Integrated Pest Management in Sorghum

Aradhana Panda, Satyabrata Sarangi, Kishore Chandra Sahoo

Sorghum, known for its resilience and high nutritional value, is a crucial millet that plays a vital role in ensuring global food security. India is a significant contributor to the world's sorghum production. Despite this, the cultivation of sorghum faces numerous challenges due to the presence of various insect pests that can cause substantial yield losses and affect the quality of the harvested crops. To address these issues effectively, the implementation of Integrated Pest Management (IPM) strategies is imperative. In this chapter, a detailed account of the primary insect pests infesting sorghum in India is presented, highlighting their biology and nature of damage. Furthermore, the chapter emphasizes the diverse array of IPM techniques that can be employed to combat these pests, encompassing cultural, mechanical, biological control practices and judicious use of chemical pesticides. By equipping farmers with the knowledge and tools necessary to apply these strategies, sustainable sorghum production can be safeguarded, enhancing both productivity and crop quality in the long term.

Keywords: *Sorghum bicolor, IPM, natural enemies, arthropod pests, Fall armyworm*

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Introduction

Sorghum bicolor (Family: Poaceae, Subfamily: Panicoideae) is the fifth highest-growing crop all around the globe (Obour et al., 2022). The major sorghum producing countries include: India, China, European countries (USA, South America, Argentina, Brazil), Australia, and African countries (Sudan, West Africa, Nigeria, etc.) with more than 5.2 million metric tons of Productions (FAO, 2023) contributing nearly 77% of total sorghum production. Among the Indian states, Maharashtra (with 1.4 million metric tons-37%) and Karnataka (22%) are the leading producers of sorghum with nearly 57.2% of the country's total production followed by other states like Tamil Nadu (10%), Rajasthan (8%), and Andhra Pradesh (6%) which also

contribute a major amount of production (Anon., 2020). With higher nutritional benefits having carbohydrates, proteins, vitamins, antioxidants, etc. combined contributing nearly 78-80% of the total biomass (Bakari et al., 2023), it has several roles in shaping global food security fulfilling the United Nations Sustainable Development Goal (SDG-2) (Shiferaw et al., 2013). Sorghum contains a higher fold of nutrients and secondary metabolites compared to traditional cereal crops i.e., 10 times higher Ca and 2-10 times iron for nutritional security (Taylor & Kruger, 2019). The whole sorghum (germ, pericarp & Testa) is rich in Vit-B complex, sterol, phenolic acids (3-deoxyanthocyanidins), carotenoids, starch, minerals making it an excellent source of bioenergy with improved nutritional derivatives (Hossain et al., 2022). It also has anti-cancerous (3-deoxy anthocyanins) and anti-atherosclerotic properties (regulating cholesterol production and synthesis) in the mammalian body (Collins et al., 2024).

Insect Pests of Sorghum in India:

Among the biotic and abiotic stress damage, insect pests and diseases cause maximum productivity losses in sorghum in India (Reddy and Patil, 2015). Sorghum is affected by several major and minor insect pests. Among the major pests, stem borer (*Chilo partellus* Swinhoe) (Crambidae; Lepidoptera), sorghum shoot fly (*Atherigona soccata* Rondani) *(*Muscidae; Diptera), sorghum midge (*Stenodiplosis sorghicola*) (Cecidomydae; Diptera), green bug (*Nezara viridula*) (Pentatomidae; Hemiptera), sorghum aphid (*Rhophalosiphum maydis*) (Aphididae; Hemiptera), and the recent invasives, fall armyworm (*Spodoptera frugiperda*) (Noctuidae; Lepidoptera), and green aphid (*Melanaphis sacchari*) (Aphididae; Homoptera) are the most devasting causing >57% damage in sorghum (Prasad et al., 2020; Shivhare et al., 2022; Vasquez et al., 2024). A list of the insect pests associated with Sorghum in India is presented in Table.1 and Figure.1.

Table 1. List of insect pests associated with Sorghum in India

Sl No.	Common name	Scientific name	Family	Order	References
1	Shoot fly	*Atherigona soccata* (Rondani)	Muscidae	Diptera	NIPHM, 2014
2	Spotted stem borer	*Chilo partellus* (Swinhoe)	Crambidae	Lepidoptera	
3	Oriental Armyworm	*Mythimna separata*	Noctuidae	Lepidoptera	
4	Shoot bug	*Peregrinus maidis* (Ashmead)	Delphacidae	Hemiptera	
5	Sugarcane aphids	*Melanaphis sacchari* (Zehntner)	Aphididae	Hemiptera	
6	Sorghum midge	*Stenodiplosis sorghicola* (Coquillett)	Cecidomyiidae	Diptera	
7	Ear head bug	*Calocoris angustatus*	Miridae	Hemiptera	
8	Head caterpillars	*Helicoverpa armigera* (Hübner), *Cryptoblabes* sp.	Noctuidae Pyralidae	Lepidoptera	
9	Spider mites	*Oligonychus indicus* Hirst	Tetranychidae	Trombidiformes	
10	Fall armyworm	*Spodoptera frugiperda*	Noctuidae	Lepidoptera	

11	Pyrilla	*Pyrilla perpurilla* (Linnaeus)	Lophopidae	Hemiptera	
12	Cut worm	*Agrotis ipsilon* (Hufnagal)	Noctuidae	Lepidoptera	
13	White Grub	*Holotrichia consanguinea* Blanchard	Scarabaeidiae	Coleoptera	

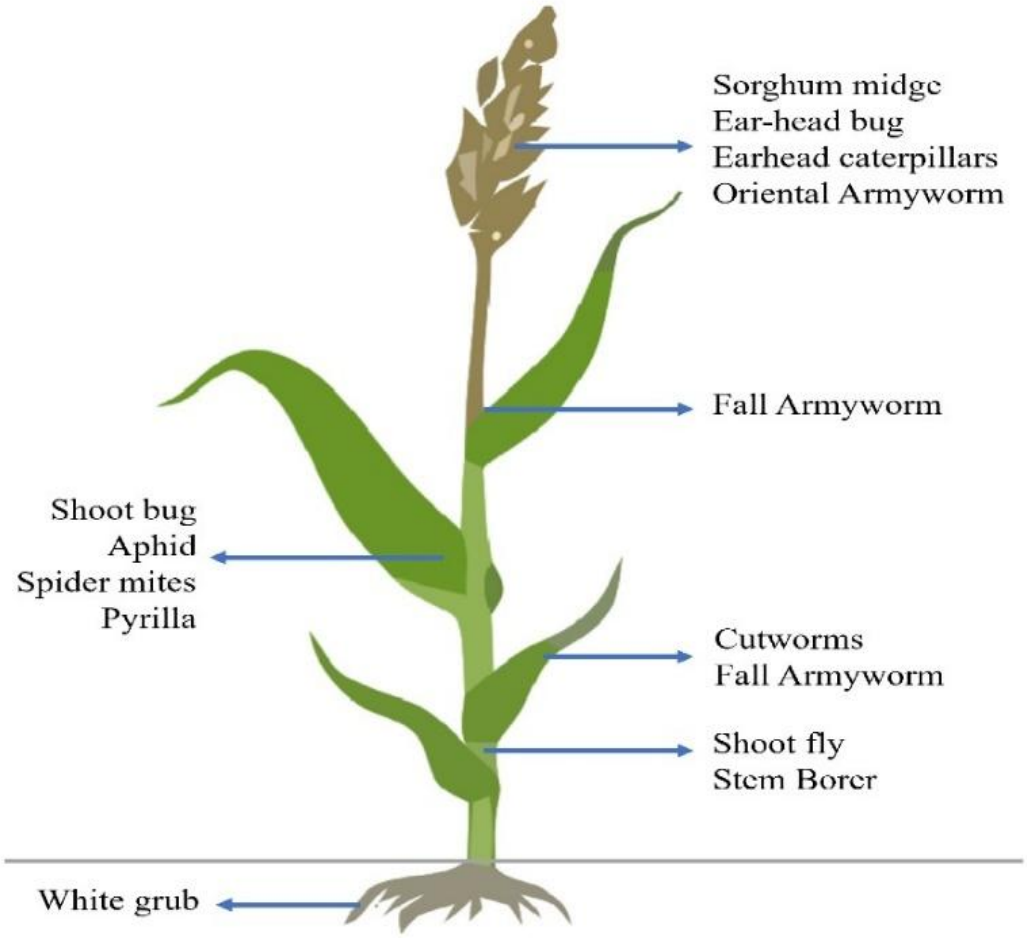

Figure 1. Insect pests of sorghum in India

1. Sorghum shoot fly: *Atherigona soccata* (Diptera: Muscidae)

Biology: Eggs: Kidney to cylindrical shaped eggs laid singly, parallel to the leaf midrib on the lower surface of 3rd or 5th leaf. Egg hatching takes place after 2-5 days.
Maggots: Newly emerged maggots are pale yellow-coloured. The larval period lasts up to 6-10days.
Pupation: Inside the decayed stem or in soil which lasts for a week
Adult- Dark brown similar to domestic housefly but half of its size with males even smaller than females. Six dark spots present in the tergum of abdomen in female (Mahato & Mahankuda, 2024). Remain active during morning and evening hours (Patil & Bagde, 2017).

Nature of damage: Attacks one to four weeks old seedlings. The emerged larva moves to the dorsal leaf surface, moves along the margin, reaches the growing point, and gives a clean cut. Because of this cut, the central leaf dries up, causing a dead heart that can be easily pulled out, giving a rotten smell. Older leaves are generally not attacked but may witness damage under high humidity conditions. In such cases, instead of dead heart the damaged leaf turns out to be thin and papery wrapping up other leaves preventing the proper growth of the plants. If attacked during the panicle initiation stage then the rotting and drying of those portions occurs. Also, generation of more side tillers is common giving a bushy appearance to the attacked plant (Balikai & Bhagwat, 2010).

2. Sorghum stem borer: *Chilo partellus* (Lepidoptera: Crambidae)

Biology: Egg: The eggs are laid on the underside of a leaf near the midrib in 3-5 rows in groups of 10-80. They are flattened and oval, each measuring about 0.8 mm long. They are stacked on top of one another. Egg period ranges between 7-10 days.

Larva: Larvae are yellowish brown in color with a dark prothoracic shield. Matured larvae measure about 25 mm in length. The larval period is about 28-35 days.
Pupa: Pupation takes place within the stem. The pupal period ranges between 7 to 10 days.

Adult: Adult moths are straw-coloured with a wingspan of 20-30 mm having various dark spots in the apical region of the forewing. Males are smaller and darker than females. The forewings of males are pale brown. The forewings of the females are much paler and the hind wings are almost white.

Nature of damage: Larvae mine into leaves causing yellow streaks. Occurrence of a series of small elongated linear pinholes and window pane-like patches of transparent leaf epidermis in the younger and older leaves respectively. Larvae make tunnels in the stem resulting in stem holes that break down on drying eventually leading to the death of the growing point i.e. dead heart (Reddy & Reddy, 2022).

3. Sorghum midge: *Stenodiplosis sorghicola* (Diptera: Cecidomyiidae)

Biology: Eggs: Around 30-250 cylindrical and white eggs are laid, each measuring about 0.3 by 0.6 mm, and are stuck to the host spikelet through a thin slender, tapering stalk. Egg hatching takes place after 9 days.
Maggot: The newly hatched larva is colourless and gradually develops pink to red-orange shade by feeding on the developing grain. The full-grown larva is slightly flattened and spindle-shaped, tapering to a point at the head measuring around 1.5 to 2.0 mm in length. The larval lasts for 9-11 days.
Pupa: Pupation takes place inside the already-fed seed. Initially, the pupa is dark orangish throughout, but the head, antennae, legs, and thorax get darkened and become completely black eventually after a few hours except the abdomen which retains the same orange colour. The pupal period lasts for 3-5 days.

Adult: It is an orange-coloured fly, with males measuring 1.3 mm in length and females 1.6 mm approximately. The male has a short life span of a few hours and females have a 2-day life span.

Nature of damage: Maggot feed on the developing ovary inside the glumes, resulting in empty or chaffy spike-lets as the kernels fail to develop. When attacked during the grain filling or milk stage, pressing the damaged spike-lets results in red ooze production which are the body contents of the dead midge maggot or

pupa. Empty or chaffy spike-lets in the mature crop, gives a blasted appearance. Small, transparent midge pupal cases seems to be attached to the tip of the damaged spike-lets.

4. Sorghum Ear-head bug: *Calocoris angustatus* (Hemiptera: Miridae)

Biology: Egg: 150-200 cigar shaped eggs are laid under the glumes or in between anthers of the sorghum florets which hatch in less than one week.
Nymphs: The emerged nymphs have 5 instars with a total duration of around 12-15 days.
Adult: Females yellowish green measuring around 5mm in length and slightly more than 1mm in width.

Nature of damage: Damage starts immediately after panicle emergence from boot leaf. Both nymphs and adults suck sap from the developing grains. Nymphs generally attacks at early stage during grain milking and soft dough stage. This makes the grains unfilled, shrunken and under severe condition it may turn chaffy. Early infestation leads to huge yield loss and at later stage leads to degradation in quality. The infested grains show reddish brown puncture marks and under severe attack the grains become tanned in colour.

5. Sorghum shoot bug: *Peregrinus maidis* (Hemiptera: Delphacidae)

Biology: Egg: White or pink, cylindrical, elongated, eggs are laid on the upper surface of the midrib either singly or in groups of 1-6 eggs covered with waxy coatings. The eggs are slightly curved with blunt tapering ends with a translucent and smooth chorion. Incubation period is for 7-10 days.

Nymph: The bug passes through five nymphal instars in 12-26 days. Freshly hatched nymphs are yellowish or pinkish and aggregate on leaf whorls for their development and protection from natural enemies. They are similar to adults without wings and well-developed genitalia but have wing pads.

Adult: They are yellowish to dark brown possessing translucent wings. Wing polymorphism is commonly witnessed in those insects depending upon population density and food quality and availability. The longevity of macropterous adult male and female is for 16 and 43 days, respectively and of brachypterous adult, male and female is for 14 and 44 days, respectively (Chelliah and Basheer, 1965).

Nature of damage: Nymphs being semi-gregarious in behaviour found feeding over leaves, on leaf whorls, and inside leaf sheath. Adult bugs and nymphs suck sap from the top shoots more resulting in yellowing and reddening ultimately drying. The leaves started wilting and drying from the tip to downwards inhibiting panicle emergence. The plant ultimately becomes stunted with less vigor and susceptible to various infections (Balikai et al., 2017). The bug is responsible for transmitting two viruses i.e. maize mosaic virus (MMV) and maize stripe virus (MStpV) (Tsai, 1996).

6. Sorghum Ear head caterpillars
a. *Helicoverpa armigera* (Lepidoptera: Noctuidae)

Biology: Egg: Eggs are creamy white and shiny, laid singly, on leaves, near glumes of flower buds, and developing fruits, and sometimes on stems and growing points. They generally lay eggs on the top third part of healthy plants and vigorously growing terminals. A single female can lay up to 1000 eggs during her lifetime. The incubation period is 3 or 6-10 days under summer and winter conditions respectively.

Larva: The larvae undergo 6 larval instars. They have a brown-black head and white or yellowish-white, dark-spotted body. The complete larval period lasts for 2-3 or 4-6 weeks during the summer or spring/ autumn period respectively.

Pupa: The full-grown larvae move to the base of the plant make a tunnel up to 10 cm and pupate inside it. Pupal duration lasts for two weeks during summer and six weeks during winter conditions.

Adult: The adult forewings are brownish or reddish-brown in females or dull greenish to yellow or light brown in males with a V-shaped speck on it. Hindwings are pale with a broad, dark outer margin with a pale patch near its centre. Adults feed on nectar and females lay eggs after mating. The whole life cycle is completed in 4-6 weeks during summer and double i.e. 8-12 weeks during winter.

Nature of damage: Larvae after emergence feed on the developing grains causing chaffy grains in the panicles and sometimes the whole panicle is cut bringing huge economic loss. The young larvae are found to be feeding over leaves.

b. *Cryptoblabes gnidiella* (Lepidoptera: Pyralidae)

Biology: Egg: The eggs are creamy white, round, or conical in shape. They are laid on the spike-lets and tender grain. The egg period lasts for 3-4 days.

Larva: The newly emerged larva is off-white, with a brown head whereas, the fully grown larva is dark brown measuring around 12 mm. Dark lateral lines runs in the body of the larvae. Larval period lasting for 9 to 10 days.

Pupa: Pupation takes place inside the silken webs. It is fully covered by silken threads that are produced by the larva.

Adult: Adult moths are smaller in size with brown forewings and light brown hindwings fringed with hairs on the anterior margin, which are larger than the forewings. The life cycle is completed in 22-24 days (Chava et al., 2023).

Nature of damage: Larvae make webbing on the heads to feed upon and stay inside them.

7. Oriental Armyworm: *Mythimna separata* (Lepidoptera: Noctuidae)

Biology: Egg: 150-200 white shiny spherical eggs are laid on the underside of green leaves, dry leaves and grasses. The eggs have small ridges in it which hatch in around 2-7 days.

Larva: The larvae have 6 instars. The fully grown larva is dirty-pale brown to dark brown with three darker brown dorsal lines. A yellow stripe is seen on each lateral side. Larval duration is completed in 14–22 days.

Pupa: Pupation occurs in earthen cells in the soil or inside the leaf sheath of the plant. The pupal duration lasts for 8–9 days.

Adult: Moths have brownish front wings with diamond shaped spots and whitish-brown hind wings.

Nature of damage: Larvae feed over leaves during night leaving only the midrib. If attacked later, they also feed on immature panicle. Being polyphagous in nature, it feeds on all poaceae family plants that comes in their way during migration (Prasad et al., 2020).

8. Cutworm: *Agrotis ipsilon* (Lepidoptera: Noctuidae)

Biology: Egg: Freshly laid eggs are white, but turn brown with age measuring around 0.43 to 0.50 mm in length and 0.51 to 0.58 mm in width. These are nearly spherical, with a slightly flattened base possessing 35 to 40 alternately long and short ribs radiating from the apex. The females lay around 1200 to 1900 eggs in clusters on the leaf surface. The duration of the egg stage is 3-6 days (NIPHM, 2014).

Larva: larval instars are around five to nine. The larva is uniformly colored as light gray or gray-brown to nearly black on the dorsal and lateral surfaces with a brown head having numerous dark spots. Larvae remain on the plant till its fourth instar and then hide in the soil during the daylight hours becoming photo-negative. The latter instars damage plants at the soil surface, pulling the plant tissue belowground. Larvae show cannibalism when placed together.

Pupa: Dark brown pupa measuring around 17 to 22 mm in length and 5 to 6 mm wide. The pupal duration is 12 to 20 days which occurs belowground at a depth of 3 to 12 cm.

Adult: The adult is large, with a wingspan of 40 to 55 mm. The proximal two-thirds, of the forewing, is uniformly dark brown with the distal area marked with a light irregular band, and a small distinct black dash extending distally from the bean-shaped wing spot. The hind wings are whitish to grey, with the veins marked with darker scales.

Nature of damage: Cutworms being nocturnal attacks during the night or overcast days. Newly hatched larvae feed on weeds, and/or young plants, leaving small irregular holes in the leaves. Larger larvae completely cut into stalks, causing plants to wilt and die reducing plant stand. Sometimes, they drag cut plants into small holes in the soil to continue feeding during the daylight hours. Increased population of cutworms could destroy as much as 75% of a crop.

9. Fall Armyworm (FAW): *Spodoptera frugiperda* (Lepidoptera: Noctuidae)

Biology: Egg: Hemispherical egg with dorsal dome and flattened base. A female moth can lay over 1000 eggs singly or in multiple clusters, covered with hairs. Generally, each egg mass has around 100 to 200 eggs laid either in layers or spread throughout the leaf surface as a single layer. The egg period is for 2-3 days.

Larva: Larvae pass through six larval instars feeding on the epidermis of the lower areas of young leaves. Young ones are greenish with a black head which develops an orange colour in the second instar. The fourth instar witnessed the browning of the dorsal surface with lateral lines. The fifth and sixth instars develop sub-dorsal and lateral lines with emerging black dots. Four black dots in the form of a square are present in the penultimate segments with an inverted Y-shaped marking on the head (Figure 2). The larval period is 14 days in summer and 30 days in winter.

Pupa: Pupation takes place in soil at a depth of 2-8cm inside a loose cocoon by binding soil and silk or with dried leaves if the soil is hard. The pupation period is for 8-9 days during summer and 20- 30 days during winter.

Adult: The forewings of the male moth are gray to brown with several triangular white spots towards the apical region and two characteristic fawn-colored spots towards the center. However, the forewings of female moths are dull with less distinctive faint markings. The hindwings of both the sexes are iridescent silvery white with a thin band of dark markings towards the apical border. They are nocturnal.

Nature of damage: The first instar larvae consume the leaf tissue from one side, leaving the opposite epidermal layer intact. The second and third instar larvae make shot holes in leaves and feed from the leaf margin towards the midrib. The latter stages feed inside the whorl of sorghum often leaving only the ribs and stalks of sorghum plants, or a ragged, torn appearance producing a characteristic row of perforations in the leaves (shot holes). The older larvae feed extensively causing excessive defoliation. Sometimes it burrows into the growing point (bud, whorl, etc.), destroying the development potential of plants, or clipping the leaves (Mooventhan et al., 2019).

Figure 2. a) Larva of FAW, b) Inverted Y-shaped marking on the head, c) Four black dots in the form of a square on the penultimate segments *(Image: Kishore C. Sahoo)*

10. Sorghum Aphid: *Melanaphis sacchari* (Hemiptera: Aphididae)

Biology: Adults and Nymphs: Wingless adult female produces around 60-100 nymphs in just two weeks as which is more as compared to the winged ones. They pass through 4 nymphal stages to become an adult (Vasquez et al., 2024). The life cycle is completed in 5–7 days during the dry season. Both of the adults and nymphs are yellow to buff-colored.

Nature of damage: Infestation starts in the seedlings immediately after emergence, but the peak population reaches later stages under dry weather conditions, causing purple discoloration in leaves. This ultimately leads to chlorosis, necrosis, slow plant growth, and late flowering, which leads to poor grain filling. Aphids generally feed on the abaxial side of the older leaves, and the leaves below them are generally covered with sooty mold (Brewer et al., 2017).

11. White grub: *Holotrichia consanguinea* (Coleoptera: Scarabaeidae)

Biology: Egg: An average of 27 white pear-shaped eggs are laid by the female in the soil, enclosed within earthen cells. Incubation period is for 8-10 days.

Grub: Fleshy 'C' shaped, whitish-yellow translucent scarabaeiform grubs emerge which remain close around the base of the clump.

Pupa: Pupae are tan to brown, occurring deep inside the soil at around 40-70 cm, enclosed within earthen chambers.

Adult: Adult beetles just after emerging from the pupal stage are rusty-red, but eventually turn into black later.

Nature of damage: Grubs cause extensive damage to the roots and shoot base by cutting them resulting in the yellowing and wilting of leaves. Subsequently drying of the entire crown occurs. The affected stem comes out easily on pulling because damaged roots lead to the poor plant stand (Nataraja et al, ICAR-DGR).

12. Spider mites: *Oligonychus indicus* (Acari: Trombidiformes: Tetranychidae)

Biology: Eggs: One female could lay up to 50 eggs on the undersurface of the leaves which hatch in about 3-4 days.

Nymphs: Nymphs are six-legged and light-colored, but the eight-legged nymphs become progressively green. The larval period is completed in about 11 days.

Adult: Adult male requires 6 days for its complete development whereas female requires 7 days for it. Females are bigger in size.

Nature of damage: The mites spin delicate webs and live inside them on the lower surface of the leaves. They suck sap resulting in the development of small red spots which joins together resulting in the reddening of the leaves. Severe attack often causes the drying of leaves and stems.

13. Pyrilla: *Pyrilla perpusilla* (Hemiptera: Lophopidae)

Biology: Egg: Around 300-700 pale oval eggs, 1mm long are laid by the female in clusters on the underside of the leaves near midrib in summer and within leaf sheaths during winter which are covered with white anal tuft of hairs. The eggs are arranged in longitudinal rows with 35-50 eggs on each row. The egg period lasts for 8-10 days during summer and 2-3 weeks during winter.

Nymphs: The nymphs undergo 5 nymphal stages to become an adult. The full-grown nymphs are pale yellow, 10-15 mm long with two distinct white feather-like filaments at the tail end of their body. The hoppers being agile, jump around in a large number, making a faint noise.

Adult: The adult measures 20 mm in length with a straw-coloured body with dark patches or spots on it. In the front end, it has a pointed snout with red eyes. It is equally active as that of the nymphs.

Nature of damage: The nymphs and adults both suck sap from the underside of the leaves which makes them pale yellowish and wilted. Honeydew secreted by the feeding nymphs or adults also attracts sooty mold fungus which lowers the photosynthetic area of the leaves making them unsuitable for even cattle feed.

Integrated pest management in sorghum

a) Cultural methods

- Ploughing twice after harvest of preceding crop and before planting to prevent carry over of the stem borer larvae and Helicoverpa pupae.
- Clean cultivation by removing weeds in and around the field.
- Early sowing to asynchronise the sustainable phase of sorghum with that of the active period of shoot fly.
- Kharif planting should be around 7-10 days after the onset of monsoon; Rabi planting at September end or 1st week of October.
- High seed rate @1.6-2kg/ acre in order to replace the shoot fly and stem borer infested plants at early stages.
- Planting of resistant varieties such as cultivars with tall and yellow glossy stem and varieties like CHS-7, CHS-8, Indian Sorghum types IS-5566, 5285 and 5613.
- Proper application of nitrogenous and phosphatic fertilizers.
- Appropriate irrigation is necessary.
- Removal of dead heart showing seedlings
- Sowing of guard/barrier crop like maize/bajra in 4 rows all around the main crop.
- Crop rotation with groundnut, cotton or sugarcane.
- Growing lablab, cowpea, or pigeon pea as an intercrop (Sorghum: Lablab 4:1) substantially reduces stem borer damage.
- Intercropping of sorghum with pest-repellent ("push") plant species (e.g., *Desmodium spp*.), surrounded by a border pest-attractive trap ("pull") plant species (E.g., napier grass or *Brachiaria sp*.). for management of FAW and borers.

b) Mechanical methods

- Setting up of fish meal traps @ 4/acre till the seedlings are 4 weeks old for managing shoot fly.
- Collecting and burning the damaged spikes for reducing sorghum midge population.
- Collection and destruction of mite-infested leaves or plants by burning.
- Hand-picking and destruction of egg masses and early instar gregarious larvae by dipping in kerosene water for FAW.
- Pheromone traps can be installed at distance of 50 meter @ 4-5 traps per acre for monitoring and mass trapping of suitable insect pests for which specific pheromone lure is available like, FAW and H. armigera.
- Installation of Light traps @ 1 trap/acre for monitoring and mass trapping insects. Light designed for exit of natural enemies should be preferred and operated during the dusk time (6 pm to 10 pm).
- Erection of bird perches to attract predatory birds to feed on the larvae of FAW.

c) Biological methods

- Release of egg parasitoids (*Trichogramma chilonis*) @ 30,000-/acre/ week for reducing stem borer population.
- Conservation of natural enemies like: larval parasitoids [*Bracon chinensis, Apanteles flavipes*, etc.] and Predators [Spiders, Coccinellids, lacewings (*Chrysoperla zastrowi sillemi*), reduviid bug, fire ant, robber fly, black drongo (King crow), common mynah, big-eyed bug (*Geocoris sp*), earwig, ground beetle, pentatomid bug (*Eocanthecona furcellata*), praying mantis, etc.]. A list of natural enemies known for different insect pests of sorghum is presented in Table.2.
- Release of predatory mites such as *Phytoseilus* spp, Amblyseius spp. to reduce the mite population.
- Integration of two different groups of microbial pathogens i.e. *Beauveria bassiana* with *Bacillus thuringiensis* (Sufyan et al., 2019) or use of CpNPV (Sethuraman and Narayanan, 2010) can be employed for managing stem borers.
- Two applications of Ha NPV at 10-day intervals @1.5 X1012 POB can be done for controlling H. armigera.
- Spray of Botanicals like: Neem seed kernel extract 5% or Azadirachtin 1%.
- Application of Entomopathogenic fungi like, *Metarhizium anisopliae* for White grubs and *Metarhizium rileyi* (Ma 4) @ 5 ml/lt (NBAIR)-1x108cfu/ml for FAW (IIMR, 2022).

d) Chemical methods

- Seed treatment with thiamethoxam 30% FS @ 10 ml/Kg seeds or imidacloprid 48% FS @12ml/Kg seeds or imidacloprid 70% WS @ 10g/Kg seeds is effective for management of shoot fly, shoot bug, aphids, etc in early growth stages. Spraying of chlorantraniliprole 20 SC @ 0.3 ml/l or 18.5 SC @ 0.006%, flubendiamide 480 SC @ 0.2 ml/l, Spinosad 45SC @ 0.002 % will subsequently reduce stem borer population (Devananda et al., 2018; Kumar and Alam, 2017).
- Spraying Emamectin benzoate @200ml/acre for *H. armigera* (Chohan et al., 2020).
- Seed treatment with Cyantraniliprole 19.8% + Thiamethoxam 19.8% FS @ 6ml/kg seeds) and Application of Chlorantraniliprole @ 0.3 ml/ltr. for FAW.
- Spraying of miticides such as Fenazaquin 10% EC @10ml, Diafenthiuron 50 WP @ 10g /10litres of water if mite infestation is severe (Pokle and Shukla, 2015).
- Besides this, the following insecticides are recommended by DPPQS (2024):

Chemical	Target Pest
Carbofuran 03 % CG @33.3 kg/ha	Shoot fly
Carbofuran 03 % CG @8.3 kg/ha	Stem borer
Dimethoate 30 % EC @1650 ml/ha	Sorghum Midge
Imidacloprid 48 % FS @1200 ml/ha	Shoot fly
Imidacloprid 70 % WS @1000 ml/ha	Shoot fly
Oxydemeton-methyl 25 % EC @1000 ml/ha	Shoot fly
Phenthoate 02 % DP @20 kg/ha	Mites
Phosalone 35 % EC @1143 ml/ha	Sorghum Midge

Phosalone 04 % DP @ 25 kg/ha	Sorghum Midge
Thiamethoxam 30 % FS @10 ml/kg seeds to be used as seed dresser	Shoot fly

Table 2. List of Natural enemies known for different pests of Sorghum

Insect host	Scientific name	Family	Order	Stage of the host	Reference
Shoot fly	*Trichogrammatoidea simmondsi*	Trichogrammatidae	Hymenoptera	Egg	Singh and Sharma, 2002
	Trichogramma kalki	Trichogrammatidae	Hymenoptera	Egg	Maxon et al. 2019
	Aprostocetus sp.	Eulophidae	Hymenoptera	Larva	Singh et al., 2017
	Callitula bipartitus	Pteromalidae	Hymenoptera	Larva	
	Neotrichoporoides nyemitawus	Eulophidae	Hymenoptera	Larva-pupa	
	Bracon greeni	Braconidae	Hymenoptera	Larva	
	Alysia sp.	Braconidae	Hymenoptera	Pupa	Singh and Sharma, 2002
	Trichosteresis sp.	Braconidae	Hymenoptera	Larva	
	Hockeria sp	Chalcididae	Hymenoptera	Larva	Singh et al., 2017; Zongo et al., 1993
	Psilus sp.	Diapriidae	Hymenoptera	Larva	Jotwani, 1983
	Monelta sp.	Diapriidae	Hymenoptera	Larva	Taley and Thakare, 1979
	Odonteucoila sp.	Diapriidae	Hymenoptera	Larva	AICSIP, 1979; Singh and Sharma, 2002
	Trichopria sp.	Diapriidae	Hymenoptera	Larva	Phukon et al., 2023
	Hemiptarsenus sp.	Eulophidae	Hymenoptera	Larva	Jotwani, 1983
	Diaulinopsis sp.	Eulophidae	Hymenoptera	Larva	Jotwani, 1983
	S. micantinpennis	Chloropidae	Diptera	Larva	Zongo et al., 1993
Stem borer	*Trichogramma chilonis*	Trichogrammatidae	Hymenoptera	Egg	Tonapi et al., 2020
	Cotesia flavipes	Braconidae	Hymenoptera	Larva	Tonapi et al., 2020
	Xanthopimpla stemmator	Ichneumonidae	Hymenoptera	Pupa	Tonapi et al., 2020; Divya et al., 2009
	Tetrastichus sp.	Eulophidae	Hymenoptera	Egg	
	Sturmiopsis inferens	Tachinidae	Diptera	Larva	Divya et al., 2009
Midge	*Aprostocetus gala*	Eulophidae	Hymenoptera		Tonapi et al., 2020; Olayemi et al., 2021
	Eupelmus popa	Eupelmidae	Hymenoptera		
	Orius maxidentex	Anthocoridae	Hemiptera		
	Tetrastichus sp.	Eupelmidae	Hymenoptera		

Armyworm	*Cotesia ruficrus*	Braconidae	Hymenoptera	Larva	Tonapi et al., 2020
	NPV	Baculoviridae	Lifavirales	Larva	
Earhead caterpillar	*Campoletis chloridae*	Ichneumonidae	Hymenoptera	Larva	Singh et al., 2010
	Trichogramma sp.	Trichogrammatidae	Hymenoptera	Egg	Yadav et al., 2022
	Telenomus sp.	Platygastridae	Hymenoptera	Egg	Baker and Tann, 2020
	Microplitis mediator	Braconidae	Hymenoptera	Larva	Lu et al., 2017
	Habrobracon hebetor	Braconidae	Hymenoptera	Larva	Pratissoli et al., 2015; Yadav et al., 2022
	Carcelia illota	Tachinidae	Diptera	Larva	Wable, 2004
	Exorista xanthaspis	Tachinidae	Diptera	Larva	Pawar et al., 1989
	Menochilus sexmaculatus	Coccinellidae	Coleoptera	Larva	Pawar et al., 1989
	Paromius gracilis (Rambur)	Rhyparochromidae (Lygaeidae)	Hemiptera	Larva	Pawar et al., 1989
	Tropiconabis capsiformis (Germar)	Nabidae	Hemiptera	Larva	Pawar et al., 1989
	Delta companiforme F *D. esuriens* F *D. conoideus* G. soyka	Eumenidae	Hymenoptera		Pawar et al., 1989
	Nala lividipes (Dufour)	Labiduridae	Dermaptera		Pawar et al., 1989
	NPV	Baculoviridae		Larva	Lu et al., 2017
	Metarhizium anisopliae	Clavicipitacea	Hypocreales	Larva	Revathi et al., 2011
	Nomurea rileyi	Clavicipitacea	Hypocreales	Larva	
	Beauvaria bassiana	Cordicipitacea	Hypocreales	Larva	
Fall Armyworm	*Telenomus sp.*	Platygastridae	Hymenoptera	Egg	Shylesha et al., 2018
	Trichogramma sp.	Trichogrammatidae	Hymenoptera	Egg	
	Glyptapanteles creatonoti (Viereck)	Braconidae	Hymenoptera	Larva	
	Campoletis chlorideae Uchida	Ichneumonidae	Hymenoptera	Larva	

	Forficula sp.	Forficulidae	Dermaptera	Larva	
	Coccygidium melleum (Roman)	Braconidae	Hymenoptera	Larva	Sharanabasappa et al., 2019; Swathi et al., 2023
	Odontepyris sp.	Bethylidae	Hymenoptera	Larva	
	Eriborus sp.	Ichneumonidae	Hymenoptera	Larva	
	Harmonia octomaculata (Fabricius) *Coccinella transversalis* (Fabricius) *Chelomenes sexmaculata*	Coccinellidae	Coleoptera	Larva	
	Eocanthecona furcelata	Pentatomidae	Hemiptera		Swathi et al., 2023
	Orius sp.	Anthocoridae	Hemiptera		
	Wolf spider	Lycosidae	Araneae		
Aphid	*Coccinella septempunctata*	Coccinellidae	Coleoptera	Adults or nymphs	Hewlett et al., 2019
	Harmonia axyridis	Coccinellidae	Coleoptera		
	Chrysoperla rufilabris	Chrysopidae	Neuroptera	Adults or nymphs	
	Aphelinus nigritus	Aphelinidae	Hymenoptera	Adults or nymphs	Maxson et al., 2019
	Lysiphlebus testaceipes	Braconidae	Hymenoptera	Adults or nymphs	
	Syrphids	Syrphidae	Diptera	Adults or nymphs	
	Brown lacewings	Hemerobiidae	Neuroptera	Adults or nymphs	
	Orius sp.	Anthocoridae	Hemiptera	Adults or nymphs	
Pyrilla	*Epiricania melanoleuca*	Epipyropidae	Lepidoptera	Adults or nymphs	Ganehiarachchi and Fernando, 2000

	Cheiloneurus pyrillae	Encyrtidae	Hymenoptera	Egg	
	Parachrysocharis javensis	Eulophidae	Hymenoptera	Egg	
	Tetrastichus gala	Eulophidae	Hymenoptera	Egg	
	Metarhizium anisopliae	Clavicipitacea	Hypocreales	Adults or nymphs	
	Paeciliomyces lilacinus	Ophiocordycipitaceae	Hypocreales	Adults or nymphs	
	Camponotus sp.	Formicidae	Hymenoptera	Adults or nymphs	
	Diacamma sp.	Formicidae	Hymenoptera	Adults or nymphs	
	Brinckochrysa sp.	Chrysopidae	Neuroptera	Adults or nymphs	
	Tetragnatha sp.	Tetragnathidae	Arachnida	Adults or nymphs	
Spider mite	*Beauveria bassiana*	Cordicipitacea	Hypocreales	Larva	Prajapati et al., 2022
	Stethorus pauperculus	Coccinellidae	coleoptera	All stages	Godhani and Shukla, 2014
Cutworm	*Cotesia* spp.	Braconidae	Hymenoptera	Larva	Caballero et al., 1993
	Heterorhabditis spp.	Heterorhabditidae	----------	Larva	Edde, 2022
	Steinernema spp.	Steinernematidae	----------	Larva	Edde, 2022
Peregrinus maidis	*Creontiades* sp. *Tytthus parviceps* (Reuter)	Miridae	Hemiptera	Egg	Dharavath et al., 2023; Kalaisekar et al., 2017; Rawat and Saxena, 1967
	Chrysoperla sp. *Micromus timidus* (Hagen)	Chrysopidae Hemerobiidae	Neuroptera	Egg and nymph	
	Cheilomenes sexmaculata (Fab.) *Coccinella septempunctata* L.	Coccinellidae	Coleoptera	Nymph and Adult	

	Monolepta signata (Olivier)	Chrysomelidae	Coleoptera	Nymph and Adult	
	Callitrichia sp.	Linyphiidae	Araneae	Nymph and Adult	
	Cheiracanthium approximatum	Cheiracanthiidae	Araneae	Nymph and Adult	
	Marengo sp. Neoscona sp. Plexippus petersi	*Salticidae Araneidae Salticidae,*	Araneae	Nymph and Adult	
	Anagrus sp.	*Mymaridae*	Hymenoptera	Eggs	
	Erythraeus sp.	Erythraeidae	Trombidiformes	Adult	
	Allograpta exotica (Wiedemann)	Syrphidae	Diptera	Nymphs	Kalaisekar et al., 2017; Ghorpade, 1983
	Brumoides saturalis F.	Coccinellidae	Coleoptera	Nymph and Adult	Fisk, 1980
	Camponotus compressus F.	Formicidae	Hymenoptera	Nymph and Adult	Fisk, 1980
	Geocoris tricolor Fabr.	Lygaeidae	Hemiptera	Nymph and Adult	Rawat and Modi, 1969
	Illeis indica Timberlake	Coccinellidae	Coleoptera	Nymph and Adult	Fisk, 1980
	Mallada boninensis (Okamoto)	Chrysopidae	Neuroptera	Nymph and Adult	Singh et al., 1993
	Termatophyllum sp.	Termatophyllidae	Hemiptera	Nymph and Adult	Singh et al., 1993
	Rhyncoris fuscipes F.	Reduvidae	Hemiptera	Nymph and Adult	Singh and Seetharama, 2008
	Bochatria sp.	Erythaeidae	Acarina	Nymph and Adult	Kumar et al., 2005
	Haplogonatopus vitiensis (Perkins)	Dryinidae	Hymenoptera	Nymph and Adult	Singh and Seetharama, 2008; Rawat and Saxena, 1967
	Ootetrastichus beatis	Eulophidae	Hymenoptera	Egg	Kalaisekar et al., 2017

Conclusion

Sorghum, an adaptable crop with considerable nutritional and economic importance, encounters various challenges from insect pests such as stem borers, shoot flies, sorghum midges, and fall armyworm, leading to significant yield reductions and quality decline. To attain sustainability in sorghum cultivation, it is crucial to implement Integrated Pest Management (IPM) approaches that encompass cultural, mechanical, biological, and chemical control techniques in a compatible manner. By utilizing these methods, farmers can efficiently control insect pests, reduce crop losses, and improve the overall productivity and quality of sorghum. Nevertheless, ongoing research and development are crucial for discovering and creating innovative, environmentally friendly, and sustainable pest control methods. This entails investigating the possibilities of resistant cultivars, enhanced monitoring methods, and the use of beneficial insects and microbial agents. By embracing a comprehensive strategy for pest management, we can protect the future of sorghum farming and aid in global food security.

Conflict of interest statement

The authors declare no conflicts of interest.

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