Review Article

Understanding the Impact: Insect Pests of Millets and Their Consequences on Yield Loss

Abstract

Millets, crucial cereal crops in many regions, face significant threats from various insect pests, leading to substantial yield losses. Insect pests such as stem borers, leaf folders, aphids, midges, bugs, caterpillars, and termites inflict damage at different growth stages of millet plants. Stem borers like *Chilopartellus* and *Sesamiainferens* bore into stems, impairing structural integrity, while leaf folders such as *Cnaphalocrocismedinalis* create folded leaf shelters for feeding, causing extensive tissue damage. Aphids such as *Rhopalosiphummaidis* and shoot bugs like *Peregrinusmaidis* extract sap, resulting in wilting and stunting of plants. Millet midges like *Geromyiapenniseti* and *Stenodiplosissorghicola* target reproductive structures, leading to grain abortion and reduced yield. Earhead pests like *Cryptoblabesgnidiella* and *Helicoverpaarmigera* feed on developing grains, causing significant losses in quality and quantity. Additionally, termites like Od*ontoterme*s spp. and *Microtermes* spp. damage roots and stems, disrupting nutrient and water uptake causing plant death. Understanding the biology and ecology and implementing appropriate pest management strategies are crucial for mitigating yield losses and ensuring millet production sustainability.

Keywords: Millets, stem borers, earhead pests, sucking pests, yield loss

Introduction

In recent years, millets have emerged as a nutritional powerhouse and a sustainable solution to global food security challenges. As staple crops in many parts of the world, millets are valued for higher nutritional content, and low water and input requirements. Recognizing their significance, the United Nations declared 2023 as the International Year of Millets, shedding light on their importance in achieving food security, nutrition, and sustainable agriculture.However, alongside their growing popularity, millets face a persistent threat from various pests and insects. Approximately 150 insect species have been documented to inflict harm on millet crops worldwide, with 116 of these species identified within India alone (Kishore, 1996). Insects that feed on various parts of the plant during different growth stages contribute to economic losses by reducing crop productivity, compromising seed quality, and diminishing silageharvest (Arun Kumar and Channaveerswami 2015).The vulnerability of millet crops to pest attacks underscores the urgent need for effective pest management strategies to safeguard this vital food source.Understanding the dynamics of pest infestation in millets is crucial for devising sustainable solutions that ensure the continued productivity and resilience of millet agriculture.

Pests attacking millets

A greater number of pests attack millets include shoot flies, borers, foliage feeders, sucking pests, earhead feeders and soil dwelling insects posing a great threat in millet production. These pests cause an yield loss upto 10-20% (Gahukar and Jotwani, 1980).

Shoot fly

"Shoot fly, *Atherigona* sp. injure a range of cereals including millets in Africa and Asia" (Deeming, 1971; Breniere, 1972; Bonzi and Gahukar, 1983; Gahukar, 1985)."The shoot fly species attacking different millet types include, Jowar, Ragi*i.e.,Atherigonasoccata*Rondani, Pearl millet: *A. approximata*Malloch,Proso millet, Kodo millet: *A. simplex* Thompson, Fox tail millet: *A. atripalpis*Malloch, Barnyard millet: *A. falcata* Thompson, Little millet: A. pullaWiedmann" (Annonymous., 2016)

"Cultivated sorghum, *Sorghum bicolor* is the most preferred host of sorghum shoot fly, *A. soccata"* (Davies and Seshu Reddy, 1981)."It attacks the crop both in seedlings and boot leaf stage whose damage is seen from 1-week to 30-days-old seedlings. If the infestation occurs a little later, damaged plants produce side tiller and become infested. The situationleads to dead hearts in young seedlings and chaffy grains in terminal portion of panicle in the mature crop. This pest survives on a wild host*Cynodondactylon"* (Talati and Upadhyay, 1978). In India, significant losses of >35% in common millet (Natarajan et al., 1974) and 39% in little millet (Selvaraj et al., 1974) have been documented. Similarly, in proso millet, yield losses of 100% and in little millet, losses of 16.6% were observed, with shoot fly infestation at the tillering stage being the primary cause (Kamakshi et al., 2017). In Ethiopia, the tef shoot fly, A.hyalinipennis, has a menace to tef crops, causing damage at both the early growth stage and reproductive stages. Yield losses owing to this fly were estimated at 9% (Mideksa et al., 2014) and 20% (Bayeh et al., 2008) in two different regions.

Stem borer

Spotted stem borer, *Chilopartellus*Swinhoe, Pink stem borer, *Sesamiainferens*Wlk., have been identified as significant borer pests (Tams and Bowden, 1953; Jepson, 1954; Ingram, 1958; Harris, 1962; Breniere, 1971). *Sesamiainferens* specifically affects finger millet crops in India (Kundu and Kishore, 1971). While pearl millet initially shows resistance to borer attacks during the early stages of growth, it becomes susceptible to internode injuries as the crop matures (Ahmed and Young, 1969).*Chilopartellus* infests the crop starting from the second week after sowing and continues until the crop reaches maturity. In younger plants, symptoms of deadhearts appear as a result of early attacks. As the infestation progresses, the larvae penetrate the stem, causing extensive tunnelling within the stem. During the larval stage, *Sesamiainferens* exhibits gregarious behavior, gathering inside the leaf whorls where they feed on the central leaves, resulting in the characteristic 'pinhole' symptoms that later progress to deadhearts. Attacks during the panicle initiation stage lead to the formation of empty panicles, known as the White ear head symptom.*Chiloparetllus* ought to cause a loss of 55-83% (grain) and 57% (fodder) in India (Jotwaniet al., 1971).

"In Africa, pearl millet encounters various pest challenges, including borer (Acigonaignefusalis), pink stem borer (Sesamiacalamistis), sugarcane borer (Eldana saccharina), and maize stalk borer (Busseolafusca)" (Nwanze and Harris 1992). "The spotted stem borer (Chilosacchariphagus) has been identified in mainland China and Taiwan" (Kalaisekar et al. 2017). A. ignefusalis is the predominant species on pearl millet in Senegal, constituting up to 92% of the total larval stem borer population (Gahukar 1990), while S. calamistis and E. saccharina are prevalent in the Ivory Coast (Bekoye and Dadie 2015). Recent findings by Goudiaby et al. (2018) suggest a shift in borer populations in Senegal, with S. calamistis emerging as a major species (making up 31–72% of the larval population), followed by A. ignefusalis (16–53%). Likewise, B. fusca, traditionally confined to eastern Africa, has extended its range to western regions of the continent (Goudiaby et al. 2018). "In the Ivory Coast, Bekoye and Dadie (2015) observed significant avoidable losses (49–52%) in cv. VPP-1 due to attacks by a stem borer complex.The millet stem borer, *Coniestaignefusalis*was also seen attacking sorghum and maize in millet belts of northern Ghana during 1996 and 1997 with higher incidence in Sudhansavannah" (Tanzubil and Mensah 2000). "This was more abundant in millets followed by sorghum and stalks of cereals as they provide refuge for diapause larvae and thus contribute to population carryover from one season to another. Hence, the proper management of cereal stalk and stubble after harvest could help reduce the population carryover. Artificial infestations with 5 and 10 larvae per plant at 2 weeks after plant emergence (WAE) resulted in 50 to 70% plants with deadhearts and 24 to 100% avoidable yield loss" (Yaye et al., 2003)

"Another stem borer *Saluriainficita* Walker also attacks finger millet" (Kalaisekar*et al.*, 2017). The infestation usually seen by the base of the tillers very close to soil. Larva bore the stem at the ground level and feed on internal tissues and cause dead heart symptom in the early stage. However, incidence more common in early stage of the crop.

Foliage feeders

These include red and black hairy caterpillar, cutworms and armyworms, grasshopper, ash weevils, leaf folder, flea beetle.

"The Red hairy caterpillar (RHC), *Amsactaalbistriga*, lays eggs in clusters either foliage or on the soil. After hatching in approximately 3-4 days, the larvae begin to feed voraciously in a group, leading to the complete defoliation of plants" (Jotwani and Butani, 1978; Verma, 1981). "Within about 10 days, the larvae gradually spread from plant to plant, continuing their voracious feeding before migrating to other fields.*Amsactamoorei*, also causes defoliation" (Srivastava and Goel, 1962). On the other hand, *Estigmenelactinea*, deposits white-colored eggs on the leaf surface. These eggs hatch into black hairy larvae that scrape the green matter from young leaves as they feed, causing damage.

Cutworms, such as *Agrotisipsilon*, inflict damage to sorghum plants by severing seedlings at or just below the soil surface, causing the affected plants to wither and eventually lodge. *Mythimnaseparata* and *M. albistigma* contribute to defoliation in finger millet, where their larvae primarily consume leaves, particularly in nursery settings, resulting in the skeletonization of foliage. Initially, the young cutworms feed on plants without severing stems or leaves, but later progress to cutting off foliage and panicles. They primarily emerge during the dark periods to feed on the roots and shoots of ragi plants, concealing themselves in the soil during the daytime. As a result of their feeding habits, the affected field may resemble grazing by cattle.*M. separata* in India (Balasubramanian et al., 1975) have been known to cause extensive ragging and crop failure. *Spodopteraexigua*larva is a serious pest of ragi nurseries feeding on leaves causing extensive defoliation (Balasubramanian et al., 1975).

"In India, grasshoppers viz., *Hieroglyphusnigrorepletus* Bol., *H. banian*Fb.,*Chrotogonus* spp., *Colemaniaspheneroides* Bol. are destructive to all millet crops" (Jotwani and Butani, 1978; Gahukar and Jotwani, 1980). Deep ploughing soon after harvest, dusting of insecticides in target areas, coupled with gathering and destruction of grasshoppers are effective measures. The nymphs and adults feed on the leaf causing marginal notchings or holes on the leaves. In case of severe infestation, they defoliate entire leaves.

"Ash weevil, *Myllocerusundecimpunctulatusmaculosus*, causes damage to sorghum by feeding on the foliage and under severe infestations the entire leaf blade is eaten up leaving only the midribs" (Kishore and Srivastava, 1976). "Adults of *Myllocerusmaculosus* (Desb), *M. viridanus* (Fab), *M. subfasciatus* Guerin-Meneville&*M. discolor*Boheman deposits light yellow eggs in the soil which hatch and produce grubs that attacks roots resulting in wilting of plants in patches and adult feeds on leaf blade causing notching on leaves. Flea Beetle *ChaetocnemaPusaensis*, found to be attacking on Finger millet and causing holes in the leaves and also affecting the vigour of young plants" (Chava*et al.*, 2023).

Leaf folder, *Cnaphalocrocismedinalis*Guenee, attacks rice, finger millet, and pearl millet crops. Its larvae exhibit a distinctive behavior of removing leaf tissues, folding leaf blades together, and securing them with silk strands. Within these folded leaves, the larvae feed, resulting in the formation of longitudinal whitish patches on the leaf blade.

Sucking pests

"Both nymphs and adult of aphids, *Rhopalosiphummaidis* Fitch, shoot bugs, *Peregrinusmaidis*Ashm., plant bugs, *Aspaviaarmigera* T., *Callidea* spp., and chinch bugs, *Blissusleucopterusleucopterus* Say, suck sap from young leaves and the whorl, leading to distortion, yellowing, and wilting of plants, ultimately resulting in shriveled chaffy grains" (Jotwani and Butani, 1978; Gahukar, 1984). "While older plants may tolerate the damage to some extent, certain species of sucking insects also serve as vectors for viruses. *Peregrinusmaidis*, for example, transmits MStrV and MMV to sorghum, maize, and Itch grass" (Rottboelliaexaltata) (Tsai and Falk, 1988).

Sugarcane aphid, *Melanaphissacchari* and Plum/ Ragi aphid, *Hysteroneurasetariae* also found attacking ragi, sorghum. Both nymphs and adult sugarcane aphids feed by sucking sap from foliage. This feeding activity causes leaves to yellow, and in cases of severe infestation, plants become stunted and leaves dry out. Aphids excrete honeydew, leading to the development of sooty mold on leaves, which then turn black. The presence of honeydew inhibits the harvesting process and results in grains of poor quality. Conversely, adults and nymphs of plum aphids suck sap from spikelets, spreading throughout entire plant and causing stunted growth with reduced vigor.

Ragi root aphid: *Tetraneuranigroabdominalis* Sasaki, which occurs occasionally during ragi cultivation in Southern India. The infestation begins in the root system and persists until flowering. Aphids suck plant sap, resulting in a withered and stunted appearance of the crop. Ants are commonly found at the base of affected plants, and upon uprooting, aphid colonies become visible (Chava *et al.*, 2023).

The spider mite *Oligonychusindicus* is a non-insect pest that feeds on sorghum, maize, rice, millets, and other members of the Poaceae family. Both female and immature stages of this pest feed on foliage, with the highest population occurring after panicle emergence. They extract plant sap from the under surface of functional leaves, initially they appear pale yellow before transitioning to reddish or brownish tan. Heavily infested leaves exhibit dense webbing on the underside, and in sometimes, they attackand web the sorghum panicle.

Earheadfeeders

In West Africa, five species of millet midges: *Geromyiapenniseti* Felt., *Contariniasorghii* Harris, Las*iop tera* sp., *Lestodiplosis* sp., and *Stenodiplosis* sp. (Coutin and Harris, 1974) are reported. *G. penniseti* is of economic significance, particularly affecting late millets in savanna regions of Africa and South India (Coutin and Harris, 1968; Santharam et al., 1976). “Larval feeding disrupts normal seed development, leading to either complete or partial spike abortion thus, resulting in harvestsufferers of up to 90%” (Coutin and Harris, 1968). “The sorghum midge, *Stenodiplosissorghicola*, survives only on the members of the genus Sorghum” (Harris, 1979; Franzmann and Hardy, 1996).

The Sorghum midge (*Stenodiplosissorghicola*) and Pearl millet midge (*Geromyiapenniseti*) are known to infest Sorghum, Pearl millet, and wild graminaceous hosts. The adult flies lay eggs within the florets, giving rise to dark orange-colored maggots that begin attacking the developing grains or damaging the ovaries, resulting in chaffy panicles. An important symptom is the presence of white pupal cases protruding on the chaffy grains, along with exit holes. The Earhead Bug, *Calocorisangustatus*, lays blue, cigar-shaped eggs either on glumes or within the middle of the florets. Both adults and nymphs cause damage to the earheads by feeding on them. They extract sap from the grains during the milky stage, leading to infested grains shrinking, turning black, and becoming chaffy or ill-filled (Chava et al., 2023).

Gahukar and Ba (2019) reported the occurrence of the millet head miner, Heliocheilusalbipunctalla, a significant pest that endangers pearl millet farming in the Sahelian region of West Africa.

The Ear head web worm, *Cryptoblabesgnidiella*, initiates the production of silken webs both on and inside the ear head during its larval stage. Heavily infested heads may be entirely covered in webbing. The larvae feed on maturing grains and create shelter by constructing small dome-shaped or elongated galleries using anthers and silk. On the other hand, the Gram caterpillar, *Helicoverpaarmigera*, emerges on earheads and consumes grains, resulting in partially eaten and chalky appearing heads. Faecal pellets are evident within the ear head. In 2016, elevated larval populations of *H. armigera* per square meter were documented in foxtail millet (15.0), barnyard millet (12.0), Kodo millet (5.0), and Finger millet (5.0) at the grain maturity stage. The impact of *H. armigera* resulted in a yield loss of 7.9% in foxtail millet, while yield losses of 8.5% and 5.1% in barnyard millet were primarily attributed to H. armigera during 2016 and 2017, respectively. (Kamakshi et al., 2017).In India, the population of *H. armigera* on pearl millet can be managed by the larval parasitoid, *Campoletischlorideae* Uchida (Pawar et al., 1986). Additionally, the larva of the tussock caterpillar, *Euproctessubnotata*, feeds on developing grains and destroys them in panicles during the milky or soft dough stage, with compact panicles being particularly vulnerable to attack.

Soil dwelling insects

“Several species of white grubs *Hototrichia* and *Anomala* have been reported. *H. consanguinea* Blanch has devasted pearl millet crop in large areas in central India” (Jotwani and Butani, 1978).“In arid and semi-arid regions, the feeding damage caused by white grubs to pearl millet roots can be substantial” (Choudhary et al. 2018). “The white grubs, *Holotrichiaserrata* and *Lachnosternaconsanguinea*, sporadically gain the serious pest status in India. The grubs feed on the roots of seedlings as well as older plants. The infested plants wither and wilt in patches. Wire wormsalso cause similar damages in sorghum seedlings” (Kalaisekar*et al.,* 2017).“In sandy regions, termites such as *Odontotermes* spp. and *Microtermes* spp. cause damage by either damaging roots or creating burrows through stems” (Gahukar, 1989). These termites are also known to target the roots of maize and sorghum, causing affected plants to collapse. Their activity disrupts the flow of nutrients and water through the plant's vascular system, ultimately leading to plant death.

Pest management strategies in millets

Shoot fly

“A common practice to control *A. approximata* is by a presowing soil application of granular formulations of disulfoton, phorate, aldicarb at 3 kg a.i./ha or sprays of 0-1 % carbaryl or phosphamidon or 0-04% endosulfan" (Jotwani and Singh, 1971; Singh and Jotwani, 1973; Raghupathy and Balasubramanian, 1978; Talati and Upadhyay, 1978). Seed treatment with carbofuran (0-4— 0-5 kg a.i./ha) may be effective. Implement synchronous and early sowings of cultivars with comparable maturity to mitigate the detrimental effects of shoot fly, midge, and head bugs. Employ a higher seed rate (1.5 times more) and postpone thinning operations to uphold an optimal plant stand, thus reducing shoot fly damage. In India, pearl millet is consistently plagued by sorghum shoot fly, *Atherigonaapproximata*Malloch. TNAU (2016) and research scientists have outlined a series of management strategies for controlling pearl millet shoot fly (see Table 1).

Table 1.Management strategies for controlling pearl millet shoot fly

TNAU (2016)	**Biradar and Sajjan (2018)**
Seed treatment with imidacloprid 70WS at 10 g/kg	Resistant Cultivars: MP16, MP19, MP53, MP67, MH9, MH49, MH52, MH82, MH99, MH105
Eliminate and dispose of plants affected by dead heart infestation	Increase seedrate by 20–30%
Install plastic meal traps treated with insecticide (30 traps/ha)	Avoid staggered plantings
Apply 5% neem seed kernel extract at 500 liters/ha	Eliminate and dispose of plants affected by dead heart infestation

Sucking pests

Resistant cultivars have reduced chinch bug infestation on pearl millet (Starks et al., 1982). Treat the seeds with Thiamethoxam 70 WS @ 3 g /1 kg of seeds to improve plant stand, seedling vigor and reduce the damage by shoot fly and to some extent stem borer and sucking pest. Apply Dimethoate 30% EC @1.5 ml/liter for sucking pests like shoot bug, aphids. For mite control apply Dicofol 18.5% EC @ 2 ml / liter. Nymphs and adults of ragi root aphid are parasitized by a small braconid wasp and a mermithid nematode and are preyed upon by lady beetles (Samraj 2023).

Stem borers

Sasmal (2015) conducted an assessment of 33 genotypes to evaluate their resistance against pink stem borer by monitoring the dead heart infestations 45 days post-planting. An infestation rate of up to 20% was observed in GPV-93, while 18 other remained unaffected by pest attacks. In Mali, Passerini (1991) conducted a comparison of the effectiveness of three applications of NSKE (3%) at a rate of 500 liters per hectare against millet stem borer, with cypermethrin 25EC at 250 ml per hectare. Both the NSKE and cypermethrin treatments exhibited reduced stem infestation rates (11%) compared to untreated fields (19%). Additionally, the application of Cypermethrin ULV at 50% male flowering (at 36 g a.i./ha) significantly decreased the rate of stem attacks (Jago et al. 1993). Managing borer populations can be achieved through field sanitation practices, including the collection and destruction of stubble and weeds after crop harvest, as well as removing dead hearts (Jotwani and Butani, 1978; Sagnia, 1983). Various parasitoids and predators identified in India on *Sesamia* spp. and *C. partellus* life stages (Sharma et al., 1966; Singh and Sandhu, 1977; Gahukar and Jotwani, 1980) may play a vital role in decreasing peak borer incidence. Carbofuran 3G granules may be applied in the whorls at 8–12 kg ai/ha, or the entire field can be sprayed with Metasystox at 2 ml/liter.

Earhead feeders

Ploughing fields to depths of 15–25 cm during April–June to expose pupae to desiccation and predators resulted in a mortality rate of 20% for pupae (Gahukar 1990). Several characteristics such as compact heads, small involucral bristles, small floral peduncles have been associated with resistance to earhead pests (Guevremont 1983, Gahukar et al. 1986). In Sudan, applying triple superphosphate at 20 kg/ha improved plant growth and reduced pest infestation by 27–36% due to a shortened period from planting to heading (Hughes and Rhind 1988). The augmentation of *Braconhebetor* was also explored for releases. Ba et al. (2014) devised a technique involving jute bags filled with grains, millet flour, larvae of *Corcyra* and mated females of B. *hebetor*. These bags were hung from trees in field sites spaced 3 km apart. Parasitoids multiplied within the bags, exited through the jute mesh, and dispersed into millet fields. By employing this method, pest mortality rates of about 97% were achieved in fields covering over 3 million hectares across 500 villages in Mali, Burkina Faso, and Niger (Ba et al. 2013). Overall, the releases of *B. hebetor* resulted in a 34% increase in grain yield compared to control fields (Baoua et al. 2014). The crop may be sprayed at the 50% flowering stage (1 midge/panicle) with cypermethrin 25 EC @ 0.5 ml/liter. Carbaryl 10% dust @20 – 25 kg/ha at 50% flowering & grain formation stage is also suggested in midge endemic areas. During the peak midge incidence, the parasitoid wasp Tetrastichus sp. and the predatory bug Orius sp. are plentiful (Coutin and Harris 1968).

Foliage feeders

Cutworms (*Mythmina, Spodoptera*), red hairy caterpillars, semilooper are efficiently controlled by poison baits comprising 10 kg rice bran + 1 kg jaggery + one literQuinolphos (25 % EC). Prepare small balls and broadcast in the fields preferably in the evening.Major natural mortality factors impacting grasshoppers involve the initiation of the rainy season and parasitism by two natural enemies during the egg/first instar stage: the tenebrionid beetle Pimeliasenegalensis Olivier and a Eurombidium sp. mite, leading to mortality rates of 40% and 51%, respectively (Jago et al. 1993). Additionally, the application of three entomopathogenic fungi—B. bassiana, M. anisopliae, and Nosema locustae Canning—significantly contributed to mortality (Maiga et al. 2008). Effective measures to control grasshopper populations involve deep ploughing soon after harvest, targeted dusting of insecticides, and the collection and destruction of grasshoppers (Gahukar 1989).

Soil dwelling insects

Seed treatment with Imidacloprid 600FS @ 10-12 ml/kg seeds is very much suited for controlling white grubs. This treatment has been demonstrated to decrease seedling mortality from 28.6% to 2.1% and to double grain yield from 12.30 to 27.52 q/ha (Choudhary et al. 2018). Another highly effective treatment involves treating seeds with clothianidin 50WDG at a rate of 10 g/kg. Similarly soil drenching with imidacloprid 17.8SL at 300 ml/ha also shown effectiveness against white grubs (Kalaisekar et al. 2017). Chlorpyriphosdust with FYM can also be applied in furrows at 2:3 ratio. In areas with regular termite occurrences, the soil should be mixed with Chlorpyriphos 5% Dust at 35 kg/ha by the time of sowing. When the pest incidence is observed in standing crops, mix Chlorpyriphos 20% EC at 4 L/ha with 50 kg of soil and evenly broadcast it over 1 ha followed by light irrigation.

Conclusion

millets stand out as a vital crop for addressing global food security due to their nutritional benefits and sustainability. However, their production is increasingly threatened by a diverse array of pests, including shoot flies, stem borers, foliage feeders, sucking pests, earhead feeders, and soil-dwelling insects. These pests can lead to significant yield losses, impacting the economic viability of millet cultivation. Effective pest management strategies are essential for safeguarding millet crops. Integrated approaches, including the use of resistant cultivars, judicious application of insecticides, biological control agents, and cultural practices, are crucial for mitigating pest damage. Continued research and adaptation of pest management practices will be vital in ensuring the resilience and productivity of millet agriculture, thus contributing to global food security and sustainable agricultural practices.

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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

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