue to monitor traps and scout fields especially where crop stage is susceptible to damage (Staley et al., 2007).

Moths of corn earworm are capable to scatter up to several hundred kilometers by means of periodic breezes, meaning that these may disperse fast when circumstances are upright. The hotter season soils inevitable to insects, which live in soil are likely to continue more. Globally, the 2°C (3.6°F) of heating would enhance appetite and number of insects triggering them to abolish 30% extra maize. Earworm spends wintertime underneath to ground and is not recognized to subsist in conditions beyond a 40 degrees latitude of north, however this is altering as soil warms and it disperses to newer regions (Porfirio et al., 2014).

### **Climate Changes Accelerate Corn Earworm's Resistance**

Worldwide, climate changes have noteworthy effects on farming and likewise on farming insect pests. Farming crops and their equivalent insects are indirectly and directly influenced through environment change. Direct influences are on pests' development, reproduction, dispersal and survival, while the climate change indirectly affects relations among pests, their atmosphere and other insect species, for instance, vectors, natural enemies, mutualists and competitors (Tilman et al., 2011). During the past some years, because usage of Bt corn has increased, corn earworm progressively established more resistance to insecticide properties of heritably altered corn that is engineered to hold a protein from *Bacillus thuringiensis* (Berliner) bacterium, which is lethal to several insects, however inoffensive to people, and study arguments to climate change as a reason of hastening the resistance development in pest. For instance, surges in temperature have caused in an amplified overwintering survive and range expansion of corn earworm (*H. zea*) and cotton bollworm (*Helicoverpa armigera* Hubner). Accordingly, this looks to be a noteworthy menace to foremost task for pest managing and harvest harm in essential food corn crop (Fand et al., 2012).

Specifically, high Bt corn acreage and exceeding normal temperature correlate by upsurges in injury to corn ear, grain ingesting of Bt corn, and share of late instars of *H. zea* noted. The spreading hazard of Bt-resistant corn earworm and its damages associated to several crops is higher for the reason that corn earworm overwintering range might further expand owing to climate change, and evolutionary selection pressure for resistance expansion applied through extensive Bt acreage. High temperature, after combined with higher use of Bt corn, might destroy Bt proteins in crops; hasten insect development permitting *H. zea* to progress each season by more generations; letting *H. zea* to subsist more overwintering; and leading to northward extension of resilient insects (Venugopal and Dively, 2017). The corn earworm harm to corn ears, grain portion consumption, average instars and number of later instars in Bt varieties are increased with temperature irregularity and Bt adoption, through interactive or additive influences (Gore et al., 2002).

### **MANAGEMENT OF CORN EARWORM IN CLIMATIC CHANGES**

For agricultural producers, creation logic of what is happening with corn earworm is actually imperative. There are many possibilities for management of corn earworm and controlling options vary dependent on which crop is being injured. On sweet corn and field corn, on silks eggs are laid, freshly hatched larvae forage downward to silk channel and then on tip of ear. In this

circumstance, there is slight chance to usage insecticides for the reason that larvae are in protected places. When insecticides are to be applied, these must be used at the period of egg laying, generally by repetitive applications from period of silking till afterward to brown silk phase is gotten (Gregory et al., 2009; Sarwar, 2013a).

Climate-smart pest management reflects climate change influences on entire features of wider habitats and farming system, along with in what way these interact with existing and new risks of insect. The furthest commonly earworm's managing strategies are monitoring of climate and insect pest population, modified integrated pest management practices, and usage of modeling predictions devices (Raza et al., 2014).

### **Monitoring of Corn Earworm**

A global system for sharing of data on insects, hostile alien species and weather information is need, and be shared between local, regional, national and international levels to improve cooperation between countries. Generally, on corn, eggs and larvae are often not appraised for the reason that eggs are actually hard to notice and soon after hatching larvae tunnel downward into silks resulting out of the insecticides reach. Moth of corn earworm can be checked with installation of pheromone and light traps. Both sexualities are arrested in light traps, while males are only lured to sex pheromone. Both types of traps bring an estimation of at what time moths emerge or invade the crop and give their relative concentrations, however, pheromone traps are easy to usage since these are selective. Usually, the pheromone is usage in combination with an upturned cone-type trap. Normally, the occurrence of 5- 10 moths for every night is adequate to stimulate pest control practice. First generation populations may or may not reach economic levels, however, once the second-generation hits, populations will likely be high for the rest of the season (Studebaker et al., 1991).

Sampling visually for larvae and eggs is the core procedure used for routinely sampler in corn. Sweep netting is an easy and quick way for sampling maximum of other crops. Monitor crops for pest's activity through taking of at least 5 sets of 10 sweeps and calculate the mean number of larvae per 10 sweeps. The usage of pheromone traps that only attract males, may offer an early caution of moths coming to a zone or their appearance from local wintertime diapause. These must be established at the beginning of spring and earworms are generally monitored by using of a *Heliothis* trap. A pheromone lure (corn earworm Luretae) that reproduces the female earworm's sexual attractant, is sited in the trap. Male earworm moths are lured to the pheromone and trapped inside the trap. Because pheromone traps catch only males, they cannot be used to resistor an invasion (Ahmad and Sarwar, 2013).

Ideally, there should be put the trap just before the corn begins to tassel and these are set just outside of crop on southwest corner of field, because that is the track where predominant breezes blow. One trap is sufficient for each farmhouse and pheromone lure must be altered after each 2- 3 weeks. Generally, an insecticide spray is applied at early silking as soon as the first corn earworm moth is captured on the farm and applications are repeated at 2- 6-day intervals based on moth pressure and corn hybrid (Sarwar, 2017a).

### **Modified Integrated Pest Management (IPM) Approaches**

Integrated pest management (IPM) offers stable and continuous destruction of pests through encouraging their natural enemies. This long-lasting tactic is likewise the minimum lethal technique for insects controlling. Chemicals, only used as per a latter option normally are the least

required. Cultural practices, host plant resistance, monitoring, natural enemies and synthetic insect killers are nowadays being used widely for pests managing. But, several of these approaches for pests controlling are sensitive to the atmosphere exceedingly. Hence, there is a necessity to raise suitable stratagems for pests managing, which might be operative under circumstances of future global warming (Sarwar, 2004). Presently existing pests managing tactics, for instance, host plant resistance, cultural control, biological control and chemical control along with use of biotechnology could be intensified in response to changing climate (Khan et al., 2020).

### **Cultural Control:**

Trap cropping is frequently proposed for earworm; the higher grade of preference for corn in green silk period by ovipositing moths may be used for lure of moths to lesser favorite crops. Lima beans are comparatively more striking to attract moths, in comparison to tomato plant. Chickpeas as a trap crop may also be used to capture overwintering populations emerging from diapause. Nevertheless, it is hard to continue an attractant crop in an attractive phase for a prolonged period. In an area where population grows initially on weeds host and then scatter to crops, handling of weeds done by cutting, weedicide or applications of insecticide against earworm can critically amend harm on adjoining crops (Sarwar, 2011; 2019).

In certain expanses, sometimes it is probable to grow or reap crop enough early to escape damage. All over the expanse of this insect, its inhabitant densities are at peak and utmost destructive late in the growing period.

Ploughing, particularly in the autumn, significantly can decrease hibernating activity of pupae in some places. Tilling of grounds would kill numerous of the hibernating pupae. But this insect is extremely moveable and migrant reinvasion can be predictable from distant sources. Slashing and cultivating can lessen its larval and pupal survivals in field (Sarwar, 2017b).

### **Host Plant Resistance:**

Resistance of corn to earworm is derivative from physical features such as ear length and husk tightness that hinder entree to ear kernels by larvae, or chemical features like maysin that prevent growth of larvae. Hereditarily engineered assortments of few crops are available now, which comprise *B. thuringiensis* toxin in plants that decreases harm by *H. zea* and damage to corn (Burkness et al., 2001; Sarwar, 2013b). There are certain varieties of sweet corn that express some resistance to damage by corn earworm. Grow mid-season assortments, which will mature among moth flights, so the ears will likely to be less injured. Productive landscapers on their corn can stop moths from laying eggs, by applicating 20 droplets of mineral oil by a medicine dropper to silks within tip of ear (3- 7 days later to silks first seem) till silks have wilted.

Preferably, host plant resistance to insects is one of the most environment friendly apparatuses of pest managing. So, it is imperative to detect and progress cultivars, which are stable in resistance expression under variable climate to target pests. There is necessity to combine host plant resistance from germplasm with the transgene expression showing stability across locations and environments (Tabashnik et al., 2013; Khalid et al., 2015).

### **Biological Control:**

Biological control is more fruitful at that time when earworm is eating on leaf or outside of fruiting structure (Sarwar, 2016a). Amongst its commonly hunters are ladybird beetles (Coleoptera:

Coccinellidae) pink spotted lady beetle *Coleomegilla maculate* DeGeer and convergent lady beetle *Hippodamia convergens* Guerin-Meneville (Sarwar, 2016b; 2016c); big-eyed bugs *Geocoris* spp. (Hemiptera: Lygaeidae); softwinged flower beetles and *Collops* spp. (Coleoptera: Melyridae); minute pirate bug *Orius tristicolor* (White) (Hemiptera: Anthocoridae); and green lacewings *Chrysoperla* and *Chrysopa* spp. (Neuroptera: Chrysopidae) (Sarwar et al., 2011; Sarwar and Salman, 2016).

The bacterium *Bacillus thuringiensis* Berliner or *Bt* bacterium provides some suppression and sprayable formulations may be useful when a minimum lethal control way is wanted. Now, inherently engineered assortments of certain crops are available, which include *B. thuringiensis* toxin that lessens injury by earworm (Sarwar, 2015a; Sarwar, 2021).

Commercially available, entomopathogenic nematodes, deliver upright destruction of emerging larvae when they are applied to corn silk. Earth outward and subsurface applications of nematodes can also disturb earworm densities due to the reason that larvae fall to soil for pupation. Nematode *Steinernema riobravis* (Nematoda: Steinernematidae) is noted to be an important factor of mortality for pupae and prepupae. Likewise, *Heterorhabditis heliothidis* (Nematoda: Heterorhabditidae) is also observed for parasitizing of corn earworm (Sarwar and Mukhtar, 2021). Pathogenic fungus *Nomuraea rileyi* and *Helicoverpa zea* nuclear polyhedrosis virus are generally intricated in occurrences of illness in earworm (Sarwar et al., 2021a), however protozoan *Nosema heliothidis* as well as other viruses and fungi have also been detected (Sarwar et al., 2021b).

Egg parasitoids *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) are raised and released for destruction of earworm in quite a lot of crops. The crop hosts seem to influence parasitism rates of earworm, by tomato being a specifically appropriate crop for releases of parasitoids (Khan et al., 2010; Sarwar, and Salman, 2015a).

Used for a slighter degree, *Telenomus* spp. (Hymenoptera: Scelionidae) are commonly parasitoids of egg. Common parasitoids of larva comprise *Campoletis* spp. (Hymenoptera: Ichneumonidae); *Microplitis croceipes* (Cresson) and *Cotesia* spp. (Hymenoptera: Braconidae); as well as *Archytas marmoratus* (Townsend) and *Eucelatoria armigera* (Coquillett) (Diptera: Tachinidae) (Sarwar, 2020a).

Crop divergence is among the greatest active procedures for enhancing the abundance and activity of usual enemies. There is necessity to create plant cultivars that are friendly to the survival of natural enemies, along with detecting cropping schemes, which may boost diversity of natural enemies for pest managing (Sarwar, 2020b).

### **Chemical Control:**

Chemical sprays are used to defend corn, on the other hand after the larvae have passed in the ear, there is no an active controller. About to happen effectively, grower needs to cover end of ear completely, with the intention of when eggs hatch, early caterpillars will instantly contact to fatal dosage of insect killer (Sarwar, 2015c; 2016d; Sarwar and Salman, 2015b). Thus, actions might be reapplied every 3- 4 day from once silks initially look till they turn out to be brown.

Spray when all subsequent circumstances are factual; smaller caterpillars seem in sweep net, smaller caterpillars originate all over the field and new ears are existing on plants. If ears are not preserved reasonably, growers always can just detach the spoiled portions of infested ears, as the

not fed portion by caterpillar is still flawlessly upright. Improved insecticides application, usage of resilient hereditarily altered crops and practices like crop rotations are helpful to resistor suffering from insects. However, it still looks that virtually under entire climate change circumstances, populations of pest will be the victors (Sarwar, 2015d; 2016e; Sarwar and Sattar, 2016).

There is essential for a bigger thoughtful upon the upshots of climate change on efficiency of artificial insecticides and their persistence in atmosphere. Hence, there is necessity to advance insecticide preparations and application timetables that would be minimum affected through climate change. Lastly, it needs to practice an integrated pest managing system by taking into attention the alteration in pest range, cropping outlines and efficiency of diverse apparatuses of pest managing for workable crop creation (Sarwar, M. 2020c).

### **Biotechnology Usage in Corn:**

Biotechnology for corn has been used in two prime ways; Bt corn that has been altered genetically to express one or more proteins from lethal bacterium *B. thuringiensis* to manage destructive insects, like corn earworm, western bean cutworm, corn rootworm and more; and herbicide tolerant corn, altered for tolerance to some herbicides within their fields during the growing period. Both kinds of these corn qualities propose numerous profits to grower and atmosphere to decrease the necessity for spray of insecticides for control of insects as well as herbicides to avoid weeds during the growing season (Noreen et al., 2021). Nevertheless, before final sanction of seeds created by biotechnology, stock can be grown in field and might be undertaken severe approval procedures at Food and Drug Administration, Department of Agriculture as well as Environmental Protection Agency.

### **Climate Forecasting and Development of Model**

Through monitoring of pest and climate, together with pest and climate risks forecast information, agriculturalists may defensively implement confident practices for insects' prevention to decrease incidence and surge of probable pest difficulties. A precautionary management package to counter corn earworm might commence as soon as 10% of ears are silked. Repetitive sprays at 3- 5 day breaks till 90% of silks have wilted would give a higher proportion of worm free ears throughout initial and midseason periods. Controlling of pest is further problematic during late period of crop growing. Even reducing spray breaks might only produce 90% of insect free ears (Duffield and Dillon, 2005).

Climate models in combination with ecological necessities of a specific pestiferous species like earworm might be an active device for protruding the probable series of variations on worldwide basis. Modelling the pest's menace along with comebacks of its host plants to climate change may thus surge the capability to forecast the consequence of an insect invasion (Heeb et al., 2019).

These models detect statistical relations between climate variables and present geographical dispersals of a specified species, which at that point are applied to forecast climate change in the future for suggesting climatically appropriate territories for that species. The ultimate productivity of models is frequently offered in the system of maps displaying forthcoming climatically suitable areas for a specified species, overall expanse of which at that time can be connected to existing geographical arrays for estimating upcoming hazard of their establishment and introduction (Evans et al., 2015). This is better that insect pest movements range are predicted to progress results that alleviate crop damage in extension expanses. Hence, there is an excessive necessity for forecasting and framing adaptation tactics in the form of improved IPM strategies, pest and climate monitoring, and usage of modelling apparatuses. Additionally,

formation of farming cooperatives is the only way to consolidate and facilitate integrated management of pest, and governments should act as facilitators in providing of incentives and training farmers in cooperative crop management.

### CONCLUSION

Broadly, this article highpoints the tasks for pest's managing possibilities, for instance, against corn earworm, in the framework of environment changes. For the study of climate change scenario, procedures for monitoring and slowing the growth of resistance within such corn pest is critical. Pheromone trap information give initial cautioning of invasion and will as well attentive handler to hit a small population level prior to it converts severe, wherein lure could be applied best by Delta trap. Sampling of corn earworm for testing and monitoring resistance is concentrated currently in some areas, wherever together Bt corn and Bt cotton are grownup. It needs to expand monitoring of resistance in entire high corn creation zones and as well stress to integrate evolutionary procedures inflated by climate change into resistance managing plans. Significant rises in pest harm prediction, necessitate action to be taken during climate change and adaptation strategies. Everyone comprising wider society, farmers, policymakers and industries must be involved in planning and formulating of improved IPM strategies, pest and climate monitoring, and usage of modelling devices. Precisely, upshots of climate change on pests and their crop hosts have to be computed further to advance reasonable pressure mitigation approaches.

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### REFERENCES

- Ahmad, N., M. Sarwar. 2013. The Cotton Bollworms: Their Survey, Detection and Management through Pheromones: A Review. *Journal of Agriculture and Allied Sciences*, 2 (3): 5-8.
- Archer, T. L. and Bynum, Jr E. D. 1994. Corn earworm (Lepidoptera: Noctuidae) biology on food corn on the High Plains. *Environmental Entomology*, 23: 343-348.
- Baker, R.H.A., Sansford, C.E., Jarvis, C.H., Cannon, R.J.C., MacLeod, A. and Walters, K.F.A. 2000. The role of climatic mapping in predicting the potential geographical distribution of non-indigenous pests under current and future climates. *Agric. Ecosyst. Environ.*, 82: 57-71.
- Bale, J.S. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Glob. Change Biol.*, 8: 1-16.
- Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K., Butterfield, Buse, A., Coulson, J.C., Farrar J., et al. 2002. Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Glob. Chang. Biol.*, 8: 1-16.
- Bezemer, T.M., Jones, T.H., Knight, K.J. 1998. Long-term effects of elevated CO<sub>2</sub> and temperature on populations of the peach potato aphid *Myzus persicae* and its parasitoid *Aphidius matricariae*. *Oecologia*, 116: 128-135.
- Bibb, J.L., Cook, D., Catchot, A., Musser, F., Stewart, S.D., Leonard, B.R., Buntin, G.D., Kerns, D., Allen, T.W., Gore, J., 2018. Impact of corn earworm (Lepidoptera: Noctuidae) on field corn (Poales: Poaceae) yield and grain quality. *Journal of Economic Entomology*, 111 (3): 1249-1255.
- Bilbo, T.R., Reay-Jones, F.P.F., Reisig, D.D., Musser, F.R., Greene, J.K., 2018. Effects of Bt corn on the development and fecundity of corn earworm (Lepidoptera: Noctuidae). *Journal of Economic Entomology*, 111 (5): 2233-2241.

- Braswell, L.R., Reisig, D.D., Sorenson, C.E., Collins, G.D. 2019. *Helicoverpa zea* (Lepidoptera: Noctuidae) oviposition and larval vertical distribution in Bt cotton under different levels of nitrogen and irrigation. *Journal of Economic Entomology*, 112 (3):1237-1250.
- Braswell, L.R., Reisig, D.D., Sorenson, C.E., Collins, G.D., 2019. *Helicoverpa zea* (Lepidoptera: Noctuidae) preference for plant structures, and their location, within Bt cotton under different nitrogen and irrigation regimes. *Journal of Economic Entomology*, 112 (4): 1741-1751.
- Burkness, E.C., W.D. Hutchinson, P.C. Bolin, D.R. Bartels, D.F. Warnock, and D.W. Davis. 2001. Field efficacy of sweet corn hybrids expressing a *Bacillus thuringiensis* toxin for management of *Ostrinia nubilalis* (Lepidoptera: Crambidae) and *Helicoverpa zea* (Lepidoptera: Noctuidae). *Journal of Economic Entomology*, 94:197-203.
- Cannon, R. J. C. 1998. The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. *Global Change Biology*, 4: 785-796.
- Capinera, J.L. 2001. *Handbook of Vegetable Pests*. Academic Press, San Diego. 729 pp.
- DeLucia, E.H., Casteel, C.L., Nabity, P.D., O'Neill, B.F. 2008. Insects take a bigger bite out of plants in a warmer, higher carbon dioxide world. *Proc. Natl. Acad. Sci. USA*, 105: 1781-1782.
- Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B., Naylor, R.L. 2018. Increase in crop losses to insect pests in a warming climate. *Science*, 361: 916-919.
- Diffenbaugh, N. S., Krupke, C. H., White, M. A. and Alexander, C. E. 2008. Global warming presents new challenges for maize pest management. *Environment Research Letter*, 3: 1-9.
- Dively, G.P., Venugopal, P.D., Finkenbinder, C. 2016. Field-Evolved Resistance in Corn Earworm to Cry Proteins Expressed by Transgenic Sweet Corn. *PLoS ONE*, 11 (12): e0169115.
- Duffield, S.J. And Dillon, M.L. 2005. The emergence and control of overwintering *Helicoverpa armigera* pupae in southern New South Wales. *Australian Journal of Entomology*, 44: 316-320.
- Evans, T.G., Diamondm S.E., Kellym M.W.X. 2015. Mechanistic species distribution modelling as a link between physiology and conservation. *Conserv. Physiol.*, 3 (1): cov056.
- Fand, B.B., Kamble, A.L., Kumar, M. 2012. Will climate change pose serious threat to crop pest management: A critical review? *Int. J. Sci. Res.*, 2: 1-14.
- Fitt, G.P. 1989. The ecology of *Heliothis* species in relation to agro-ecosystems. *Annual Review of Entomology*, 34: 17-52.
- Fuhrer, J. 2003. Agroecosystem responses to combinations of elevated CO<sub>2</sub>, ozone, and global climate change. *Agric. Ecosyst. Environ.*, 97: 1-20.
- Furlong, M.J, Zalucki, M.P. 2017 Climate change and biological control: the consequences of increasing temperatures on host-parasitoid interactions. *Curr. Opin. Insect Sci.*, 20: 39-44.
- Gore, J., Leonard, B.R., Church, G.E, Cook, D.R. 2002. Behavior of bollworm (Lepidoptera: Noctuidae) larvae on genetically engineered cotton. *Journal of Economic Entomology*, 95: 763-769.
- Gregory, P.J., Johnson, S.N., Newton, A.C., Ingram, J.S.I. 2009. Integrating pests and pathogens into the climate change/ food security debate. *J. Exp. Bot.*, 60: 2827-2838.
- Guo, H., Sun, Y., Ren, Q., Zhu-Salzman, K. 2012. Elevated CO<sub>2</sub> reduces the resistance and tolerance of tomato plants to *Helicoverpa armigera* by suppressing the JA signaling pathway. *PLoS ONE*, 7 (7): e41426.

- Heeb, L., Jenner, E., Cock, M.J. 2019. Climate-smart pest management: Building resilience of farms and landscapes to changing pest threats. *J. Pest. Sci.*, 92: 951-969.
- Herbert, A., Hull, C., Day, E. 2003. Corn earworm biology and management in soybeans. Virginia Cooperative Extension Entomology, Blacksburg, Virginia. Publication 444-770: 5.
- Kearney, M.R., Wintle, B.A., Porter, W.P. 2010. Correlative and mechanistic models of species distribution provide congruent forecasts under climate change. *Conserv. Lett.*, 3: 203-213.
- Khalid, P.A., M. Hussain, M. Hassan, M. Sarwar and N. Sarwar. 2015. Evaluation of Bt-cotton Genotypes for Resistance to Cotton Leaf Curl Disease under High Inoculum Pressure in the Field and Using Graft Inoculation in Glasshouse. *The Plant Pathology Journal*, 31 (2): 132-139.
- Khan, M. H., Jander, G., Mukhtar, Z., Arshad, M., Sarwar, M. and Asad, S. 2020. Comparison of in Vitro and in Planta Toxicity of Vip3A for Lepidopteran Herbivores. *Journal of Economic Entomology*, 113 (6): 2959-2971.
- Khan, M.H., M. Sarwar, A. Farid and F. Syed. 2010. Compatibility of pyrethroid and different concentrations of neem seed extract on parasitoid *Trichogramma chilonis* (Ishii) (Hymenoptera: Trichogrammatidae) under laboratory conditions. *The Nucleus*, 47 (4): 327-331.
- Kocmankova, E., Trnka, M., Juroch, J., Dubrovsky, M., Semeradova, D., Mozny, M., Zalud, Z., Pokorny, R., Lebeda, A. 2010. Impact of climate change on the occurrence and activity of harmful organisms. *Plant Prot. Sci.*, 45: S48-S52.
- Meola, R., Kaska, H. and Gray, R. 1983. Physiological changes associated with stemmatal pigment retraction in pupae of *Heliothis zea*. *Southwestern Entomologist*, 8: 226-230.
- Mitter, C., Poole, R.W., Matthews, M. 1993. *Biosystematics of the heliothinae (Lepidoptera: Noctuidae)*. *Annual Review of Entomology*, 38 (1): 207-225.
- Noreen, A., Sarwar, M. and Babar, H. S. 2021. Biotechnological Trends in Insect Pests Control Strategy. In: *Biopesticides in Organic Farming: Recent Advances*. L. P. Awasthi (Ed.). CRC Press, Boca Raton. p. 333-339.
- Olivi, B.M., Gore, J., Musser, F.M., Catchot, A.L., Cook, D.R., 2019. Impact of simulated corn earworm (Lepidoptera: Noctuidae) kernel feeding on field corn yield. *Journal of Economic Entomology*, 112 (5): 2193-2198.
- Porfirio, L.L., Harris, R.M., Lefroy, E.C., Hugh, S., Gould, S.F., Lee, G., Bindoff, N.B., Mackey, B. 2014. Improving the use of species distribution models in conservation planning and management under climate change. *PLoS ONE*, 9: e113749.
- Porter, J. H., Parry, M. L. and Carter, T. R. 1991. The potential effects of climate change on agricultural insect pests. *Agricultural and Forest Meteorology* 57: 221-240.
- Rachel, S., Dominic, R. and Hannah, B. 2017. Feeding Preference and Performance of *Helicoverpa zea* (Lepidoptera: Noctuidae) Larvae on Various Soybean Tissue Types. *Florida Entomologist*, 100 (1): 162-167,
- Raza, M.M., Khan, M.A., Arshad, M., Sagheer, M., Sattar, Z., Shafi, J., Haq, E.U., Ali, A., Aslam, U., Mushtaq A., et al. 2014. Impact of global warming on insects. *Arch. Phytopathol. Plant Prot.*, 48: 84-94.
- Sandstrom, M.A., Changnon, D. and Flood, B.R. 2007. Improving our understanding of *Helicoverpa zea* migration in the Midwest: assessment of source populations. *Plant Health Prog.*, 8: 63.
- Sarwar, M. 2004. Concept of integrated insect pests' management. *Pakistan & Gulf Economists*, 23 (46 & 47): 39-41.
- Sarwar, M. 2011. Effects of wheat and barley intercropping ecosystem on the prevalence of aphid (Hemiptera: Aphididae) population in canola (*Brassica napus* L.) crop. *Biological Diversity and Conservation*, 4 (1): 11-16.



- Sarwar, M., N. Ahmad, M. Tofique and A. Salam. 2011. Efficacy of some natural hosts on the development of *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) - A laboratory investigation. *The Nucleus*, 48 (2): 169-173.
- Sarwar, M. 2013a. Integrated Pest Management (IPM) - A Constructive Utensil to Manage Plant Fatalities. *Journal of Agriculture and Allied Sciences*, 2 (3): 1-4.
- Sarwar, M. 2013b. Comparing abundance of predacious and phytophagous mites (Acarina) in conjunction with resistance identification between Bt and non-Bt cotton cultivars. *African Entomology*, 21 (1): 108-118.
- Sarwar, M. 2014a. Some Insect Pests (Arthropoda: Insecta) of Summer Vegetables, Their Identification, Occurrence, Damage and Adoption of Management Practices. *International Journal of Sustainable Agricultural Research*, 1 (4): 108-117.
- Sarwar, M. 2014b. Knowing About Identify and Mode of Damage by Insect Pests Attacking Winter Vegetables and Their Management. *Journal of Ecology and Environmental Sciences*, 2 (4): 1-8.
- Sarwar, M. 2015a. Protecting Dried Fruits and Vegetables against Insect Pests Invasions during Drying and Storage. *American Journal of Marketing Research*, 1 (3): 142-149.
- Sarwar, M. 2015b. Microbial Insecticides- An Ecofriendly Effective Line of Attack for Insect Pests Management. *International Journal of Engineering and Advanced Research Technology*, 1 (2): 4-9.
- Sarwar, M. 2015c. Commonly Available Commercial Insecticide Formulations and Their Applications in the Field. *International Journal of Materials Chemistry and Physics*, 1 (2): 116-123.
- Sarwar, M. 2015d. The Killer Chemicals as Controller of Agriculture Insect Pests: The Conventional Insecticides. *International Journal of Chemical and Biomolecular Science*, 1 (3): 141-147.
- Sarwar, M. and M. Salman. 2015a. Biological insecticide *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) strikes for caterpillar control. *International Journal of Entomology Research*, 1 (1): 31-36.
- Sarwar, M. and M. Salman. 2015b. The Paramount Benefits of Using Insecticides and Their Worldwide Importance in Food Production. *International Journal of Bioinformatics and Biomedical Engineering*, 1 (3): 359-365.
- Sarwar, M. 2016a. Usage spots of biological insecticides in consort with target insect pests or vectors and application in habitat. *International Journal of Entomology and Nematology*, 3 (1): 14-20.
- Sarwar, M. 2016b. Biological Control to Maintain Natural Densities of Insects and Mites by Field Releases of Lady Beetles (Coleoptera: Coccinellidae). *International Journal of Entomology and Nematology*, 2 (1): 21-26.
- Sarwar, M. 2016c. Recognition of some lady beetles (Coleoptera: Coccinellidae) deadly sighted for insect and mite pests in agroecosystems. *International Journal of Entomology Research*, 1 (2): 29-34.
- Sarwar, M. 2016d. A Glance at Pesticides Usage: Remunerations and Complications Associated with Insecticides Putting in Practice. *International Journal for Research in Agricultural Research*, 1 (7): 10-19.
- Sarwar, M. 2016e. Outdoors Agricultural Insecticides Pose Worth Global Risks and Espousal of Safety Practices among Farmers. *International Journal for Research in Agricultural Research*, 1 (7): 1-9.
- Sarwar, M. and M. Salman. 2016. From Production to Field Application Methodology of Generalist Predator Green Lacewing, *Chrysoperla carnea* [Stephens] (Neuroptera: Chrysopidae). *International Journal of Zoology Studies*, 1 (1): 35-40.
- Sarwar, M. and M. Sattar. 2016. An Analysis of Comparative Efficacies of Various Insecticides on the Densities of Important Insect Pests and the Natural Enemies of Cotton, *Gossypium hirsutum* L. *Pakistan Journal of Zoology*, 48 (1): 131-136.

- Sarwar, M. 2017a. Cotton Bollworm *Helicoverpa armigera* (Hubner, 1809) (Lepidoptera: Noctuidae) and Development of Integrated Pest Management Platform. *Scholars Journal of Research in Agriculture and Biology*, 2 (1): 63-70.
- Sarwar, M. 2017b. Integrated Control of Insect Pests on Canola and Other Brassica Oilseed Crops in Pakistan. In: *Integrated Management of Insect Pests on Canola and Other Brassica Oilseed Crops*. G. V.P. Reddy (Ed.). CABI, Wallingford, UK. pp. 193-221.
- Sarwar, M. 2019. Multiple Integrated Pest Management (IPM) and Area-Wide Management (AWM) Approaches for Insect Pests of Chickpea *Cicer arietinum* (L.) Walp Crop. In: *Handbook of Chickpeas: Nutritional Value, Health Benefits and Management*, Albert T. Lund and N. D. Schultz (Eds.). Nova Science Publishers, Inc., New York, USA. pp. 237-263.
- Sarwar, M. 2020a. Typical Flies: Natural History, Lifestyle and Diversity of Diptera. In: *Life Cycle and Development of Diptera* (M. Sarwar, Editor). IntechOpen Ltd., London, UK. p. 50.
- Sarwar, M. 2020b. Essential Services by Pollen Vectors to Ecosystem Impacted by Incidents of Pesticides Toxicity alongside Pollinators Protection and Conservation. *Journal of Environment Protection and Sustainable Development*, 6 (2): 48-56.
- Sarwar, M. 2020c. Insect Pests that Negatively Impact Bell Peppers *Capsicum annuum* L., and Schemes for Crop Protection. In: *Capsicum: Production, Varieties and Nutrition*, P. Norris (Ed.). Nova Science Publishers, Inc., New York, USA.
- Sarwar, M. 2021. Killing Bacteria as Agents of Insect Pest Control. In: *Biopesticides in Organic Farming: Recent Advances*. L. P. Awasthi (Ed.). CRC Press, Boca Raton. p. 71-79.
- Sarwar, M. and Mukhtar, Z. 2021. Management of Insect Pests by means of Entomopathogenic Nematodes. In: *Biopesticides in Organic Farming: Recent Advances*. L. P. Awasthi (Ed.). CRC Press, Boca Raton. p. 225-231.
- Sarwar, M., Sidra, S. and Roohi, A. 2021a. Usage of Entomopathogenic Viruses for Insect Pest Control. In: *Biopesticides in Organic Farming: Recent Advances*. L. P. Awasthi (Ed.). CRC Press, Boca Raton. p. 99-107.
- Sarwar, M., Shad, N. A. and Batool. R. 2021b. Entomopathogenic Protozoa Roles in the Management of Insects Pest Populations. In: *Biopesticides in Organic Farming: Recent Advances*. L. P. Awasthi (Ed.). CRC Press, Boca Raton. p. 129-136.
- Shah, M.S., Khan, I.A., Salman, M., Ahmad, J., Akbar, I., Shah, J.A., Khan, G.Z. and Sarwar, M. 2015. Study on different life parameters of *Trichogramma chilonis* (Ishii) on eggs of *Sitotroga cerealella* (Olivier) fed on old and new varieties of wheat, maize and sorghum. *Journal of Entomology and Zoology Studies*, 3 (6): 397-400.
- Shrestha, S. 2019. Effects of climate change in agricultural insect pest. *Acta Sci. Agric.*; 3: 74-80.
- Sravan, K. D., Krishnayya, V., P. V., Srinivasa, R. M., Anil, K. P., Srinivasa, R. V. 2021. Impact of Elevated CO<sub>2</sub> and Temperature on Growth and Development of *Helicoverpa armigera* Hubner. *Journal of Experimental Agriculture International*, 43 (3): 42-54.
- Stadelbacher, E. A. 1981. Role of early-season wild and naturalized host plants in the buildup of the F<sub>1</sub> generation of *Heliothis zea* and *H. virescens* in the Delta of Mississippi. *Environmental Entomology*, 10: 766-770,
- Staley, J.T., Hodgson, C.J., Mortimer, S.R., Morecroft, M.D., Masters, G.J., Brown, V.K., Taylor, M.E. 2007. Effects of summer rainfall manipulations on the abundance and vertical distribution of herbivorous soil macro-invertebrates. *Eur. J. Soil Biol.*, 43: 189-198.
- Storer, N.P., J.W. Van Duyn, and G.G. Kennedy. 2001. Life history traits of *Helicoverpa zea* (Lepidoptera: Noctuidae) on non-Bt and Bt transgenic corn hybrids in eastern North Carolina. *Journal of Economic Entomology*, 94: 1268-1279.

- Stuebaker, G.E., Spurgeon, D.W. and Mueller, A.J. 1991. Calibration of ground cloth and sweep net sampling methods for larvae of corn earworm and soybean looper (Lepidoptera: Noctuidae) in soybean. *Journal of Economic Entomology*, 84: 1625-1629.
- Tabashnik, B.E., T. Brevault, and Y. Carriere. 2013. Insect resistance to Bt crops: lessons from the first billion acres. *Nature Biotechnology*, 31: 510-521.
- Terry, I., Bradley, Jr J.R., Van Duyn, J.W. 1987. Within-plant distribution of *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae) eggs on soybeans. *Environmental Entomology*, 16: 625-629.
- Terry, I., Bradley, Jr J.R., Van Duyn, J.W. 1989. Establishment of early instar *Heliothis zea* on soybeans. *Entomologia Experimentalis et Applicata*, 51: 233-240.
- Tilman, D., Balzer, C., Hill, J., Befort, B.L. 2011. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA.*, 108: 20260-20264.
- Venugopal, P.D., Dively, G.P. 2017. Climate change, transgenic corn adoption and field-evolved resistance in corn earworm. *R. Soc. Open Sci.*, 4: 170210.
- Waldbauer, G.P., Cohen, R.W., Friedman, S. 1984. Self-selection of an optimal nutrient mix from defined diets by larvae of the corn earworm, *Heliothis zea* (Boddie). *Physiological Zoology*, 57: 590-597.
- Westbrook, J. K., Lopez Jr, J. D. 2010. Long-Distance Migration in *Helicoverpa zea*: What We Know and Need to Know. *Southwestern Entomologist*, 35 (3): 355-360.
- Wiseman, B. R., D. J. Isenhour. 1989. Effects of Temperature on Development of Corn Earworm (Lepidoptera: Noctuidae) on Meridic Diets of Resistant and Susceptible Corn Silks. *Environmental Entomology*, 18 (4): 683-686.
- Yihdego, Y., Salem, H.S., Muhammed, H.H. 2019. Agricultural pest management policies during drought: Case studies in Australia and the state of Palestine. *Nat. Hazards Rev.*, 20: 05018010.
- Zalucki, M.P., Clarke, A.R., Malcolm, S.B. 2002. Ecology and behavior of first instar larval Lepidoptera. *Annual Review of Entomology*, 47: 361-393.