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Sustainable management of shoot fly in sorghum: A comprehensive review

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Abstract
Sorghum [*Sorghum bicolor* (Linnaeus)] also known as Jowar is an important food and fodder crop of dryland agriculture with wide range of adaptability to various agro-ecological conditions in the semi-arid tropics and cultivated on marginal, fragile, and drought-prone environments. Sorghum is attacked by around 150 insect pest damage from seedling stage to maturity, of which sorghum shoot fly, *Atherigona soccata* (Rondani) is a notorius pest which is responsible for causing a loss of 80–90% of grain, and 68% of fodder yield in sorghum due to its regular occurrence. To manage pest problem, farmers still rely on pesticides use, but excessive use of chemical has resulted many problems. Hence, integration of all these approaches in a unified manner has exposed more good results for eco-friendly management of shoot fly and consequently high yield of sorghum obtained.

Keywords: Sorghum, shoot fly, resistant varieties, loss, cultural control and management

Introduction

Sorghum crop [*Sorghum bicolor* (Linnaeus) Moench, 2n = 2x = 20)] is belong to family Poaceae also known as *jwaarie, jowar, cholam, jonna, jola, jondhalaa, Guinea corn* in West Africa, *Mtama* in Eastern Africa, *Kafir* corn in South Africa, *Milo or Milo-maize* in North America and *Kaoliang* in China. It is a globally important food and fodder security crop cultivated in almost all regions and marginal, fragile, and drought-prone environments in the semi-arid tropics by subsistence farmers for wide use particularly in arid and semiarid environments (Ashok *et al*., 2011) [3]. Sorghum is used in various ways in our country as edible starchy seeds used for food to human and major ingredients in poultry and cattle feed in USA, China and Australia (Bramel-Cox *et al*., 1995) [15], leaf and stalk are used as animal feed for green chop, silage or hay and fodder, broomcorn used in making brooms, brushes and sweet sorghums for forage, syrup and ethanol production as liquor and beer. The reclaimed stalks of the sorghum plant are used as decorative millwork material marketed as Kirei board and construction of houses and fences and as fuel wood (Masresha and Belay, 2020) [41]. Sorghum is widely used in various culinary preparations *viz*., unleavened flat breads (roti) (Murty and Subramanian, 1981) [44]., infant food, syrup, popped grain as similar to popcorn, Indian bread, *bhakri, jowar roti*, or *jolada rotti*, used as wheat substitutes in gluten-free recipes and products in India. In Korea, it is cooked with rice, or its flour is used to make cake called *susu bukkumi*, *droo*, *tortillas* in Tunisia, *Honduras* in Central America, *injera, porridge, Nifro*, "Tella" in USA, *Arekie* in Ethopia and flour as an alternative to wheat in Northern China. Nutritionally, 100grams of sorghum contain 339kcal energy, 74.63g carbohydrates, 11.30g protein, 6.3g dietary fiber, 3.30g fat and amino acids is around 126.72 and 168.42 mg/g in red sorghum and white sorghum, respectively (Linko *et al*., 2005) [40]. Sorghum also contains less starches, sugars and diverse phenolic compounds *viz*., simple phenolic acids, flavonoids, and tannins compared to other major cereal crops confers sorghum with a number of health benefits such as reducing oxidative stress, cancer prevention obesity, oxidative stress, inflammation, dyslipidemia and hypertension and Celiac Disease (CD) and diabetes in sorghum (Gonzalez-Montilla *et al*., 2012) [26]. Sorghum is the fifth most important and oldest cereal crop in the world after rice, wheat, corn and barley. Besides, it is also the main staple cereal food for over 750 million people living in semi-arid tropical regions of Africa, Asia and Latin America (CCCF, 2011) [17].

In India, Sorghum is an important dual-purpose crop grown extensively by resource poor farmers in the states of Maharashtra, Karnataka, Telangana, and Andhra Pradesh indicates lifeline for resource-poor farmers in drylands as it tolerates water deficit stress. Globally, sorghum is grown over an area of 40.98 million hectares with a production of 59.77MT (metric ton) and productivity of 1.46MT per hactare (USDA, 2020) [68]. Region wise, production share of sorghum is highest in Africa accounting for overproduction 50.2% followed by America (32.4%), Asia 13.4% Ocenia (2%) and Europe (1.8%) (FAOSTAT, 2018) [23]. According to USDA (2020) [68], India ranks 6th in sorghum production (4.40 MT) after US (8.92 MT), Nigeria (6.90 MT), Ethopia (5.20 MT) Sudan (5MT) and Maxico (4.40MT) at global level and in area cultivation under sorghum, India ranks 3rd with a land of 4.80 Million Hectares after Nigeria (5.90 MH) and Sudan (7.00MH). In India, sorghum is cultivated over an area of 4960000 hectare and production of 4800000 tons with productivity of 10.33 tons/hectare (FAOSTAT, 2018) [23]. Sorghum is attacked by 150 insects and right from the nursery stage to till harvesting including the major ones being sorghum shoot fly (*Atherigona soccata* Rondani), spotted stem borer (*Chilo partellu*s), pink borer (*Sesamia inferens*), *Eldana saccharina*, and *Diatraea spp*) (Jotwani *et al*., 1971) [35], armyworms (*Mythimna separata*, *Spodoptera frugiperda* and *S. exempta*), Shoot bug or plant hopper (*Peregrinus maidis*), sorghum midge (*Contarinia sorghicola*) and a complex of earhead bugs (*Calocoris angustatus* and *Eurystylus oldi*), and head caterpillars (*Helicoverpa*, *Eublemma*, *Cryptoblabes*, *Pyroderces* and *Nola* sp.), white grub (*Holotrichia serrata*) and *Lachnosterna consanguinea*), Flea beetle (*Chaetocnema indica*, *Longitarises sp.*, and *Phyllotreta chotanica*),cutworms, grasshoppers and locusts (*Hieroglyphus*, *Oedaleus*, *Aiolopus*, *Schistocerca* and *Locusta* sp.) and leaf-eating beetles and spiders mite, *Oligonychus indicus*) and stored grain pests including *Sitotroga cerealella*, *Corcyra cephalonica*, *Ephestia cautella*, *Sitophilus oryzae*, *Rhyzopertha dominica*, *Tribolium castaneum*, *Trogoderma granarium*, *Oryzaephilus surinamensis*, *Latheticus oryzae* and *Lasioderma serricorne* (ICRISAT, 1985) [29]. Out of these, *A. soccata* has attained noxious pest status in Asia and other countries (Atwal and Dhaliwal, 2008) [5] that reduces sorghum production in the semi-arid tropics. Several biotic and abiotic constraints influence the production and productivity of sorghum. Among the biotic constraints, insect pests are one of the major factors influencing the grain yield in sorghum and result in losses of over $1000 million in grain and forage yield (ICRISAT, 2007) [28]. Nearly 32% of the actual production of sorghum is lost because of insect pests in India (Barad and Mittal, 1983) [12]. This notorious pest is considered a limiting factor in sorghum cultivation causing average yield loss of 50% in India (Jotwani, 1982) [33], 80–90% of grain and 68% of fodder losses (Kahate *et al*., 2014) [35] and yield losses up to 90% (Jotwani and Srivastava 1970) [31] but the infestations at times may be over 90% was recorded in India by its attack. Atwal (1976) [4] reported 75.6% grain loss and 68.6% in fodder loss due to shoot fly attack. Shoot fly causes nearly loss of 20% actual produce in Africa and Latin America, 9% in USA reported by Wiseman and Morrison (1981) [69]. Identifying sorghum genotypes with stable shoot fly resistance is highly important as it will help to reduce the cost of cultivation and stabilize the yields. Economic threshold level for sorghum shoot fly is 5-10% dead heart appearance in the plant (Atwal and Dhaliwal, 2008) [5].

Nature of damage

The maggots crawl inside the sheath and bore into the heart of the young shoot killing the growing point and the youngest leaf, which turns brown and withers and the resulted damage is known as “dead heart”. The damaged seedling is killed but may produce side tillers. In weak plant, repeated infestation may cause serious losses. Sometimes the damage is so severe that many seedlings die and the field has to be replanted. Older plants may also be attacked, but they do not produce the dead-heart symptoms. Instead, the damaged leaf becomes thin and papery, and wraps around the other leaves. As a result, the plants may fail to grow normally. Late infestations may also damage the panicle in the formative stage, resulting in rotting or drying up of the panicle portion (Biradar and Sajjan, 2018) [14].

Management strategies:

Different management practices reported by different workers for sorghum shoot fly have been reviewed under different headings.

Cultural control

Sorghum shoot fly can be effectively controlled by modifying the cultural practices like sowing time, seed rate, fertilization etc. have been used for many years to control pest. Shoot fly infestation can be avoided by suitable adjustment of planting time so that the vulnerable stage of the crop does not coincide with its active period. Young (1981) [70] pointed out that continuous cropping over several months favors population buildup and fly injury. Delobel (1982) [21] found that in low density plots (22 plants/m^2), plants received 3.35 times more eggs than in higher density plots (704 plants/m^2). In India, several authors from different localities have studied the effects of sowing dates and seed rates on the incidence of the shoot fly and found that early sowing helped to avoid and reduce damage (Mote, 1983) [43]. Early sowing (second week of June) with high seed rate @ 10 kg/ha and thinning dead heart plants at 28 days after emergence was found superior for checking the infestation of shoot fly and obtaining maximum yield (Shekharappa and Bhuti, 2007) [58]. As the sowing was delayed, infestation of shoot fly increased and it adversely affected the plant height, weight and length of earhead, number of primaries and spikelets, grain and stover yield (Ameta and Sumeria, 2004) [2]. During the rainy season, if planting is done within 7-10 days of the onset of the monsoon rains, the crop can escape from shoot fly infestation. In the post-rainy season, planting from September last week to October first week relatively reduced the shoot fly damage (Balikai, 1999) [6]. Under delayed plantings in the rainy season, increased seed rate, followed by thinning and destroying the dead hearts to maintain the optimum plant stand can be adopted. Application of nitrogen and phosphorous @ 80 and 40 kg/ha, respectively reduced the shoot fly infestation than the lower doses (Bhanderi and Patel, 2016) [13]. Shoot fly infestation can also be reduced by creating water stress conditions during young seedling stage (7-28 days after emergence) for different lengths of time (Nwanze *et al*., 1996) [48]. Intercropping also plays an important role in reducing the population of sorghum shoot fly. Garlic or onion intercrops can be used for the management of shoot fly with paired row planting of sorghum without affecting plant population (Karibasavaraja *et al*., 2005) [37]. Sorghum-cowpea intercrop also increased the parasitism by *Neotrichoporoides nyemitawus* compared to sole crop and recorded less number of eggs and per cent dead heart (Spurthi *et al*., 2007) [64]. Shoot fly damage is found reduced when sorghum is intercropped with leguminous crops (Nagesh, 2007) [45]. Seed treatment with thiamethoxam 70 WS @ 3g/kg seeds proved highly effective against shoot fly and significantly superior over rest of the treatments by recording 5.2 per cent dead hearts. The next best treatment in respect of shoot fly suppression was seed treatment with thiamethoxam 70 WS @ 2g/kg seeds which in turn was on par with imidacloprid 70 WS @ 5g/kg seeds (Balkai, 2011).

Table 1: Physical Control

Types of trap	Female trapped	Reference
Fishmeal trap	80 to 97%	(Gahukar, 1987) [24].
Fish meal	49.78%	(Mohan, 1991) [42].
Fish meal yeast + ammonium sulphide	85%	(Reddy *et al*., 1981) [51]
Hanging trap	342 adults daily	(Natarajan and Chellaiah, 1983) [47].
Fishmeal trap	50-80%	(Nagesh, 2007) [45]

Host Plant Resistance

Host plant resistance to insects has been an extremely successful technique for suppressing pest populations or damage. The most attractive feature of HPR is that farmers virtually do not need any skill in application techniques, and there is no cash investment by the resource poor farmers. There are so many genotypes of sorghum which exhibit resistance against sorghum shoot fly. The influence of cytoplasmic male sterility (CMS) on the expression of resistance to sorghum shoot fly was studied and results indicate that the hybrids based on shoot fly-resistant CMS x resistant restorer lines were significantly less preferred for oviposition than the hybrids based on other cross combinations and exhibited the highest frequency (69.1%) of shoot fly-resistant hybrids (Sharma *et al*., 2006) [59]. Kumar *et al*. (2008) [39] observed that the hybrids ICSA 434 × M 35-1-19 (6.1 t ha-1) and ICSA 445 × ICSV 702 (5.2 t ha-1) recorded higher grain yields with better shoot fly resistance as they were developed using shoot fly resistant seed parents and restorers. The insects fed on resistant genotypes *viz*., SFCR 151, ICSV 705, SFCR 125 and IS 18551 exhibited longer larval period, lower larval survival and adult emergence (Dhillon *et al*., 2005). Leaf glossiness character of varieties (ICSB 425, ICSB 42 and IS 2312) which acts as non-preference mechanism for oviposition against sorghum shoot fly (Kalpande *et al*., 2015) [36]. Similarly, the genotypes S-1049, AFS-14, CVS-21F (Bangar *et al*., 2012) [11], ICVS 745, IS 2205 (Subbarayudu *et al*., 2011) [65], IS-2191, IS-4481 (Balikai and Biradar, 2004) [10], KC-1, PGN-8, PGN-19 (Kishore and Kishore, 2001) [38] were reported resistant to sorghum shoot fly. Sandhu (2016) [56] found that the genotypes PSC 2, PSC 3 and PSC 6 were promising against shoot fly. The genotypes RSV-175, RSV- 176, RSV-182 and RSV-290 were also reported as resistant sources stable across several locations by Narkhede *et al*., (2002) [46]. Sorghum parental line 104A, 104B, RR 9817, RR 585 and RS 653 were found to be resistant (Balikai and Biradar, 2007) [7] which can be used for effective control of shoot fly. Further, genotypes SR 770-2, SR 970-2, SR 833 and GFS 261 (Subbarayudu *et al*., 2011) [65] and forage sorghum lines Katakhatav, Ramkel, Rampur Local depicted multiple resistance to sorghum shoot fly (Prasad *et al*., 2015) [50]. Taddi *et al*. (2019) [66] have evaluated 102 sorghum genotypes against sorghum shoot fly and out of these 31 genotypes exhibited resistance to shoot fly, 25 genotypes showed antixenosis for oviposition, and 26 also exhibited antibiosis to *A. soccata*.

Biological control

The biological control minimizes the environmental, legal and public safety concerns. In nature there are different natural enemies of sorghum shoot fly especially predators and parasitoids and these agents are playing an important role to keep the different stages of *A. soccata* population below threshold levels if utilized properly. The levels of egg parasitism have been recorded widely across seasons and locations.

Table 2: Show the Biocontrol agents and Location

Location	Biocontrol agents used	Predatory/ parasitism on	Reference
Predators			
Burkina Faso	*Tapinoma* sp. Forster (Formicidae)	Egg	(Zongo *et al*., 1993) [71]
	Thysanopteran sp. (Phlaethripidae Haplothripinae), Cecidomyiid (*Dicrodiplosis* sp), Mite (Histiotomtidae and *Suidasia pontifica*	Egg	(Zongo *et al*., 1993) [71]
India	*Abrolophus* spp.	Egg and larvae	(Reddy and Davies, 1979) [52]
Kenya	Spider	Egg	(Delobel and Lubega, 1984) [22]
Uganda	*Dasyproctus bipunctatus*	Adult	(Deeming, 1983) [19]
Parasitoid			
India, Itly Nigeria Burkina Faso Kenya	*Trichogramma chilonis* Ishii and *T. japonicum* Ashmead*T. evanescens T. kalkae* Sch. & Feij.	Egg	(Taley and Thakare, 1979) [67], (Deeming, 1971) [18], (Breniere, 1972) [16], (ICIPE, 1982) [27]
Burkina Faso	*Trichogrmmatoidea simmondsi*	Egg	(Zongo *et al*., 1993) [71]
India	*Neotrichoporoides nyemitawus* *Bracon* sp. and *Hockeria* sp.	Larvae	(Rohwer, 1921) [53] (Zongo *et al*., 1993) [71].
Itly	*Trichoplasta* Benoit	Pupae	(Del Bene, 1986) [20]
India	*Aprostocetus* sp., *Callitula bipartitus* Farooqui, *Neotrichoporoides* sp., and *N. Nyemitawus*	Pupae	(Jotwani, 1981) [32].
India	*Monelta* sp., and *Rhoptromeris* sp.	Pupae	Taley & Thakare, 1979) [67]

Integrated control

Management of this pest through integrated approach will play a key role in the sustainable production of sorghum. It was reported that three sprays (7th, 14th and 21st day after germination) of neem oil 2% and karanj oil 2% recorded lower oviposition and reduced the dead heart formation, considerably (Joshi *et al*., 2016) [30]. Similarly, neem oil 2% treated plots produced the yield at par with plant mixture and NSKE 5 per cent (Sable, 2009) [55]. Also NSKE 5% alone sprayed at 21st day after germination reduced egg laying of shoot fly and per cent dead heart formation at par with carbofuran (Shrinivasan and Shekharappa, 2009) [60, 61]. Maximum grain yield and highest Cost Benefit ratio were recorded from neem oil l3 per cent (Gautam *et al*., 2014) [25]. NSKE in combination with panchagavya and cow urine could be equally effective to chemical insecticides apart from being environmentally safe and eco-friendly in nature (Shrinivasan *et al*., 2009) [60, 61]. Another neem product, Azadirachtin 1500 ppm also resulted in lowering the egg lying of sorghum shoot fly and reduction of dead heart formation (Parteti *et al*., 2014) [49]. Likewise, Vitex negundo spray recorded significantly least per cent dead hearts caused by shoot fly. It was also reported that at 14 days after germination (DAG) the extract from mint and tulsi leaves and neem seed kernel suspension may be used to reduce the shoot fly infestation, considerably. Balikai (2003) [8] reported that treatment with Carbofuran 3G @ 2 g/meter row + High seed rate of 10 kg/ha and thinning at 20 days after germination + Release of egg parasitoid, *Trichogramma chilonis* Ishi @ 5 lakh adults on 7, 14 and 21 days after germination recorded the lowest shoot fly incidence of 11.5 per cent and highest grain yield of 30.0 q/ha. Six insecticides *viz*; thiamethoxam, imidacloprid, acetamiprid, profenofos 40 per cent + cypermethrin 4 per cent, endosulfan @ 0.07 per cent and carbofuran with various concentrations were evaluated against shoot fly of Sorghum by Aghav *et al*. (2007) [1]. Out of these insecticides imidacloprid gave the good control of this pest followed by thiamethoxam. The shoot fly infestation was recorded less with the seed treatment of imidacloprid 70 WS @ 10 ml/kg seed followed by quinalphos 25% EC spray @ 20 ml/10 lit water 15 days after emergence found significantly most effective (Sonalkar *et al*., 2018) [63].

Conclusion

The various control techniques have been practiced by different workers and among them cultural control, host plant resistance, biological control and chemical control are more effective against sorghum shoot fly. High rainfall after first week of emergence of the crop leading to mortality of eggs leading to less dead heart in the later growth stage of the crop and humidity in the morning and rainfall found important during oviposition but rainfall has no significance during dead heart formation. Genotypes with diverse shoot fly resistance and morphological traits can be effectively utilised as parents in developing high yielding shoot fly-resistant sorghums. We conclude that an integrated approach is the most effective for long-term sustainable and eco-friendly management programs for shoot fly.

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