Journal of Scientific Research and Reports

Volume 30, Issue 8, Page 987-994, 2024; Article no.JSRR.120206
ISSN: 2320-0227

Managing Insect Pests in Millets: Harnessing Host Plant Resistance in Integrated Pest Management

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jsrr/2024/v30i82320

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/120206

Review Article

Received: 23/05/2024
Accepted: 25/07/2024
Published: 21/08/2024

ABSTRACT

Insect pests are major constraints in the production of millets. Proper identification and timely management of insects are important to protect the crops. Chemical insecticides are being applied for the management of insect pests in high yielding varieties of millets. An integrated approach has to be followed for sustainable pest control, minimizing the reliance on chemical insecticides in millet crops. Ecology, evolutionary pest biology, knowledge of the local agro-ecosystem, host plant resistance and utilization of natural enemies must become the components of integrated pest management strategy for holistic management of pests in millets. A combination of cultural practices, resistant cultivars has proved to be effective in pest management. Plant defenses have generally been assumed to be constitutive, being always expressed in the plant. Host plant

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Cite as: *Vijayashanthi , V. A., C. Tamilselvi, P. Yogameenakshi, K. Sivagamy, T. L. Preehi, G. Sathish, and S. Banumathy. 2024. "Managing Insect Pests in Millets: Harnessing Host Plant Resistance in Integrated Pest Management". Journal of Scientific Research and Reports 30 (8):987-94. https://doi.org/10.9734/jsrr/2024/v30i82320.*

resistance is a reasonable and ecologically safe method wherein resistance mechanisms of crops could lower the insect infestation. The foremost challenge in understanding the mechanism would be to detect the genes of interest in the crop using novel biotechnological approaches. The fundamental criterion for developing insect-resistant lines relies on recognizing the mechanism of plant resistance. Recently it has come to be realized that induced responses reduce insect survival, reproductive output as well as the performance of the pest, so that the plant benefits from such responses. It is an important component of integrated pest management, which can be triggered by biotic or abiotic elicitors, and can be used very effectively when combined with selective pesticides and induced resistance techniques. Induced response in plants is one of the important components of pest control in agriculture, and has been exploited for regulation of insect herbivore population. Plants often increase their resistance to herbivores by locally increasing the production of defensive compounds at the site of damage, as well as systemically on undamaged leaves. Induced resistance in crop protection to herbivore pests have not exploited the full potential of induced resistance for agriculture. Hence, in this review, an attempt has been made to provide details on integrated pest management, host plant resistance, induced resistance mechanisms against insect pests and its perspectives in integrated pest management.

Keywords: Millets; harnessing; insect pests; pest management.

1. INTRODUCTION

Millets are coarse grain cereals that are nutrient-rich, drought tolerant and short duration crops. India is the highest producer of millets, with a production of 10 lakh tonnes per year and provides food and fodder security to dry land and rainfed agriculture. Millets are the most secure crops for small farmers as they are the hardiest and most climate resilient crops in hot and drought environments. Millet crops grown in India are sorghum, pearl millet, finger millet, foxtail millet, kodo millet, little millet, proso millet and barnyard millet. Major millet crop sorghum is cultivated in 4.6 million hectares with a production of 4.5 million tonnes followed by finger millets in 11.94 lakh hectare area with a production of19.85 lakh metric tonnes, foxtail millet and kodo millet in 0.87 and 1.96 lakh hectares with the production of 0.66 lakh tonnes, 0.84 lakh tonnes respectively. Little millet, proso millet and barnyard millet are grown in 2.34 lakh hectares, 0.41 lakh hectares and 0.146 million hectares with the production of 1.27 lakh tonnes, 0.22 lakh tonnes and 0.147 million tonnes respectively. Insect pests are major constraints in the production of millets. In India, 10 to 20 percent reduction in yield in millets is recorded due to the insect pests, stem borers and shoot flies. Insects like stem borers, shoot flies, armyworms, aphids, midges, white grub and termites, which attack millets cause huge yield loss [1]. It is very important that an integrated pest management approach has to be followed for effective pest management and pesticide residue free production of produce. Resistant varieties in millet crops proved to be effective in insect pest management. Multiple pest resistance varieties played a vital role has become in reduction in usage of insecticides [2].

Host plant relations have to be explored to arrive effective management srategy against insect pests [3]. Host plant resistance to insects includes plants transformed with insect resistance genes, termed as "substantial crop development''. Hence, host plant resistance mechanisms is the most viable and sustainable method for pest management [4]. In India, crop loss of 6 to 9 percent is due to insect pests damage Oerke, [5] and Oishimayaya, [6]. "Pesticides usage are a reliable method to reduce the yield losses caused by stem borers and maintain sustainable production and productivity. However, stem borers are challenging to manage as the entire immature stages hide inside the stem, besides the nocturnal nature of the adult moths. Climatic change with modern crop cultivation practices has hustled stem borers to the status of major pests of millets in India" [7]. "Identification and utilization of resistant cultivars are the cheapest, practicable and environmentally friendly way to combat the insect pest problems. The resistant genetic resources can be utilized in a molecular breeding program with the aid of DNA markers. Improving the defense mechanism against insects and exploration of resistance genes is the only way to manage the insect pests using transgenic approaches" [8].

2. MAJOR INSECT PESTS OF MILLETS

Insect pests of millets causing economic damage are stem borers, shoot flies, caterpillars, cutworms, armyworms, grasshoppers, bugs, aphids, midges, white grub, termites, *etc.,* which attack millets and cause huge yield loss. It is very important to adopt an integrated pest management approach for effective management of insect pests. Major insect pests of millet cops and their management following integrative approach are detailed below.

Stem borers: Spotted stem borer (*Chilo partellus*) and pink stem borer (*Sesamia inferens)* (Crambidae: Lepidoptera) are the important species of stem borers infesting sorghum, pearl millet and finger millet. Dead hearts, peduncle tunnelling and partial chaffy panicles are the prominent symptoms for spotted stem borer. Incidence of pink stem borer causes typical 'pinhole' symptoms. The central shoot become brownish and dries out and the lower leaves remain healthy, called as 'dead heart'.

Shoot flies: Infests seedlings from 1st to 6thweek after germination. Maggot feeds the growing tip causing wilting of leaves and dead hearts. It produces side tillers at the boot leaf stage.

Caterpillars: Red hairy caterpillar **[***Amsacta albistriga*Walker (Erebidae:Lepidoptera)] is gregarious and voracious feeder and complete defoliation of millet plants will occur within a short time. Cutworms and armyworms **[***Mythimna separata* Walker, *Spodoptera litura* (Fab) (Noctuidae: Lepidoptera)] feed on the leaves, especially during the nursery and vegetative phase and they emerge during night to feed on the rootsand shoots of ragi plants and hide in the soil during day time. Gram caterpillar *(Helicoverpa armigera)*isa polyphagous pest and the larvae hide within the ear heads and feed on the grains. Ear heads are partially eaten and appear chalky.

Grasshoppers [*Hieroglyphus nigrorepletus* (Bolivar), *H. banian* (Fab), *Colemania sphenarioides* (Bolivar) and *Chrotogonus* spp. (Acrididae: Orthoptera)] feeds on all millets and defoliates which gives the grazed appearance.

Shoot bugs *[Peregrinus maidis* Ashmead (Delphacidae, Hemiptera)] infests 30day old *kharif* crop (summer) and also on *rabi* crop (winter) at the seedling stage. Heavy incidence at the vegetative stage may twist the top leaves and prevent the emergence of panicles and also acts as a vector for transmitting stripe disease of maize.

Aphids (Ragi aphid; *Hystero neurasetariae, Rhopalosiphum maidis,* and ragi root aphid; *Tetraneura nigriabdominalis)***:** Adults and nymphs suck sap from the tender leaves and spikelets and spread to entire plant leading to stunted growth and *R. maidis* transmits the mosaic virus.

Sorghum midge *(Stenodiplosis sorghicola) and Pearl millet midge (Geromyia penniseti)* maggot feeds on the developing grains and pupates in where they destroy the ovaries affecting the development of seeds. White pupal cases protruding out from the spikelet and causing chaffy grains with exit holes are seen.

Earhead bugs *Calocoris angustatus* (Lethiery) cause damage to pearl millet, sorghum, maize, and tenai crop. The adults and nymphs damage the ear heads by sucking the sap from the grains at the milky stage and the grains shrink and turn black in colour and become chaffy.

White grubs (*Holotrichia*sp, *Anomola*sp.) cut the roots resulting in wilting of plants in patches and die. Termites (*Odontotermes spp, and Microtermes spp*) also attack the roots of maize and sorghum, and the damaged plants topple and eventually disrupt the movement of nutrients and water through the vascular system resulting in the death of the plant.

3. INTEGRATED PEST MANAGEMENT IN MILLETS

Cultural methods such as early sowing, resistant varieties, judicious nutrient usage, and biological methods can help to restrict the pest population. Ecology, evolutionary pest biology, knowledge of the local agro-ecosystem, host plant resistance, and utilization of natural enemies must become the components of new IPM strategy for the management of insect pests. Collection and burning of stubbles, chaffy ear heads will prevent the carry over of over wintering pests. Exposure of the immature stages of insects by deep ploughing one month prior to planting, serve as food for predators. Synchronous and timely or early sowing will reduce the damage of shoot fly, midge and head bugs, and crop rotation with cotton, groundnut and sunflower, to reduce the damage by shoot fly, midge and head bugs. Intercropping sorghum with pigeon pea, cowpea or lablab also reduces the damage by stem borers. High seed rate (1.5 times more) and delayed thinning minimizes the shoot fly damage. Mechanical method includes light traps and fishmeal traps impregnated with arpocarb insecticides @12/ha till the crop is 30 days old helps to monitor, attract and kill adults of stem borer, grain midge, june beetle and other moth pests. Biorational management following balanced fertilizer dosage to reduce shoot fly populations and for stem borers can by setting up of sex pheromone trap at 12 per hectare. For white grub adult management, three pheromone (synthetic pheromone Anisole) dispensers per tree at 15 meter radius for three consecutive evenings may be placed after the first monsoon rains. To reduce the damage of shoot fly and to some extent stem borer and sucking pests, treat the seeds with thiamethoxam 70 WS @3 g/1 kg of seeds.

4. HOST PLANT RESISTANCE IN INTEGRATED PEST MANAGEMENT

“Plants have developed diversity of defense mechanisms against adverse environmental conditions caused by either biotic or abiotic factors. These defenses are commonly divided into constitutive or passive and induced or active defenses. Passive defense systems are constitutively expressed in anticipation of an attack and include, Physical barriers and morphological adaptations such as thick cell wall, seed coat, thorns and hairs which are obstacles for penetrating pathogens or as deterrents against herbivores” [9,10]. “Biochemical adaptations such as accumulation of toxic-low molecular weight compounds such as antibiotics, saponins, alkaloids, glycosides, cyanide-generating compounds, phenolic compounds” [11,12]. Accumulation of toxic proteins such as ribosome-inactivating proteins, lectin-like toxins Dhaliwal and Ramesh, [13] and selective toxicity against particular group of organisms such as antifungal proteins, insecticidal proteins [11]. Mechanical wounding or gnawing by insects triggers the rapid and systemic accumulation of defense proteins (PI-protease inhibitor) throughout the aerial tissues of the plant. In passive defense there is allocation cost as resources are diverted towards preparedness for a possible attack which may not necessarily occur. Consequently there is a reduction in reproductive efficiency. Also allomones produced constitutively may serve as a kairomone that could attract the predators.

5. INDUCED RESISTANCE IN HOST PLANT RESISTANCE

“The development of pest resistance to insecticides has played an exceedingly important role in the increasing difficulties encountered in pest control in agro-ecosystems. Plant defenses have generally been assumed to be constitutive, being always expressed in the plant. Recently it has come to be realized that induced responses reduce insect survival, reproductive output as well as the performance of the pest, so that the plant benefits from such responses. It is an important component of integrated pest management, which can be triggered by biotic or abiotic elicitors, and can be used very effectively when combined with selective pesticides and induced resistance techniques. Plants often increase their resistance to herbivores by locally increasing the production of defensive compounds at the site of damage, as well as systemically on undamaged leaves” [14].

“Silicon accumulation plays a significant role in resistance against biotic and abiotic stresses in plants. Major cereal crops are known for its higher silicon accumulation ability including millets” [15,16]. “The major mechanism of Si-mediated plant resistance was the physical barrier through silicon deposition in epidemic cells to prevent the entry of invading insects, pests and pathogens. Many plant secondary metabolic compounds have a dominant role in defense against pests and pathogens which are resistant to biotic stress” [17]. “Phenyl Alanine Ammonia lyase (PAL) and Peroxidase (POX) enzyme activities involved in biosynthesis of phytoalexins, phenols, and lignins that can restrict the development of insects” [18]. “Usually, the Polyphenoil oxidase (POL) activity increased in stem borer infestation alone, but the increases were prominent in without Si and with SB plants as compared with Si and SB plants. It indicates that Si alters PAL and PPO activities, and confers increased resistance to herbivores” [19]. “Silicon amendment to ragi plants much reduced the feeding ability of pink stem borer *Sesamiainferens* (Walker) through modulation of leaf sheaths silicification. It also induces the chemical defense system by influencing the defense-related enzymes, syntheses of secondary metabolites, and concentrations of malondialdehyde, total phenol and soluble protein in a leaf sheath of infested susceptible (Suvra) and resistant (HR-379) ragi plants. Inclusion of silicon encouraged the increase of H_2O_2 concentration and suppressed the malondialdehyde concentration in both infested susceptible and resistant varieties. Superoxide dismutase, catalase and peroxidase activities were higher in both the varieties amended with silicon than in non-amended stem borer infested plants. Stem borer infestation activate the secondary metabolites, PAL, β-1,3-glucanase and phenols in silicon amended plants, but performance of PPO and soluble protein content was lower in Silicon amended plants than in non-amended plants" [20].

Screening for resistance to insect pests: "Varieties tolerant/resistant to insect pests are to be screened. Marker assisted selection and development of transgenic plants with insect resistance depends on the precision of resistance screening techniques. Infester row, cage and leaf disc screening techniques have been standardized to evaluate germplasm, breeding material and mapping populations for resistance to insect pests under field and greenhouse conditions" [21,22].

6. IDENTIFICATION AND UTILIZATION OF SOURCES OF RESISTANCE TO INSECT PESTS

"Large-scale screening of the sorghum germplasm at ICRISAT has resulted in identification of several lines with reasonable levels of resistance to shoot fly, stem borer, midge, and head bugs" [21,22]. Sources of resistance to insects in sorghum have been used in the breeding program, and many varieties with resistance to insect pests have been developed. Sharma et al., 2003 "reported low to moderate levels of resistance to sorghum shoot fly and stem borer in cultivated germplasm. Hence, wild relatives of sorghum with high levels of resistance to these pests have to be identified". "Wild relatives of sorghum evaluated for resistance against sorghum shoot fly at ICRISAT, indicated that the accessions belonging to *Parasorghum* (*S. australiense, S. purpureosericeum, S. brevicallosum, S. timorense, S. versicolor, S. matarankense,* and *S. nitidum*) and *Stiposorghum*(*S. angustum, S. ecarinatum, S. extans, S. intrans, S. interjectum,* and *S. stipoideum*) did not show any shoot fly damage under multi-choice conditions in the field" [23]. "*Heterosorghum* (*S. laxiflorum*) and *Chaetosorghum*(*S. macrospermum*) showed very low damage. Further accessions belonging to *Heterosorghum*, *Parasorghum* and *Stiposorghum* showed little damage by the spotted stem borer under artificial infestation in the field, except for one accession of *Heterosorghum,* which showed 2% dead hearts" [23]. "Sorghum midge females did not lay any eggs in the spikelets of *S. angustum*, *S. amplum*, and *S. bulbosum*compared to 30 eggs in spikelets of *S. halepense* under no-choice conditions. Odors from the panicles of *S. halepense*are more attractive to the females of sorghum midge than the odors from panicles of *S. stipoideum, S. brachypodum, S. angustum, S. macropsermum, S. nitidum, S. laxiflorum,* and *S. amplum"* [24].

"Inheritance of resistance to shoot fly *Atherigona soccata*in sorghum, the genotypes ICSV 700, Phule Anuradha, ICSV 25019, PS 35805, IS 2123, IS 2146, and IS 18551 exhibited resistance to shoot fly damage across seasons. The plant morphological traits associated with expression of resistance/susceptibility to shoot fly damage such as leaf glossiness, plant vigor, and leaf sheath pigmentation showed significant general combining ability effects by resistant genotypes, suggesting the potential for use as a selection criterion to breed for resistance to shoot fly, *A. soccata*. ICSV 700, Phule Anuradha, IS 2146 and IS 18551 with significant positive general combining ability effects for trichome density can also be utilized in improving sorghums for shoot fly resistance. The parents involved in hybrids with negative specific combining ability effects for shoot fly resistance traits can be used in developing sorghum hybrids with adaptation to post rainy season. The significant reciprocal effects of combining abilities for oviposition, leaf glossy score and trichome density suggested the influence of cytoplasmic factors in inheritance of shoot fly resistance" [25]. "The evaluation of parents and their hybrids during the rainy and post rainy seasons indicated variation in expression of shoot fly resistance across seasons; with greater susceptibility in the rainy season" [26]. "This was largely because of available favorable environmental conditions suitable for shoot fly multiplication in the rainy season. The performance of hybrids was season specific indicating the influence of environmental factors in the expression of shoot fly resistance" [25]. "High G x E interactions for shoot fly dead hearts percentage, has been reported earlier" [27,28]. "Most of the crosses and their reciprocals showed resistance to shoot fly, suggesting that shoot fly resistance can be easily transferred into the progenies. Most of the crosses exhibited oviposition non-preference and tolerance mechanisms of resistance, which are the major components of resistance in sorghum to shoot fly" [29,30].

7. BIOTECHNOLOGICAL APPROACHES FOR HOST PLANT RESISTANCE TO INSECT PESTS

Host plant resistance plays a vital role in integrated pest management but the development of insect-resistant varieties through conventional ways of host plant resistance takes time, and is challenging as it involves many quantitative traits positioned at various loci. Biotechnological approaches such as gene editing, gene transformation, marker-assisted selection etc. in this direction have recently opened up a new era of insect control options. These could contribute towards exploring a much wider array of novel insecticidal genes that would otherwise be beyond the scope of conventional breeding. Biotechnological interventions can alter the gene expression level and pattern as well as the development of transgenic varieties with insecticidal genes and can improve pest management by providing access to novel molecules.

"The deployment of transgenic plants with insecticidal genes lead to reduction in insecticide sprays, reduction in harmful effects of insecticides on non-target beneficial organisms, increased activity of natural enemies, reduced amounts of pesticide residues in food and food products". Sharma et al. [21], James [31]. "Toxins from *Bacillus thuringiensis var morrisoni* have shown biological activity against the sorghum shoot fly, *A. soccata*. The *B. thuringiensis* toxins Cry1Ac and Cry2A are moderately effective against spotted stem borer, *C. partellus*, while Cry1Ac is effective against *H. armigera"* [22]. "Sorghum plants having cry1Ac genes have been developed at ICRISAT, and are presently being tested for resistance to spotted stem borer, *C. partellus*. Combining transgenic resistance to insects with conventional plant resistance will render plant resistance an effective component for pest management in sorghum. Many secondary plant metabolites such as flavonoids have been implicated in host plant resistance to insects in sorghum. Many compounds of the flavonoid biosynthetic pathway accumulate in response to biotic and abiotic stresses" [32,33]. Genetic engineering offers the opportunity to change the metabolic pathways to increase the amounts of various flavonoids that play an important role in host plant resistance to insect pests [34]. Biotechnology also offers the opportunity to increase the production of secondary metabolites in plants to increase the levels of resistance to insect pests or inhibit the production of toxic metabolites [35,36].

8. CONCLUSION

Community level adoptions of cultural methods, resistant varieties, judicious nutrient and pesticide usage can help to restrict the pest population build-up and the damage caused. An understanding of host plant resistance mechanisms and induced resistance in plants can be utilized for interpreting the ecological interactions between plants and insect pests and for exploiting in integrated pest management in crops. Since the biochemical pathways that lead to induced resistance are highly conserved among the plants, the elicitors of these pathways could be used as inducers in many crops. The future challenge is to exploit the elicitors of induced defense in plants for pest management, and identify the genes encoding proteins that are regulated during plant response to the insect attack, which can be deployed for conferring resistance to the herbivores through genetic transformation. Complexity of volatile blend and large number of different herbivore enemies suggests that many of these defenses remain to be characterized. Improvement in precision and accuracy of screening and selection criteria for varieties and resistance to insect pests, gene pyramiding and development of cultivars with multiple resistance to insect pests and diseases and development of transgenic plants with resistance and identification of molecular markers associated with resistance are the areas of future research for insect pest management. Application of these strategies will offer new eco-friendly approaches in insect pest management in millets.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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