The Pharma Innovation Journal 2022; SP-11(2): 1006-1010

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; SP-11(2): 1006-1010

www.thepharmajournal.com
Received: 04-12-2021
Accepted: 06-01-2022

Ashok Kumar Sau
Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi, India

Rajesh
Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi, India

Mukesh K Dhillon
Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi, India

Corresponding Author
Ashok Kumar Sau
Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi, India

Aspects of host plant resistance with reference to *Sesamia inferens* (Walker): A review

Ashok Kumar Sau, Rajesh and Mukesh K Dhillon

Abstract
The loss of productivity due to insect pest infestations in agricultural crop production is a major concern. Farmers use the chemical method for quick relief from insect infestation, but it has several drawbacks, such as insecticide resistance development, resurgence of insect pests, pesticide residue issues, adverse effects on non-target organisms, and environmental pollution. Cereals and millets are vulnerable to a variety of biotic and abiotic stresses. The polyphagous pink stem borer, *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) which is gaining national importance, is limiting cereal and millet cultivation. Because its larvae and pupae are hidden within the stem, no management approaches have been proven to be helpful in controlling the threat. Host plant resistance (HPR) to insect pests is an environmentally acceptable and cost-effective form of pest control that is compatible with all insect pest control strategies. Recognizing the mechanism and basis of plant resistance, understanding pest biology and nature of damage, and finding the source of resistance is the prerequisite for generating insect-resistant varieties. Since the *S. inferens* is a major pest of maize this review paper is mainly deals with the elements of host plant resistance against *S. inferens* in maize.

Keywords: host plant resistance, *Sesamia inferens*, biology, maize, biochemical basis

Introduction

Host plant resistance refers to heritable qualities of a cultivar to counteract the activities of insects so as to cause minimum reduction in yield as compared to other cultivars under similar conditions [1]. It allows a plant to prevent insect pests from selecting a host plant for settling, oviposition, and feeding, and even if they do, it interferes with insect pests' biology by affecting their growth and development and reducing their survival, or else plant have the ability to tolerate or recover from insect injury. As a result, insect pests are unable to develop successfully on the resistant plants [2]. Mechanisms of resistance are classified in to three categories viz., antixenosis/non-preference, antibiosis and tolerance/recovery. Antixenosis mechanism of resistance influence larval orientation, settling and feeding response due to presence of chemical and/or morphological factors [3]. Antibiosis mechanism of resistance affects biology of the insect, and the most commonly observed adverse effects are in terms of nutritional physiology including consumption, assimilation, utilization and subsequent allocation of food resources for reproduction. Since plant resistance is the result of interaction between the plant and the insect, four resistance characteristics viz., heritable, relative, measurable and variable are important to compare the performance of particular genotype for resistance to target insect [4].

Among the cereals, maize is one among the most important crops of the world which together with rice and wheat, provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries of the world. It is also a key ingredient of the animal feed and is used extensively in industrial products, including the biofuels production. Maize is having an important role in the livelihood's security of millions of poor farmers and an important source of food and nutritional security for the millions of people in the developing world. Of the total, 75% is being used as poultry feed and human food, however, 25% is used for animal feed and industrial purposes [5]. It is an important component of feed for the meat industry, in the poultry industry on average broiler rations contain 60–65% maize only [6]. The production of maize in India is 27.23 million tonnes in 9.18 million hectares with productivity of 2965 Kg/hectare [7] which is much lesser than it yields potential, and limited by biotic and abiotic stresses. Among the insect pests attacking the maize crop, the lepidopteran stem borers infest the crop right from seedling to maturity stage, and are considered as major constraints of yield loss [8, 9]. Seventeen species belonging to two taxonomic families i.e., Crambidae and

Noctuidae have been found to attack maize in various parts of Asia. Out of which, *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) is of great importance causes considerable yield losses to maize [10]. In India, the maize production is highly influenced by the attack of *S. inferens.* This review major focus on the aspects of the biology, nature of damage, mechanisms, bases of resistance and identification of sources of resistant genotypes from the germplasm in maize.

Egg laying pattern of *Sesamia inferens*

Adult female *S. inferens* chose the inner side mostly of the first and second leaf sheath for oviposition. The studies on egg laying pattern revealed that the number of eggs laid by *S. inferens* were significantly higher in the first leaf sheath (59%) followed by second leaf sheath (27%) and least number on basal leaf sheath (14%) of maize plants [11, 12]. Conversely, the third leaf sheath (80%) of paddy was preferred over second leaf sheath (13%) for egg laying by *S. inferens* females [13]. In study the maximum number of plants used by a single female for egg laying were four out of ten plants offered. The total oviposition period was recorded up to 7 days, and maximum number of eggs was obtained on second day of adult emergence [12]. The choice of host by insect for egg laying is indication of antixenosis factor present in that plant [14]. The thermal constants for egg, larval and pupal stages were recorded as 64-, 535- and 164-Degree Days while, the lower developmental threshold was found to be 13, 8 and 11 ˚C, respectively [15].

Biology of *Sesamia inferens* on different hosts

Pink stem borer appears at the end of March and continually present till November in the maize crop, with peak in spring [16]. A female of *S. inferens* lays 150-400 eggs between the leaf sheath and the stem of maize plant with 87% of hatchability [17] the total number of eggs laid were recorded from 30 to 191 on selected maize germplasm by Divekar *et al.*, (2019) [18]. The colour of eggs is creamy-white and around 0.7 mm in diameter, with fine ridges in longitudinal line from the upper pole [19]. The eggs start to hatch within 7 days and the larva passes through eight instars and complete the larval development within 68 days on wheat [20]. Similarly, Rajendra (1976) [21] reported that the egg period of *S. inferens* lasts for 8-9 days in February month and larvae pass through eight instars. However, Joshi (2005) [13] reported that *S. inferens* passes through 6-8 instars and complete the larval development within 53-74 days on rice while according to Viswajyothi *et al*., (2019) [22] there were six larval instars and the larval development was completed in 29.95±0.16 days on maize. Pupal period is 9-11 days and adults live for five to seven days [21] and there are ~5 overlapping generations in a year [16]. Total life span of *S. inferens* females and males were found to vary from 63-72 days and 45-58 days, respectively [23]. Joshi *et al*. (2009) [17] reported that on Ragi, the duration of the life-cycle of *S. inferens* were averaged 46 days in summer and 71 days in winter season and completed four generations in a year.

Seasonal abundance of *Sesamia inferens*

The pink stem borer hibernates in rice stubbles in winter from November to March and adults emerge in mid-April and lay eggs [24]. The highest larval population of *S. inferens* was found during last week of February on maize crop and peak activity of adult moths was found during 2nd week of March in Chandigarh [25]. *S. inferens* was first appeared in third week of August (10% dead-heart) and reached to its peak infestation level (60% dead-heart) during the third week of September on maize [26]. In India, it has been reported as economically important pest of cereal crops in Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Orissa, West Bengal, Assam, Bihar, Uttar Pradesh, Delhi and Punjab [27].

Cold tolerance in *Sesamia inferens*

Low winter temperature is main environmental constraint for survival of many insect species, but *S. inferens* has mechanism to survive cold winters. The maximum tolerance recorded in *S. inferens* larvae was found in January collected larvae. Before March water content of larvae was found to stabilize at low level of 63.5 percent, but after that it rose significantly to 75.2 percent. Low molecular weight sugars and polyols (glycerol, trehalose, fructose, glucose, *myo*-inositol) associated with freeze tolerance activity were increased from low levels to their peaks in January, after that declined [28]. The adaptation mechanisms will help *S. inferens* to survive in the winter and from March onward it starts to infest the different field crops.

Nature of damage of *Sesamia inferens*

At the time of hatching, pink stem borer larvae remain inside or behind the leaf sheath and feed on the epidermal layer of the leaf sheath in groups. The first feeding site for larvae is the bottom most leaf sheath. Because of feeding, water-soaked lesions are formed on the infested leaf sheath in the initial stages of feeding which are visible from outside. Thereafter by boring through the sheath, the larvae reach to the central growing point of plant. Subsequently, it feed on leaves in the whorl in folded condition which results in formation of oblong (elongated or oval) shot holes of 2-3 mm size in parallel rows when leaf become unfolded. As plant grows, these holes extend and become slits and streaks. In extreme cases, tunneling on mid rib is also evident on the leaf blades and plants show ragged like appearance. Infestation in the growing point of the shoot result in drying up of central leaf, formation of dead heart at seedling stage in cereals and white ears at ear head stage in wheat as well as rice. Maximum amount of damage on stem are between first to fifth internodes. Exit holes (2-5 holes per plant) may be found on the stem. The stem tunnels may be horizontal (sometimes extended to other internodes) S-shaped or circular or vertical. Dark circular ring like cuts on lower internodes may be seen externally in the stem and excreta also present on stems outer surface near the bore hole [29]. Single larva may cause damage to more than one plant, as larva could leave the old tunnels and prepare fresh ones. In artificial infestation of maize crop with *S. inferens,* the highest mean Leaf Injury Rating (LIR) were recorded when larvae were released at 2 leaf stage (7 DAG). The LIR increase with increasing in larval density irrespective of the age of crop. It shows that maize crop at 2 leaf stage is most critical stage for *S. inferens* infestation irrespective of the larval density per plant [30].

Extent of damage done by *Sesamia inferens*

Stem borers are categorized as the most damaging group of insect pests in maize production and estimated to cause an average annual loss of ~18%. Among them *S. inferens* is key pest of Rabi maize causing major damage in peninsular India and is present throughout the year. It also causes extensive damage in the northern states in Rabi maize [31]. Pink stem borer may cause up to 78.9% damage in maize crop during winter [32] with estimated annual loss of Rs. 110 million in India [14]. It is a polyphagous pest and feed on variety of cereals *viz.*, sorghum, pearl millet, finger millet, wheat, rice, oats, barley and sugarcane. Ragi is being increasingly attacked by *S. inferens.* Pink stem borer is emerging pest of wheat crop in India because of change in cultivation and tillage pattern [33]. The yield loss due to *S. inferens* vary from 25.7 to 78.9% in maize and more than 11% in wheat [34, 35].

Assessment of damage done by *Sesamia inferens*

Foliar lesions, dead heart and stem tunnelling are the main damaging parameters used for the damage assessment of stalk borers like *C. partellus* and *S. inferens*. Yield loss caused by the stalk stem borers is mainly because of stem tunnelling of the maize plants [36]. Foliage damage, number of entry or exit holes, number of egg masses, percentage of stem length tunneled and stalk breakage due to attack of stem borer are some of the very important parameters which distinguish between resistant and susceptible genotypes or varieties. Moreover, resistance/susceptibility index is calculated by relative ratios of all the parameters for every genotype. Some important parameters like leaf damage, dead heart and stalk damage are generally considered in breeding programme of maize to develop resistant genotype. Based on the nature and extent of damage, a rating scale of 1 (healthy plant) to 9 (dead heart) is used in the screening of maize genotypes for resistance to *S. inferens*. It categorizes the maize plants in three distinct groups, namely least susceptible (1-3 score), moderately susceptible (4-6) and highly susceptible (7-9) [37].

Basis of resistance to pink stem borer

Morphological, allelochemical and biochemical characteristics of a plant determine its quality and host suitability to stem borer [38]. Plant morphological characters interfere with insect behavioral activities such as mating, oviposition, feeding and ingestion. To measure orientation and settling behavior of *S. inferens*, various choice tests have been developed and used for such studies. The no choice tests have been performed to determine level of antibiosis in various maize hybrids [39]. Apart from various morphological characteristics such as plant height, trichrome, pubescence hair, stem hardiness, leaf texture, glossiness and tassel ratio [40], biochemical characteristics *viz.*, tannin, phenol, flavonoids, chlorophyll, carotenoids, protein, sugar, starch have also been reported to be effective for imparting resistance to insect pests in maize [41, 42]. Biochemical characteristics of plant adversely affect the feeding behavior of insect by producing toxic substances which ultimately prevent metabolic processes [43]. The feeding potential of first instar larvae of European corn borer, *Ostrinia nubialis* (Hubner) on young seedlings of resistant maize genotypes was found reduced due to biochemical factor, 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA). The concentration of DIMBOA in maize plant decreases with plant age [44]. Expression of resistance in host plant not only governed by single constitutive factor, but is the result of interaction between all the constitutive biochemical factors [45]. Phenol compounds could play an important role in resistance to stem borer *S. nonagrioides.* The amount of free *p-coumaric* acid was correlated with the resistance level in different maize genotypes. Higher amount of p-coumaric in the pith could contribute to general resistance to stem borer attack. Jointly with ferulic acid, the p-coumaric could provide resistance mechanisms also through cell wall fortification and lignification [46].

The constitutive and induced plant metabolic compounds govern the insect-plant interaction, which ultimately leads to plant defense against insects [47]. Host plant quality can be determined by specific allelochemicals, nutrients and anatomical factors present in the host plant [48]. The sum of all the morphological, biochemical and anatomical plant features contribute to durable resistance against insect pests [49]. Anti-nutritional factors like lignin and phenolic compounds also play a major role in plant defense against herbivores [42]. The plant chemicals influence the resistance/susceptibility to insect pests in several ways: like, by determining the orientation, feeding and oviposition behaviour of the insects, by determining the metabolism of insects, which could be either helpful in normal metabolic processes resulting in insect's normal survival, development and egg production, or production of plant toxins interfering with survival, development and egg production. The induced plant defense chemicals adversely affect growth, development, feeding and survival of insect and overcome damage by the herbivores [50, 51].

Morphological factors responsible for resistance to pink stem borer

Six inbred lines with different levels of stem resistance against *S. nonagrioides* were compared in several trials. Potential structural resistance factors are the rind and pith puncture resistance (RPR and PPR), rind thickness, length of the meristematic area (LMA), and pith parenchyma interlumen thickness (PPIT). Susceptible inbred lines normally showing the higher values for the LMA, so PPIT and LMA was the most promising indicator of resistance in maize against pink stem borer [52]. In *S. nonagrioides* resistant inbreds of maize (CM151, CO125 and EP39) there is low damage in the stem due to antibiotic pith that also affected the weight and the larval survival of stem borer. So, pith antibiosis appeared to be one of the factors that confer resistance against stem borer [53]. The leaf sheath of maize plants appears to play a role in the successful development of neonates of *S. nonagrioides*. In the presence of phenolic carbohydrate complexes, fiber strength increases, which provides a tough physical barrier to restrict insect penetration and render nutrients within tissues less accessible [54]. Plants anti-nutritional defenses against insects reduces the nutrient value and limit food supplies to insects through physical barriers such as the cell wall fortification. Lignin and other phenolics can strengthen cell walls against digestion [55].

Biochemical factors responsible for resistance to *Sesamia inferens*

Plants produce hundreds of thousands of unique low-mass natural products, known as secondary metabolites. Plants respond to herbivory through various biochemical mechanisms including limiting food supply, reducing nutrient value, reducing preference and inhibiting chemical pathways of the insect. Earlier studies have demonstrated that the plant attributes can affect herbivores, natural enemies of herbivores, and their interaction [56]. Plant secondary metabolites are different from primary metabolites in terms of their basic metabolic processes in plant as they are generally non-essential, but improve defense against microbial attack, herbivore feeding and control allelopathic interactions in plants [57]. These secondary metabolites are produced in plant tissue independent of the presence of the pest and development-specific manner. Production of toxic chemicals such as terpenoids, alkaloids, anthocyanins, phenols, and quinones were affecting the biology of insect. Plants contain significant quantities of various phenolic acids, as well as their glycosides and esters. Plant phenols constitute one of the most common and widespread group of defensive compounds, which play a very important role in plant resistance. These phenolic compounds are act by two defense concepts, the phenolic fortification of cell walls and the deterrent effect of fiber content. Main components that strengthen the cell wall as mechanical barrier are ferulic and *p* -coumaric acid [57]. Free phenols, mainly 4-coumaric and ferulic acid, were implicated as factors contributing to resistance of maize against maize weevil (*Sitophilus sp*), and recently, to pink stalk borer (*S. nonagrioides*). Furthermore, maize genotypes in which pith contain higher quantities of phenylpropanoids in cell wall was found resistant to *S. nonagrioides.* Presence of ubiquitous phenolic acids, especially ferulic acid, may contribute to insect resistance in maize. Free phenols, mainly p-coumaric (CA) and ferulic acid (FA), were implicated as factors contributing resistance to various insect pests including pink stalk borer, *S. nonagrioides* in maize [58]. The *S. inferens* feeding strongly induced defense responses resulted in the accumulation of higher content of phenolic acids-p-CA and FA in leaf tissues of resistant and moderately resistant genotypes possibly contributes to enhanced resistance in maize. Changes in FA content in stalk tissues of maize genotypes were induced due to wounding and regurgitation followed by *S. inferens* feeding [59]. Tannins have a strong deleterious effect and affect insect growth and development by binding to the proteins, reduce nutrient absorption efficiency and decrease the nutritive value of plants to herbivores. The increase in nitrogen content in maize seedlings significantly increase the larval survival, larval weight, and female fecundity, while silica content had opposite effect on these biological traits of *S. calamistis* Hampson [60]. Plant surveillance system detects attacks by specific signals and detected signals are then transduced through a network of signal transduction pathways, which eventually lead to the production of defense chemicals [61]. Salicylic acid is an important phytohormone involved in regulation of plant defense that generates a wide range of metabolic and physiological responses in plants involved in defense. Plants with high variability in defensive chemicals exhibit a better defense compared with those with moderate variability. The biosynthesis of these defense-related metabolites has a common root in the shikimic acid pathway [58]. Maize plants respond to the attack of *S. nonagrioides* through cell-wall fortification, activating genes involved in cell-wall organization, which finally is reflected in a higher concentration of some cell-wall components, especially in resistant genotypes. The amount of free phenolic compounds like p-coumaric acid was correlated with resistance to stem borer, *S. nonagrioides* in which *p*-coumaric together with ferulic acids could provide higher level of resistance through cell wall fortification and lignification. The amount of these compounds was correlated with the resistance level in the maize genotypes, with the resistant inbreds having the highest concentrations [46].

In plant defense against herbivores, reactive oxygen species (ROS) play a major role and act as secondary messenger for signaling various defense reaction pathways in plants [62]. Oxidative state of the host plants has been associated with plant resistance to insects, which results in production of ROS are subsequently eliminated by antioxidative enzymes [63]. ROS promote beneficial oxidation to generate energy and kill microbial invaders and herbivore. But in excess, it can cause pigment co-oxidation, lipid peroxidation, membrane destruction, protein denaturation, and DNA mutation [64]. In order to prevent oxidation, plant itself develops important ROS scavenging mechanism [65]. Antioxidative enzymes are the most important components in the scavenging system of ROS, and are involved in defense against herbivores. Induced resistance in host plants is regulated by various antioxidative defense enzyme such as peroxidases (PODs), polyphenol oxidases (PPO), phenylalanine ammonia lyase (PAL), superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase [66]. The enzymes that impair the nutrient uptake by insects include ascorbate peroxidases by oxidizing mono- or dihydroxyphenols to o-quinones which in turn form covalent adducts with the nucleophilic groups of proteins. Qualitative or quantitative alteration in phenols and enhanced activity of antioxidative enzymes in response to herbivore attack is general phenomenon [67], and play major role in plant defense against stem borer [68].

Sources of resistance to *Sesamia inferens*

For a good host plant resistance program, it is necessary to establish an efficient and reliable screening technique of the maize genotypes that ensures the desired level of insect pressure uniformly on all plants, at the most susceptible stage of the crop. These necessities can be fulfilled either by selection of a location where the insect pest occurs regularly (hot spot) or by testing the germplasm materials under the artificial infestation with insectary reared insects. The most critical damage which causes the maximum grain yield reduction is formation of dead-heart. This symptom can be achieved only if we are infesting the relatively young plants. In this programme efficient planning is necessary to produce sufficient numbers of insects which can infest the test material at the proper growth stage and uniformly to all plants [69].

In the screening programme of ten genotypes of maize against *S. inferens*, the leaf injury varied from 5.03 to 7.9 in which genotype Madhuri and BML 7 recorded as lowest leaf injury while Basi Local and HQPM-1 as highest leaf injury. Basi Local shows the highest dead-heart (39%) in plants [70]. Another research on screening of 15 maize genotypes were carried out for their reaction to stem borers, the hybrids Super 900M and Bioseed 9681 was found resistant to *S. inferens*, whereas, NK 6240, NK 30 and Arjun were highly susceptible in terms of leaf damage score and per cent infestation [71]. Nagarjuna, *et al*. (2015) [72] conducted research on screening of nine hybrids of maize for resistance to *S. inferens* in which hybrid CP-828 and NAH 2049 showed minimum damage while Allrounder and Bioseed-9544 showed maximum damage. Screening of ten maize genotypes based on the dead-hearts and leaf injury rating, with artificial infestation of *S. inferens* under field conditions, it was found that maize genotype Madhuri is highly resistant, BML 7 and HKI 163 moderately resistant, and the remaining genotypes *viz.*, HQPM 1, MP 717, BML 6, BH 40625 and BH 1576 are highly susceptible [73]. In another research on screening of 22 hybrids of maize against *S. inferens*, based on number of pin hole, leaf injury rating, dead-heart and grain yield, Hishell was found most tolerant, while IAHM-2013-09 and IAHM-2013-26 tolerant [26] while the genotypes BU1, BU2, BU3 and BU5 were found to be relatively resistant to borers attack in another study [74]. The maize genotypes CPM 1, CPM 2, CPM 4, CPM 8, CPM 15 and CPM 18 were found resistant to *C. partellus* [5] and have antibiosis mechanism of resistance against this pest [42]. Among the 56 inbred lines screened, eight lines, viz., BGS-86, CM111, CML141, CML33#-4, DML-1432, EC619101, HEY Pool-2011-30-4-1-2-2-1 and HEY Pool-2011-41-2- 1-1-1-1 were found resistant to *S. inferens* [75]. This difference in resistance may be due to their morphological, biochemical characters and genetic variations. The *S. nonagrioides* attack significantly increased the DIMBOA content in leaf tissues of maize inbred lines, A-619 and W-117 as compared with healthy seedlings which shows resistance to this pest [76]. The three mechanisms of defense to the pink stem borer (*S. nonagrioides*) attack (antixenosis, antibiosis, and tolerance) were found among inbred lines and hybrids of maize and multi-trait selection scheme using damage traits and yield could improve the defense level against this pest [77].

Conclusion

Several management strategies including crop rotation, field sanitation, biological control agents and synthetic pesticides have been recommended for *S. inferens* but none of these have been found effective for successfully control of this pest particularly when the larvae enter inside the stalks. Under such situations, HPR could be one of the most effective mean of minimizing losses due to this pest. For a good HPR program, it is necessary to establish an efficient and reliable screening technique of the genotypes that ensures the desired level of insect pressure uniformly on all plants, at the most susceptible stage of the crop. Many wild relatives and native cultivars of plants have important genetic variants that have yet to be utilized for agricultural enhancement. There are so many genotypes of maize reported to be resistant to this pest by different worker by following different screening techniques. This synthesized information is useful for future breeding programs aiming at resistance to *S. inferens* infestation for effective and sustainable management. Further, substantial yield losses and insecticidal applications can be minimized resulting in an eco-friendly environmental footprint.

References

1. Dhaliwal GS, Dilawari VK, Saini RS. Host plant resistance to insects: Basic concepts. In: Advances in Host Plant Resistance to Insects (Dhaliwal GS, Dilawari VK. eds.). Kalyani Publishers, New Delhi, 1993, 172-210.
2. Mookiah S, Sivasubramaniam B, Thangaraj T, Govindaraj S. Host Plant Resistance. In: Omkar (eds) Molecular Approaches for Sustainable Insect Pest Management. Springer, Singapore, 2021. https://doi.org/10.1007/978-981-16-3591-5_1
3. Khan ZR. A review of entomological techniques and methods used to determine mechanisms and bases of stem borer resistance in maize. In: Proceedings of International Symposium on Insect Resistant Maize: Recent Advances and Utilization (Mihm J. eds.). International Maize and Wheat Improvement Center (CIMMYT), Mexico, USA, 1997.
4. Panda N, Khush GS. Host Plant Resistance to Insects. CAB International, Wallingford, UK. 1995, 315p.
5. Dhillon MK, Gujar GT. Maize genotypes identified with resistance to spotted stem borer, *Chilo partellus* and favourable agronomic traits. Annals of Plant Protection Sciences. 2013;21:224-28.
6. Shiferaw B, Prasanna BM, Hellin J, Banziger M. Crops that feed the world: Past successes and future challenges to the role played by maize in global food security. Food Security. 2011;3:307-27.
7. Agricultural Statistics at a Glance Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Govt. of India, New Delhi-2019.
8. Ahad I, Bhagat RM, Hafeez A, Sharma D, Jamwal VS. Insect pest complex and their succession on maize. Annals of Plant Protection Sciences. 2012;20:467-68.
9. Dhillon MK, Kalia VK, Gujar GT. Insect pests and their management: Current status and future need of research in quality maize. In: Maize: Nutrition Dynamics and Novel Uses (Choudhary, D.P., Kumar, S. and Langyan, S., eds.). Springer, New York, USA, 2014, 95-103.
10. Arabjafari KH, Jalali SK. Identification and analysis of host plant resistance in leading maize genotypes against spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae). Pakistan Journal of Biological Science. 2007;10:1885-895.
11. Sekhar JC, Kumar P, Rakshit S, Singh KP, Dass S. Differential preference for oviposition by *Sesamia inferens* Walker on maize genotypes. Annals of Plant Protection Sciences 2009;17:46-49.
12. Kaur J, Kumar P, Singh J, Suby SB, Bajya DR. Egg laying pattern of *Sesamia inferens* on maize (*Zea mays*). Indian Journal of Agricultural Sciences. 2015;85:109-113.
13. Joshi G. Population dynamics of paddy borers and biology of pink stem borer *Sesamia inferens* (Walker). M.Sc. Thesis. CCS Haryana Agricultural University, Hisar, 2005.
14. Kaur J, Singh J, Suby SB, Kumar P. Differential preference for oviposition- A potential indicator of antixenosis in maize genotypes against *Sesamia inferens*. Indian Journal of Experimental Biology. 2019;57:231-38.
15. Viswajyothi K. Biology of *Sesamia inferens* Walker on maize vis-à-vis impact of selected environmental variables. M.Sc. Thesis, Punjab Agricultural University Ludhiana, 2016.
16. Younis MA, Hamoudi RF, Abid MK. Ecological and biological studies of corn stem borer *Sesamia cretica* L Lepidoptera: Noctuidae in central Iraq. Journal of Agricultural and Water Resources Research. 1984;3:88-96.
17. Joshi G, Ram L, Singh R. Biology of pink borer, *Sesamia inferens* (Walker) on taraori basmati rice. Annals of Biology. 2009;25:41-45.
18. Divekar P, Kumar P, Suby SB. Oviposition preference of pink stem borer, *Sesamia inferens* (Walker) in maize germplasm. J Entomol. Zool. Stud. 2019;7:1115-119.
19. Nagayama A, Arakaki N, Kishita M, Yamada Y. Emergence and mating behavior of the pink borer, *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae). Applied Entomology and Zoology. 2004;39(4):625-29.
20. Singh B, Kular JS. Notes on the bionomics of the pink stem borer *Sesamia inferens* Walker (Lepidoptera: Noctuidae): An upcoming pest of wheat in India. Acta Phytopathologicaet Entomologica Hungarica. 2015;50(2):239-59.
21. Rajendra A. Studies on *Sesamia inferens* (Walker), the

shoot-borer pest of the Sugarcane in Sri Lanka. Journal of Natural Science Foundation of Sri Lanka. 1976;4(2):99-108.
22. Viswajyothi K, Aggarwal N, Jindal J. The biology of Sesamia inferens (Walker) (Lepidoptera: Noctuidae) on maize in the north western plains of India. Acta Phytopathologica et Entomologica Hungarica 2019;54(1):69-84.
23. Sharma H, Jaglan MS, Yadav SS. Biology of pink stem borer, *Sesamia inferens* (Walker) on maize, *Zea mays*. Journal of Applied and Natural Science. 2017;9(4):1994-2003.
24. Garg DK. Host range and overwintering of rice pink stem borer (PSB) in a hilly region of India. International Rice Research Notes. 1988;13:2.
25. Deole S. Studies on pink stem borer, *Sesamia inferens* Walker of maize, *Zea mays* L. with particular reference to neonate larval behavior and its management. Ph.D. Thesis submitted to Indira Gandhi Krishi Vishwavidhyalaya, Raipur, 2016.
26. Sidar Y, Deole S, Yadu YK, Ganguli RN. Seasonal incidence of major insect pests in maize crop (*Zea mays* L.) under Chhattisgarh plains. Trends in Biosciences. 2015;8:4848-854.
27. Siddiqui KH, Marwaha KK. The vistas of maize Entomology in India. Kalyani Publishers, Ludhiana, Punjab, India, 1993, 184 p.
28. Sun M, Tang XT, Lu MX, Yan WF, Du YZ. Cold tolerance characteristics and overwintering strategy of *Sesamia inferens* (Lepidoptera: Noctuidae). Florida Entomologist. 2014;97(4):1544-553.
29. Reddy ML. Bio-ecology and management of *Sesamia inferens* (Walker) on maize. Ph.D. Thesis. Acharya N.G. Ranga Agricultural University, Hyderabad, 2001.
30. Pavani T. Studies on management of pink borer *Sesamia inferens* Walker on maize. M.Sc. thesis submitted to N.G. Ranga Agricultural University, Hyderabad, 2011.
31. Groote DH. Maize yield losses from stem borers in Kenya. Insect Science and Applications. 2001;22:89-96.
32. Santosh HB, Sekhar JC, Rakshit S, Gadag RN, Dass S. Detection of epistatic interaction for susceptibility towards pink borer (*Sesamia inferens* Walker) in maize (*Zea mays* L.). Indian Journal of Genetics. 2012;72(3):284-89.
33. Singh B. Incidence of pink noctuid stem borer *Sesamia inferens* Walker on wheat under two tillage conditions and three sowing dates in North – Western plains in India. Journal of Entomology. 2012;9(6):368-74.
34. Sekhar JC, Karjagi CG, Kumar BH, Rakshit S, Soujanya L, Kumar P, Singh KP, Dhandapani A, Dass S. Genetics of resistance to *Sesamia inferens* infestation and its correlation with yield in maize. Plant Breeding. 2015;134:394-99.
35. Baladhiya HC, Sisodiya DB, Pathan NP. A review on pink stem borer, *Sesamia inferens* Walker: A threat to cereals. Journal of Entomology and Zoology Studies. 2018;6(3):1235-239.
36. Ajala OS, Saxena NK. Interrelationship among *Chilo partellus* (Swinhoe) damage parameters and their contribution to grain yield reduction in maize (*Zea mays* L.). Applied Entomology and Zoology. 1994;29:469-476.
37. Reddy ML, Babut R, Venkatesh S. A new rating scale for *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) damage to maize. Insect Science and its Application 2003;23:293-99.
38. Agrawal AA. Current trends in the evolutionary ecology of plant defense. Functional Ecology. 2011;25:420-32.
39. Davis FM, Seong S, Williams WP. Mechanisms of resistance in corn to leaf feeding by southwestern corn borer and European corn borer (Lepidoptera: Pyralidae). Journal of Economic Entomology. 1989;82(3):919-22.
40. Kumar H. Resistance in maize to *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae), an overview. Crop Protection. 1997;16:243-50.
41. Yele YM. Biology and nutritional biochemistry of spotted stem borer, *Chilo Partellus* (Swinehoe) on diverse array of maize genotypes. M.Sc. Thesis. Indian Agricultural Research Institute, New Delhi, India, 2014.
42. Dhillon MK, Chaudhary DP. Biochemical interactions for antibiosis mechanism of resistance to *Chilo partellus* (Swinhoe) in different maize types. Arthropod-Plant Interactions. 2015;9(4):373-82.
43. Kumar H. Effects of water stress, nitrogen stress and certain sensory stimuli on infestation and damage by *Chilo partellus* (Swinhoe) to maize. Annals of Applied Biology. 1994;125:35-43.
44. Beck SD. Resistance of plants to insects. Annual Review of Entomology. 1965;10:207-32.
45. Dhillon MK, Sharma HC, Singh R, Naresh JS. Mechanisms of resistance to shoot fly, *Atherigona soccata* in sorghum. Euphytica. 2005;144:301-12.
46. Santiago R, Butron A, Arnason JT, Reid LM, Souto XC, Malva RA. Putative Role of Pith Cell Wall Phenylpropanoids in *Sesamia nonagrioides* (Lepidoptera: Noctuidae) Resistance. Journal of Agriculture and Food Chemistry. 2005;54(6):2274-279.
47. Sharma HC. Biotechnological approaches for pest management and ecological sustainability. CRC Press, Taylor and Francis Group, LLC. 2009, 526.
48. Agrawal AA. Mechanisms, ecological consequences and agricultural implications of tri-trophic interactions. Current Opinion on Plant Biology. 2001;3:329-35.
49. Huang Y, Sharma HC, Dhillon MK. Bridging conventional and molecular genetics of sorghum insect resistance. In: Plant Genetics and Genomics: Crops and Models Genomics of the Saccharinae (Paterson AK. ed.). Springer, New York, USA, 2013; 11:67-89.
50. Chen Y, Ni X, Buntin GD. Physiological, nutritional and biochemical bases of corn resistance to foliage-feeding fall armyworm. Journal of Chemical Ecology. 2009;35:297-306.
51. Wu J, Baldwin IT. New insights into plant responses to attack from insect herbivores. Annual Review of Genetics. 2010;44:1-24.
52. Santiago R, Souto XC, Sotelo J, Butro A, Malvar RA. Relationship between maize stem structural characteristics and resistance to pink stem borer (Lepidoptera: Noctuidae) attack. Journal of Economic Entomology. 2003;96(5):1563-570.
53. Ordas B, Butron A, Soengas P, Ordas A, Malvar RA. Antibiosis of the pith maize to *Sesamia nonagrioides* (Lepidoptera: Noctuidae). Journal of Economic Entomology. 2002;95(5):1044-048.
54. Rodriguez VM, Santiago R, Malvar RA, Butron A. Inducible maize defense mechanisms against the corn borer *Sesamia nonagrioides*: A transcriptome and biochemical approach. Molecular Plant Microbe Interaction Journal. 2012;25:61-68.

55. Santiago R, Rios JB, Malvar RA. Impact of cell wall composition on maize resistance to pests and diseases. International Journal of Molecular Science. 2013;14:6960-980.
56. Schnee C, Kollner TG, Held M, Turlings TJ, Gershenzon J, Degenhardt J. The products of a single maize sesquiterpene synthase form a volatile defense signal that attracts natural enemies of maize herbivores. Proceedings of the National Academy of Sciences USA 2006;103:1129-134.
57. Mullen MD, Frey M, Degenhardt J. Genetics and biochemistry of insect resistance in maize. In: Handbook of maize: its biology (Bennetzen JL, Hake SC. eds). Springer, New York, 2009.
58. Santiago R, Butron A, Reid LM, Arnason JT, Sandoya G, Souto XC, Malvar RA. Diferulate content of maize sheaths is associated with resistance to the Mediterranean corn borer *Sesamia nonagrioides* (Lepidoptera: Noctuidae). Journal of Agricultural and Food Chemistry. 2006;54:9140-144.
59. Soujanya PL, Sekhar JC, Ratnavathi CV, Karjagi CG, Shobha E, Suby SB, Yathish KR, Sunil N, Rakshit S. Induction of cell wall phenolic monomers as part of direct defense response in maize to pink stem borer (*Sesamia inferens* Walker) and non-insect interactions. Scientific reports. 2021;11(1):1-10.
60. Setamou M, Schulthess F. Effect of plant nitrogen and silica on the bionomics of *Sesamia calamistis* (Lepidoptera: Noctuidae). Bulletin of Entomological Research. 1993;83:405-11.
61. Chen MS. Inducible direct plant defense against insect herbivores: A review. Insect Science. 2008;15:101-14.
62. Asada K. Production and scavenging of reactive oxygen species in chloroplasts and their functions. Plant Physiology. 2006;141(2):391-96.
63. War AR, Paulraj MG, War MY, Ignacimuthu S. Herbivore induced resistance in different groundnut germplasm lines to Asian armyworm, *Spodopteralitura* (Fab.) (Lepidoptera: Noctuidae). Acta Physiologiae Plantarum. 2012;34:343-52.
64. Mittler R. Oxidative stress, antioxidants and stress tolerance. Trends in Plant Sciences. 2002;7(9):405-10.
65. Howe GA, Schilmiller AL. Oxylipin metabolism in response to stress. Current Opinion in Plant Biology. 2002;5:230-36.
66. Gulsen O, Eickhoff T, Heng-Moss T, Shearman R, Baxendale F, Sarath G, Lee D. Characterization of peroxidase changes in resistant and susceptible warm-season turf grasses challenged by *Blissus occiduus*. Arthropod- Plant Interactions. 2010;4:45-55.
67. Barakat A, Bagniewska ZA, Frost CJ, Carlson JE. Phylogeny and expression profiling of CAD and CAD-like genes in hybrid *Populus* (*P. deltoides*× *P. nigra*): evidence from herbivore damage for sub-fictionalization and functional divergence. BMC Plant Biology. 2010;10(1):100.
68. Howe GA, Jander G. Plant immunity to herbivores. Annual Review of Plant Biology. 2008;59:41-66.
69. Taneja SL, Leuschner K. Methods of Rearing, Infestation, and Evaluation for *Chilo partellus* Resistance in Sorghum. In: Proceedings of the International Sorghum Entomology Workshop, Texas A& M University, College Station, TX, USA and International Crops Research Institute for the Semi-Arid Tropics, Patancheru, A.P., India, 1984.
70. Sailaja V, Vijaya LK, Reddy LK, Sekhar JC. Differential preference of maize genotypes to pink stem borer, *Sesamia inferens*. Indian Journal of Plant Protection. 2012;40:71-73.
71. Kulkarni S, Mallapur CP, Balikai RA. Influence of plant morphological traits on the incidence of stem borers in different maize hybrids. Journal of Eco-friendly Agriculture. 2015;10(2):157-62.
72. Nagarjuna B, Manjunath M, Latha M. Studies on varietal screening of maize hybrids against stem borer, *Sesamia inferens* (Walker). Journal of Eco-friendly Agriculture. 2015;10:64-66.
73. Sailaja V, Lakshmi KV, Reddy KL. Screening of maize genotypes against pink borer, *Sesamia inferens* under artificial infestation in the field. Agriculture Update. 2017;12(4):681-84.
74. Rabbani MT, Yaqubi SA, Mohammadi TN, Rezaie M, Ghaderian M. Evaluation of corn genotypes for resistance to *Sesamia inferens.* International Journal of Plant & Soil Science. 2016;11(3):1-8.
75. Soujanya PL, Sekhar JC, Karjagi CG, Suby SB, Sunil N, Yathis KR *et al.* Field screening of maize inbred lines for resistance to stem borers *Chilo partellus* (Swinhoe) and Sesamia inferens Walker. Maize Journal. 2019;8(1):8-14.
76. Gutierrez C, Castarera P, Torres V. Wound-induced changes in DIMBOA (2, 4 dihydroxy- 7 -methoxy- 2H-1,4 benzoxazin-3(4H)-one) concentration in maize plants caused by *Sesamia nonagrioides* (Lepidoptera: Noctuidae). Annals of Applied Biology. 1988;113:441-54.
77. Butron A, Malvar RA, Velasco P, Revilla P. Defense mechanisms of maize against pink stem borer. Crop Science. 1998;38(5):1159-163.