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BIO-ECOLOGY AND MANAGEMENT OF SHOOT BUG, *PEREGRINUS MAIDIS* (ASHMEAD) ON SORGHUM AND MAIZE - A REVIEW

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ABSTRACT : The shoot bug, *Peregrinus maidis* (Ashmead) is a dreadful pest that attacks sorghum in India and many other countries in all over the world. The economic impact of *P. maidis* throughout the maize and sorghum agro-ecosystems can be categorized as destruction of young seedlings, stunted growth, predisposition of the crop to severe moisture stress, plant mortality due to transmission of virus disease(s), and reduction in crop yields. The present article therefore focuses on literature generated on various aspects of shoot bug *viz*., pest status and their distribution, biology, damage, losses, seasonal incidence, host range and ecology and different management strategies such as, host plant resistance, role of natural enemies and need based chemical control besides integrated pest management strategies employed against this pest.

Key words : Shoot bug, *Peregrinus maidis*, biology, management, virus diseases.

INTRODUCTION

The cereals are crop plants belonging to the grass family Graminae that are grown for their edible starchy seeds. The term cereal applies to the entire plant as well as the grain and loosely applied to the grain products. Grain is collective term applied to cereals. About half the ploughed land of the world is being used for growing the principal cereals. Cereal grains dominate world agricultural production because they directly or indirectly provide a large portion of the human substance. They are by far the most important source of concentrated carbohydrates for man and beast. Cereals are the chief items in the diet for many people, particularly in the orient, because they are a comparatively cheap source of calories. Grains represent the flexible fraction in the ration of the domestic animals, which supply meat, milk and other food products. Cereals are also used as forage for livestock. The cereals are the world's most important food crops. Wheat and rice together provide an estimated 60% of the world's human energy. Cereals as a group proved three quarters of man's energy needs and more than one-half of his protein needs. They are indeed the dietary mainstays of mankind.

Plants directly or indirectly provide almost all of the world's food supply. Out of the total 3,50,000 plant species on earth, only 150 appear in the world commerce and less than 300 are used for food. Even more surprisingly, world food supply relies almost entirely on only 15 species. The cereals compare more than one-half of the later group, which globally stand between people and starvation. Since the advent of agriculture, man and insect pests have taken up an endless battle in the survival many times and in some instance insects have the heavier side. In the beginning, insecticides gave phenomenal control of the pests but as time progressed insects developed resistance to each and every type of insecticides which resulted into a disaster phase in agriculture. Therefore, it has been taken into consideration to take a holistic approach in the management of insects with an integrated approach. All the possible non-pesticidal methods are tried and if required need-based insecticidal spray can be taken up.

Distribution

Sorghum is distributed in all over the world particularly in semi-arid tropics of the world *viz*., West Africa, Cuba, Nicaragua, Brazil, West Indies, North America, Hawaii, Fiji, Australia, Java, Philippines and India.

Host range

Sorghum shoot bug was recorded for the first time on corn from America (Ashmead, 1890). In India, it was found on grasses and on green plants (Lefroy, 1909). The various hosts of this enemy are given in Table 1.

Habitat

Nymphs are semi gregarious. Found on leaves, leaf whorls and inner sides of leaf sheath. Top shoots are made crowded with nymphs and adults than middle and bottom portion of the plants. During feeding, the insect will secrete clear, viscous and shiny honeydew as fine droplets. Association of ants is found common with shoot bugs for feeding on secreted honeydew.

Damage symptoms

Peregrinus maidis pierces the vascular tissues in the vessels of corn and sorghum by sucking sap from the leaves, leaf sheaths, and stem during exploratory feeding. Direct damage consists of sap removal from the leaves by adults and nymphs massed inside the leaf whorl, and on the inner side of the leaf sheath, causing reduced plant vigor, stunting, yellowing of leaves, and predisposition of the plant to moisture stress. Severe infestations result in withering of leaves downwards from the top of the plant, inhibition of panicle formation or emergence, and sometimes death of plant (Chelliah and Basheer, 1965), through girdling of stems (Singh and Rana, 1992; Chandra Shekar, 1991; Chandra Shekar *et al,* 1993; Singh, 1997). However, infestation during later stages of sorghum results in poorly developed panicles (Rawat and Saxena 1967). This is mainly due to disruption of photosynthetic flow to the root system leading to leaf senescence. Severe oviposition in the midribs of leaves causes leaves to desiccate (Chelliah and Basheer, 1965) and the tissue surrounding the eggs sometimes becomes septic and turns reddish (Napompeth, 1973). Indirect damage due to oviposition and feeding punctures, and copious excretion of honeydew by *P. maidis* predisposes corn or sorghum plants to sooty mold development (Chelliah and Basheer, 1965; Borikar and Deshpande, 1978; Kulkarni *et al*, 1978), which is considered as an important contributing factor to poor quality silage, especially during the wet season (Nishida, 1978). Several factors influence the plant response to feeding by *P. maidis*, such as density and nutritional status of the plant. In particular, growth stage, and water balance are critical, because small or drought stressed plants have less ability to tolerate or recover from feeding damage. *Peregrinus maidis* feeding not only has a strong impact on the mobility of mineral nutrients, amino compounds and carbohydrates in the phloem, but it also alters the carbohydrate-partitioning patterns, suggesting that infestation might alter sink–source relationships within the infested plant. In addition, *P. maidis* transmits a number of virus diseases in cereal crops. In India, the leaf sugary exudation ('chikta') due to oviposition and feeding punctures as well as excretion of honeydew by *P. maidis* is a serious menace in sorghum, and more so in soils of low fertility and in bunded areas (Managoli, 1973; Borade *et al,* 1993). *Peregrinus maidis* vectors several important virus diseases in corn/maize and sorghum such as maize mosaic (Tsai and Zitter, 1982; Naidu *et al*, 1989; Jyothi *et al*, 1996), maize stripe (Singh and Rana, 1992; Jyothi *et al,* 1996), maize streak, maize line, freckled yellow (Cherian and Kylsam, 1939) and male sterile stunt. In addition, *P. maidis* possess staphylococcus, paramyxovirus-like, rickettsia-like, and other structures (Ammar, 1987) also known to cause chlorosis in sorghum (Capoor *et al,* 1968; Peterschmitt *et al,* 1991).

Extent of losses

The economic impact of *P. maidis* throughout the maize and sorghum agro-ecosystems can be categorized as: (i) destruction of young seedlings, (ii) stunted growth, (iii) predisposition of the crop to severe moisture stress, (iv) plant mortality due to transmission of virus disease(s), and (v) reduction in crop yields. Thus, it has been difficult to accurately associate specific levels of damage with reduction in crop yields. In India, it has been estimated to cause a loss of 10 ton15% due to leaf sugar exudation (Chavan *et al,* 1959; Naik 1965; Borikar and Deshpande 1978; Mote *et al,* 1985; Mote and Shahane, 1994), 12 to 35% sorghum and maize plants at Jabalpur and about 45 to 60% plants at Indore (Rawat and Sexana, 1967), 10–18% loss of plant stand (Managoli 1973) and 30% of grain sorghum yield (Mote *et al,* 1985), 25.46 to 41.61% loss in grain yield, 48% fodder yield (Shivamurthappa *et al*, 1989). Similarly, losses caused by viruses transmitted by *P. maidis* in corn/maize range from 9 to 90% with crop damage estimates of 22 to 64% in Indonesia (Baru, 2000); 20 to 70% in Mexico (Rocha-Pena *et al,* 1984), and Australia by maize mosaic virus (Autrey, 1983), and in Burundi by maize stripe virus (Anonymous, 1999). An economic injury level of 3.7 nymphs per plant has been determined in sorghum (Rajasekhar 1996a) and an economic threshold level of 30 to 40% infestation was reported in corn (Nishida, 1978). The economic injury level was worked out to be 3.13 shoot bugs per plant (Anaji and Balikai, 2007). About 71.7 per cent of damage was recorded when 40 nymphs are allowed to feed with a grain loss of 7.3 g per plant. However, less per cent of loss (16.1) recorded with nymphal population of 15 (Rajasekhar, 1996a).

Balikai *et al* (2009) reported that, the overall loss of 11.16, 21.11 and 2.97 per cent in grain yield, fodder yield and 1000 grain weight, respectively was recorded under unprotected conditions as compared to protected ones across five dates of sowings. The unprotected plot recorded significantly higher sorghum stripe virus disease incidence as compared to protected ones with 18.72 and 9.51 per cent respectively, thus accounting for 51.26 per cent over all increased incidences in unprotected plot over protected ones. The unprotected plot recorded significantly higher shoot bug population over protected ones with 39.87 and 3.27 shoot bugs per five plants, respectively with 92.02 per cent overall increase in population in the unprotected plot over protected ones. The unprotected plot was significantly inferior over protected ones with leaf sugary exudation grade of 3.70 and 1.31, respectively with 63.86 per cent overall increase in unprotected plot over protected ones across five dates of sowings. The crops sown during September IV and October I week under unprotected conditions were significantly inferior by recording 89.20 and 85.73 per cent leaf sugary malady affected plants, respectively over October II, III, IV week sown crop under unprotected and were at par with each other. As the sowing was delayed, there was decrease in the plants affected by leaf sugary malady and panicle emergence in unprotected conditions.

Anaji and Balikai (2007) reported that, the highest reduction in plant height (170.7 cm) was noticed in the treatment with release of 30 first instar nymphs per plant which was on par with release of 25 first instar nymphs per plant. With respect to avoidable loss in grain yield, highest loss was recorded in the treatments with release of 30 and 25 first instar nymphs per plant (51.5 and 43.3%, respectively). Remaining treatments with release of 20, 15, 10 and 5 first instar nymphs per plant recorded gradually decreasing avoidable loss of 35.1, 27.4, 16.6 and 7.0 per cent, respectively. With regard to per cent avoidable loss in fodder yield, highest loss was recorded in the treatments with 30 and 25 first instar nymphs per plant with 49.4 and 42.3 per cent, respectively. The per cent loss in fodder yield gradually increased with increase in number of nymphs released. Release of 5, 10, 15 and 20 nymphs per plant exhibited avoidable loss of 9.3, 16.3, 25.7 and 34.2 per cent, respectively. The highest per cent of avoidable loss of 1000-grain weight was recorded in treatment with release of 30 first instar nymphs per plant (16.3%) and it gradually decreased with release of 25, 20, 15, 10 and 5 first instar nymphs per plant accounting for 14.0, 13.0, 9.30, 7.6 and 2.3 per cent respectively. The correlation coefficients between shoot bug incidence and plant height ($r = -0.98$), grain yield ($r = -0.97$), fodder yield ($r = -0.98$) and 1000-grain weight ($r = -0.98$) were negative and highly significant.

Bionomics of sorghum shoot bug, *Peregrinus maidis*

The taxonomic position of shoot bug, *P. maidis*: It belongs to family Delphacidae, superfamily Fulgoridea and order Homoptera.

Oviposition

In general mainly the upper surface of the midrib is preferred for oviposition. Female will make a slit by its ovipositor in the plant tissue. The eggs are either laid singly or in small groups of 1 to 6, which are covered by white waxy substance secreted by female. Oviposition lasts for 3 to 7 days (Ayyar, 1940).

Eggs

Whitish or pinkish in colour. Elongated, cylindrical and slightly tapering at both the ends, the ends are quite blunt (Chelliah and Basheer, 1965). The anterior end is narrower than the posterior end. The average length and breadth (10 eggs) is 1.29 mm and 0.35 mm, respectively. Single female lays a maximum of 97 eggs in 7 days. Incubation period range from 7 to 10 days. Just before hatching a pair of shiny brownish red eyes could be seed through egg chorion.

Nymphal period

There will be five nymphal instars with total nymphal period ranging from 12 to 26 days (Table 2). Freshly hatched nymphs are yellowish or pinkish. The nymphs congregate in the leaf whorl and leaf sheath for protection and development.

First instar nymph

The newly hatched nymph is yellowish orange in colour turning pale yellow after it starts feeding. Head prominent, with subcircular depressions in the frontal region. Eyes oval, bright red in colour, situated at the posterior end of the head on either side distally. Antenna two segmented with characteristic antennal sensorial in the second segment. Hind leg longer than the other two. Active, found in the interior of the top whorls (Chelliah and Basheer, 1965; Vijay kumar *et al,* 2008).

Second instar nymph

Pale yellow in colour. Eyes are darker and more prominent than first instar. Abdomen little darker than rest of the body. Development of wing pads on the meso and meta thorax. Legs proportionately longer with uniformly two segmented tarsi. Nymphs active, move in all directions with equal ease, found in large numbers inside the leaf sheath of top whorls.

Third instar nymph

Pale yellow, darker and bigger than second instar. Head distinct with brown compound eyes. Wing pads more prominent than the second instar. The first pair overlaps a portion of the antero-lateral part of the second pair. Second pair extends up to the second abdominal segment. Legs similar to second instar (Chelliah and Basheer, 1965; Vijay kumar *et al,* 2008). Abdominal terga dark coloured than the rest of the body. Very active and jump quickly if disturbed.

Fourth instar nymph

After moulting from third instar, the colour of the nymph pale yellow but slightly darker than earlier stage. Body relatively proportional with equally enlarged parts. Eyes are large and prominent. Meso and meta thorax are well developed with prominent wing pads. Nymphs are more active than earlier instar. Antenna with well developed scape and pedicel. Sensorial well represented in the pedicel as circular pits surrounded by short pointed spines. Meso and meta thorax well developed with prominent wing pads (Chelliah and Basheer, 1965; Vijay kumar *et al*, 2008). The tenth segment of the abdomen is seen as a conical projection from the ninth segment with a posterior median cleft. More active than third instar.

Fifth instar nymph

Light brown, with turgal border being dark brown in colour. Eyes were prominent with distinct lateral ocelli. Wing pads are very prominent and first pair of wing almost covered the second pair, legs are strong and well developed with tibial spur, developing genitalia distinct at the distal end of the abdomen (Chelliah and Basheer, 1965; Vijay kumar *et al,* 2008). Abdomen darker than the rest of the body.

Adult

In case of shoot bug wing polymorphism mechanism is common phenomenon, this accrued in the nature under two important conditions. According to Fernandez Badillo and Clavijo (1990) wing polymorphism mechanism seems to be an efficient reproduction and colonization strategies in shoot bug.

Wing polymorphism

i. Population density

High population density during nymphal stage favours the appearance of large winged forms also called macropterous form. Similarly low population density during nymphal stage favours the appearance of short winged forms also called brachypterous form.

ii. Food quality and quantity

Low food quality leads to appearance of large winged forms and high food quality favours the appearance of short winged forms.

Adult longevity

In general, the longevity of shoot bug adults male and female is 16 and 43 days, respectively for the macropterous from. In case of brachypterous form, male and female live for 14 and 44 days, respectively (Chelliah and Basheer, 1965).

Macropterous form

Females are yellowish brown and bigger, male are dark brown and smaller. Wings translucent with prominent veins provide with macrotrichiae all along the vein turgum with black border.

Brachypterous form

Females are yellowish brown and one and half times bigger than male. Males are dark brown and smaller. Wings extended only up to sixth abdominal segment.

Chellliah and Basheer (1965) studied the biology of shoot bug on caged sorghum under laboratory condition, pre-oviposition period ranged from 1 to 3 days with an average of 2 days. Oviposition was observed both in the field and the laboratory. Mainly the upper surface of the midrib was preferred for oviposition, the female made a slot out of its strong ovipositor in the plant tissue inside which the eggs were deposited in a groups of 1 to 4 were laid. A maximum 97 eggs were laid and oviposition continued for a week. The incubation period varied from 7 to 10 days with average of 8.25 days. There were five nynphal instars. The total nymphal period on an average was 16.2 days with duration of 3.4. 3.0, 2.9, 3.2 and 3.7 days, respectively, for the five nymphal instars. The longevity of adults showed that in both the forms the female lived longer than the male. The maximum longevity for the brachypterous female and male, which lived to a maximum of 44 and 14 days, respectively (Table 2).

Rawat and Saxena (1967) studied the biology of *P. maidis* under laboratory condition at Jabalpur. The bugs laid eggs singly or in groups of 2 to 6. They were deposited in longitudinal slits made by the ovipositor of the female in soft leaves, tender stems enclosed by the leaf sheaths and along the sides of the midrib on the upper surface of the leaves. The fecundity of a female varied from 19 to 98 eggs in the macropterous and 5 to 64 in brachypterous forms. The freshly hatched nymphs were yellowish white in colour, later turned to pale yellowish or pinkish. The total developmental period ranged from 12 to 26 days in macropterous and 14 to 23 days in brachypterous form. The adult longevity of male and female ranged from 2 to 27 days and 7 to 45 days, respectively. The corresponding values in brachypterous forms ranged from 3 to 18 days and 8 to 39 days.

Vijay Kumar *et al* (2008) reported that the mean egg incubation period on CSH-14, CSH-16, and M 35-1 genotypes was 9.75±1.25, 9.25±0.75 and 8.35±1.05 days, respectively. The higher nymphal period (18.24±1.93) was observed in CSH-14, while it was 17.75±1.67 and 16.06±2.03 days in CSH-16 and M 35-1, respectively. Among the 3 genotypes, variations in pre-mating, mating, pre-oviposition, oviposition, and post oviposition duration was observed and was 8.10±1.90 hours, 0.61±0.23 hours, 2.40±1.10 days, 5.66±1.74 days and 15.45 to 24.91 days on M 35-1, respectively, which was slightly lesser with CSH-14 and CSH-16. Both macropterous and brachypterous adults were found in each sex and in both the forms, females were nearly one and half times bigger than males. The brachypterous forms of *P. maidis* were found more fecund compared to macropterous forms in all the genotypes, however, a maximum of 106 eggs was recorded by the brachypterous female on M 35-1 as against 84 and 72 eggs in CSH 14 and CSH 16, respectively, and the percentage of hatching was also more on M 35-1. The mean total life cycle from egg to emergence of adult was more on CSH-14 and CSH-16 compared to M 35-1.

Wang *et al* (2006) reported that the *P. maidis* fed on different nitrogen (100, 300 and 500 mg N/l) fertilization plants had no significant effect egg development period with a mean of 9.6 days. However, there was a significant difference observed with nymphal development period 16.5 and 22.7 days with highest and lowest fertilization, respectively. Nymphal Survival rate of total nymphal stage was low (57.6%) in lowest nitrogen level treatment compared to other treatment. Pre-oviposition and adult longevity period among the treatment showed no significant difference but the significant difference was observed in female fecundity of 212.8 and 24 eggs in females fed on highest and lowest nitrogen applied plants of corn.

Seasonal incidence and status in Karnataka

Chellian and Basheer (1965) made the observation in the field on the occurrence of shoot bug in different months of the year, these insects were found most abundantly on sorghum during September-January. They decreased in number from February onwards and extremely scare during March to June. With the onset of rains during July and August, the insects starts multiplying in noticeable number in September and reaching peak during December.

Kulkarni *et al* (1978) studied the seasonal incidence of shoot bug on CSH-1 sorghum. Incidence was noticed on two days old seedlings. The incidence of shoot bugs per plant on October 1, 15, November 1 and 15 was 1.8, 1.9, 2.1 and 2.5, respectively. Seasonal prevalence of population of shoot bug was recorded from 10 days after emergence (DAE) to 110 DAE. However, it reached peak (678) at 70 DAE. This population is associated with cloudy weather with low temperature (Prabhakar *et al*, 1986).

In Bijapur, Mudhol taluk recorded maximum incidence (12.8%) followed by Jamakhandi (8.8%), whereas southern parts of Karnataka recorded very low incidence of disease in sorghum (Narayana and Muniappa, 1995).

Hundekar *et al* (2007) carried out roving survey for three years during post rainy season from 2004-05 to 2006-07 in Bijapur district covering five talukas to assess the impact shoot bug. In each taluka ten fields were visited randomly at around 45 days after emergence of the crop. The shoot bug population per plant was recorded. The plants showing yellowing of leaves and stunted growth symptoms were recorded. At about 60 and 75 days after emergence of the crop, the same fields were visited for recording girdling of topmost leaves without panicle development and poor panicle exertion, respectively. Similarly, the above observations were also recorded on the research farm on three varieties grown on larger area. The population of shoot bug varied from 20.51 to 26.34 per plant in different talukas of the district on farmer's fields mostly on M 35-1 variety. Whereas, on research farm comparatively higher population of 36.34, 28.67 and 29.13 per plant was observed on M 35-1, DSV-4 and DSV-5 varieties, respectively. The plants showing yellowing and stunted growth varied from 6.97 to 10.61 per cent on farmer's fields over the district. On research farm, it varied from 4.46 to 14.32 per cent on three ruling varieties. The plants showing girdling of top most leaves and poor panicle exertion ranged from 2.91 to 5.54 and 1.74 to 3.56 per cent, respectively on farmer's fields. On research farm, the plants showing girdling of top most leaves and poor panicle exertion ranged from 5.88 to 7.26 and 3.48 to 4.84 per cent, respectively and were little higher compared to farmer's fields. The overall stripe virus incidence and shoot bug damage ranged from 12.66 to 18.67 per cent over the district on farmer's field mostly on M 35-1 while on research farm, it was 26.42, 19.52 and 13.82 per cent on M 35-1, DSV-4 and DSV-5 varieties, respectively. The higher incidence of the disease was observed towards border areas of the fields as compared to the interior ones. This was due to the presence of alternate hosts like grasses growing on the bunds.

Host plant resistance

The detailed host plant interactions of the corn planthopper, *P. maidis* in maize and sorghum agro-ecosystems have been reviewed by Singh and Seetharama (2008). Agrawal *et al* (1978) studied the activity of shoot bugs in central India. The activity of the pest has been noticed from middle of July to end of December and their population reaches peak during September. During past three years, difference in degree of damage due to shoot bug on various sorghum lines was noticed. This suggested possibilities of finding out some resistance lines. About 127 lines have been screened for the relative resistance to the pest. The observation for the bug infestation was recorded in first week of October, on sorghum grown in five different replicated trails. For recording degrees of infestation, ten plants per plot were selected at random on each plant whorl and

Table 1 : Host plants of shoot bug, *Peregrinus maidis*.

Host plants	Author	Reported from
Maize	Ashmead (1890) Fullaway (1919) Muir (1917) Ritchie (1917) Catindig *et al* (1995)	America Hawaii Philippines Jamaica Philippines
Sorghum and Pearl millet	Lefroy (1915) Fletcher (1917) Ayyar (1940)	India
Sorghum halepense, *S. italic*, *Echinochloa colona* Linn. *Paspalum scrobiculatum* Linn.	Chelliah and Basheer (1965)	India
Cocoa	Distant (1914)	North America
Cucumber	Jones (1915)	Peurto Rica
Cotton	Fullaway (1919)	Peurto Rica
Sugarcane	Williams (1921)	Trinidad
Sugarcane Grasses	Watson (1939) Lefroy (1909)	Florida India
Napier grass, *Pennisetum purpureum* Shum.	Watson (1939)	Florida
Itch grass (*Rottboellia exaltata*), Gamma grass (*Tripsacum dactyloides* L.), Oats, rye and Bran grass (*Echinochloa crusgalli* L.)	Tsai (1996)	-
Cynodon dactylon L., *Paspalum* spp., *Bromus inioloides* Wild. and *Zea perennnis* Hitche	Remes Lenicov *et al* (2001)	Argentina
Rice	Catindig *et al* (1995)	Philippines

also inner sides of the leaf sheath were examined. The entries I-735, H-109, GIB-3677B and BP-53 were found completely free from shoot bug infestation. While the entries SPH-30, CSH-5, CSH-1 and I-751 have shown low infestation. All the above varieties, which carried low infestation, have an axils of leaves tightly fixed with the stem and thus no space for the shelter of the shoot bugs. The susceptible genotypes associated with biophysical characters such as dark green colour leaves, glossiness leaves, leaves with less trichome and non-waxyness and the biochemical characters like low phosphorous, low potash, high sugar and low poly phenol content.

Rajasekhar (1989) evaluated 88 sorghum genotypes and found that hybrid MSH-65 and SPH-888 and varieties SPV Nos 475, 678, 736, 741, 756, 775, 819 and CSV-10 showed promising resistance to shoot bug. The susceptible genotypes were associated with biophysical characters such as green colour leaves, non-glossiness leaves, leaves with more trichome and waxyness and the biochemical characters like high phosphorous, high potash and high poly phenol content (Mote and Shahane, 1994). Some sorghum germplasm accessions are relatively less susceptible to leaf sugary exudates (Mote and Shahane, 1993).

Rajashekar (1996) evaluated 38 genotypes for their relative susceptibility to shoot bug. The varieties were sown during first week of July in a single line of 6 meter length. The trails were also repeated in October. Commencing form 30 days after plant emergence, the variety SPV-736 and hybrid MSH-65 were considered promising harbouring the lowest bugs population 68 and 86 bugs per ten plants, respectively. The genotypes, which proved promising in rainy season, were also found to carry low bug population in post rainy season. Sorghum genotypes *viz.,* DJ-6514, ICSV-700, IS-2205 and CSH-13 were found to be tolerant to shoot bug and these genotypes have potential for incorporation in sorghum shoot bug resistance breeding programmes. The genotypes *viz*., Swathi, M 35-1, CSH-9, SPV-462 and ICSV-745 are highly susceptible to shoot bug damage (Subbarayudu, 2002).

Anaji and Balikai (2006) reported that, there was no significant correlation between any of the morphological characters and shoot bug infestation. However, there was a positive correlation between plant height, distance between leaves and leaf angle with shoot bug. Whereas, number of leaves per plant showed negative correlation with shoot bugs. Similarly, there was no significant correlation between shoot bug population and the biochemical constituents of all the twenty sorghum genotypes selected for comparison. Even then reducing sugars was positively correlated whereas, total sugars and total phenols were negatively correlated. However, these correlations were non-significant and very weak.

Anaji and Balikai (2007a) reported that, among the genotypes screened against shoot bug, the sorghum lines *viz*., 61508, 61526, 61543, 61544, 61576, 61582, 61587, 61588, 61589, 61590, 61592, 61595, 61596, 61607, 61608, 61611, 61612, 61613, CK 60B, Swati and RS-29 were promising against shoot bug by recording lower population (less than 2 shoot bugs/plant). The entries, 61504, 61506, 61516, IS-37190, DSV-4, DSV-5, Hathi kunta and M 35-1 were highly susceptible by recording higher population (10.3 to 12.5 shoot bugs/plant).

Chikkarugi and Balikai (2011) documented that, the entries *viz*., T x 428, RSV-824, RSV-744, BRJ-356, RSV-823, RSV-842 and Y-75 were found to be resistant to shoot bug by recording lower percentage of plant damage

Table 2 : Biological parameters of sorghum shoot bug, *Peregrinus maidis* in Indian continent.

Stages		Period (days)	Reference
Eggs	Per Female Per generation Brachypteres Macropterous	3-20 29-46[a] 34-45[b] 18-98 18-94 5-64	Chelliah and Basheer (1965) Rajasekhar (1989) Rajasekhar (1989) Rawat and Saxena (1967) Rajasekhar (1989) Rawat and Saxena (1967), Rajasekhar (1989)
Egg incubation (Days)		7-10 4-9 4-5 6.50-10.50	Chelliah and Basheer (1965) Rawat and Saxena (1967) Rajasekhar (1989) Vijay Kumar *et al* (2008)
Nymphs	Instar-I	3.4 2-4.25	Chelliah and Basheer (1965) Vijay Kumar *et al* (2008)
	Instar-II	3.0 2.25-4.25	Chelliah and Basheer (1965) Vijay Kumar *et al* (2008)
	Instar-III	2.9 2.25-4.50	Chelliah and Basheer (1965) Vijay Kumar *et al* (2008)
	Instar-IV	3.2 2.25-5.00	Chelliah and Basheer (1965) Vijay Kumar *et al.* (2008)
	Instar-V	3.7 3.25-5.00	Chelliah and Basheer (1965) Vijay Kumar *et al* (2008)
	Total	18-31 8-17 22-26 12-22.85	Chelliah and Basheer (1965) Rawat and Saxena (1967) Rajasekhar (1997) Vijay Kumar *et al.* (2008)
Oviposition	Pre oviposition	1-3 0.65-3.75	Chelliah and Basheer (1965) Vijay Kumar *et al* (2008)
	Oviposition	6-7 2-9.30	Rajasekhar (1989), Vijay Kumar *et al.* (2008)
Adult longevity			
Macropterous (♀)	Generation-I	43 14-53	Rajasekhar (1989, 1997) Rawat and Saxena (1967)
	Generation-II	37	Rajasekhar (1989, 1997)
Macropterous (♂)	Generation-I	16 19-71	Rajasekhar (1989, 1997) Rawat and Saxena (1967)
	Generation-II	12	Rajasekhar (1989, 1997)
Brachypteres (♀)		42 22-62	Rajasekhar (1989, 1997) Rawat and Saxena (1967)
Brachypteres (♂)		14 17-41	Rajasekhar (1989, 1997) Rawat and Saxena (1967)
Total life cycle		37-69	Vijay Kumar *et al* (2008)

a, Month: September, b, Month: November–January

due to sorghum stripe disease caused by shoot bug. Chikkarugi *et al* (2011) reported that, significantly lower percentage of plant damage due to sorghum stripe disease caused by shoot bug was recorded in T x 428, CSV-216R and CSH-15R and were on par with resistant check Y-75. Chikkarugi and Balikai (2011a) reported that, the entries *viz*., T x 428, CSV-216R, SLV-29, SLV-31, SLR-35, SLR-37, SLR-10 and Y-75 were found to be resistant to shoot bug by recording significantly lowest shoot bug population density per plant and percentage of plant damage due to sorghum stripe disease caused by shoot bug.

Chikkarugi and Balikai (2011b) studied biochemical causes of resistance against shoot bug (*P. maidis*) in 53 genotypes of *rabi* sorghum with varied level of pest infestation and reported no significant correlation between shoot bug resistance and biochemical constituents of *rabi* sorghum genotypes selected for comparison. However,

Table 3 : Parasitoids recorded on shoot bug, *Peregrinus maidis* (Singh and Seetharama, 2008).

Species	Family	Order	Stage	Author	Year
Bochartia sp.	Tetranychidae	Acarina	Adults & nymphs	Haiti,	Olmi (1984)
Ootetrastichus indicus (Girr.)	Chalcididae	Hymenoptera	Eggs	India	Westgate (1918)
Bochatria sp.	Erythaeidae	Acarina	Nymphs and Adults	India	Rawat and Modi (1969)
Haplogonatopus vitiensis Perkins	Dryinidae	Hymenoptera	Adults & nymphs	India (Madhya Pradesh) Trinidad, USA (Hawaii)	Rawat and Saxena (1967) Olmi (1984) Olmi (1984)
Ootetrastichus pallidipes Perkins	Dryinidae	Hymenoptera	Adults & nymphs	Fiji USA (Hawaii)	Perkins (1905); Swezey (1936) Pemberton (1944); Zimmerman (1948)
Paranagrus sp.	Mymaridae	Hymenoptera	Eggs	Chile	Rioja *et al.* (2006)
*Paranagrus flaveolus*Waterhouse [Syn: *Anagrus flaveolus* Waterhouse]	Mymaridae	Hymenoptera	Eggs	Argentina Brazil Cuba Haiti Mauritius Puerto Rico Trinidad USA (Hawaii) Venezuela	Marin Acosta (1964); De Santis *et al*. (1992) Leao Veiga (1977) Box (1953) Waterhouse (1913); Dozier (1932, 1936); Wilson (1980) Williams (1957) Waterhouse (1913); Dozier (1932, 1936) Wilson (1980) Wilson (1980) Box (1953); Marin Acosta (1964), Guppy (1914)
Paranagrus frequens Perkins [Syn: *Anagrus frequens*]	Mymaridae	Hymenoptera	Eggs	Australia Haiti Trinidad USA (Hawaii)	Fullaway (1918); Timberlake (1924); Dozier (1932, 1936); Swezey (1936) Dozier (1932); Wilson (1980) Dozier (1932); Wilson (1980) Fullaway (1918); Timberlake (1924); Dozier (1932, 1936); Swezey (1936); Zimmerman (1948)
Paranagrus optabilis Perkins Syn: *Paranagrus osborni* Fullaway	Mymaridae	Hymenoptera	Eggs	Australia Guam	Perkins (1906); Ayyar (1919); Swezey (1936) Swezey (1936)
Anagrus panicicolae [Sahid]				Java Philippines India Samoa USA (Hawaii)	Girault (1914) Fullaway (1918, 1919) Ayyar (1940) Swezey (1936); Zimmerman (1948) Fullaway (1918); Swezey (1936); Zimmerman (1948); Napompeth (1973)
Pseudogonatopus hospes Perkins	Dryinidae	Hymenoptera	Adults &nymphs	China USA (Hawaii)	Perkins (1905); Williams (1931); Swezey (1936) Perkins (1905); Williams (1931); Swezey (1936); Napompeth (1973)
Unidentified	Chalcidoidae	Diptera	Eggs &nymphinstar-1	India (MP)	Rawat and Saxena (1967)

Table 4 : Predators feeding on shoot bug, *Peregrinus maidis* (Singh and Seetharama, 2008).

Species	Family	Order	Stage	Country/Location	Reference
Allograpta exotica (Wiedemann)	Syrphidae	Diptera	Nymphs	USA (Hawaii)	Napompeth (1973)
Allograpta javana (Wiedemann) *Argiope avara* Thorell	Syrphidae Mimetiae	Diptera Araeneida	Nymphs Adults & nymphs	India Chile USA (Hawaii)	Ghorpade (1983) Rioja *et al.* (2006) Napompeth (1973)
Brumoides saturalis F.	Coccinellidae	Coleoptera	Adults & nymphs	India (Andhra Pradesh)	Fisk (1980)
Camponotus compressus F.	Formicidae	Hymenoptera	Adults & nymphs	India (Andhra Pradesh)	Fisk (1980)
Camponotus acvapimensis (Mayr)	Formicidae	Hymenoptera	Adults & nymphs	Brazil	Dejean *et al.* (2000)
Cheliosoches morio (F.)	Chelisochidae	Dermaptera	Adults & nymphs	USA (Hawaii)	Swezey (1936); Napompeth (1973)
Chrysoperla sp.	Chrysopidae	Neuroptera	Adults & nymphs	Chile	Rioja *et al.* (2006)
Chrysoperla *basalis* Walker	Chrysopidae	Neuroptera	Adults & nymphs	USA (Hawaii)	Swezey (1936); Zimmerman (1948); Napompeth (1973)
Chrysoperla 7-punctata var.Brucki	Chrysopidae Hemerobiidae	Neuroptera Neuroptera	Adults & nymphs Adults & nymphs	USA (Hawaii) Chile	Napompeth (1973) Rioja *et al.* (2006)
Coccinella 7-punctata var. brucki.	Coccinellidae	Coleoptera	Adults & nymphs	Venezuela	Marin Acosta (1964)
Coccinella septempunctata L.	Coccinellidae	Coleoptera	Adults & nymphs	India (Madhya Pradesh)	Bagal and Trehan (1945); Rawat and Saxena (1967)
Coelophora inaequalis Fabricius	Tettigonidae	Orthoptera	Adults & nymphs	USA (Hawaii)	Fullaway (1918); Swezey (1936); Zimmerman (1948)
Conocephalus saltator (Saussure)	Miridae	Hemioptera	Eggs	USA (Hawaii)	Swezey (1936); Napompeth (1973)
Cyrtorhinus mundulus (Breddin) [Syn: *Cimex triguttatus* Linnaeus]	Miridae	Hemiptera	Eggs	USA (Hawaii)	Verma (1955)
Crematogaster sp.	Formicidae	Hymenoptera	Adults & nymphs	Brazil	Dejean *et al.* (2000)
Doru lineare (Eschscholtz)	Formicidae	Hymenoptera	Adults & nymphs	Venezuela	Marin Acosta (1964)
Geocoris tricolor Fabr.	Lygaeidae	Hemiptera	Adults & nymphs	India (Madhya Pradesh)	Rawat and Modi (1969)
Hasarius adansoni (Aud.)	Salticidae	Araeneida	Adults & nymphs	USA (Hawaii)	Napompeth (1973)
Illeis indica Timberlake	Coccinellidae	Coleoptera	Adults & nymphs	India (Andhra Pradesh)	Fisk (1980)
Leis dimidiata Fabricius	Coccinellidae	Coleoptera	Adults & nymphs	USA (Florida)	Watson *et al.* (1939)
Mallada boninensis (Okamoto)	Chrysopidae	Neuroptera	Adults & nymphs	India (Karnataka)	Singh *et al.* (1993)
Menochilus sexmaculatus (F.) [Syn: *Cheilomenessex maculatus*]	Coccinellidae	Coleoptera	Adults & nymphs	India (Madhya Pradesh) India (Andhra Pradesh), India (Karnataka)	Bagal and Trehan (1945); Rawat and Saxena (1967) Fisk (1980) Singh *et al.* (1993)
Mesogramma subannulatum Loew	Syrphidae	Diptera	Adults & nymphs	Cuba	Loftin and Christenson (1933)
Myrmicaria opaciventris (Emery)	Formicidae	Hymenoptera	Adults & nymphs	Brazil	Dejean *et al.* (2000)

Table 4 continued...

Table 4 continued...

Nabis sp.	Nabidae	Hemiptera	Adults & nymphs	Chile	Rioja *et al.* (2006)
Pagiopalus atomarius Simon	Salticidae	Araeneida	Adults & nymphs	USA (Hawaii)	Napompeth (1973)
Pheidole megacephala (F.)	Formicidae	Hymenoptera	Adults & nymphs	USA (Hawaii)	Fullaway (1912); Zimmerman (1948)
Plexippus paykulli (Aud.)	Salticidae	Araeneida	Adults & nymphs	USA (Hawaii)	Napompeth (1973)
Red mite	Tetranychidae	Acarina	Adults & nymphs	Venezuela	Marin Acosta (1964)
Rhyncoris fuscipes F.	Reduvidae	Hemiptera	Adults & nymphs	India(Tamil Nadu)	Cherian and Kylasam (1939)
Termatophyllum sp.	Termatophyllidae	Hemiptera	Adults & nymphs	India (Karnataka)	Singh *et al.* (1993)
Tetragnatha mandibulata Walck	Tetragnathidae	Orthoptera	Adults & nymphs	USA (Hawaii)	Napompeth (1973)
Tytthus lividipennis Reuter [Syn: *Cyrtorhinus lividipennis* Reuter]	Miridae	Hemiptera	Eggs	Guam USA (Hawaii	Pemberton (1937) Pemberton (1937); Fullaway and Krauss (1945); Verma (1955); Nakao (1960); Davis (1960); Napompeth (1973); Liquido and Nishida (1985a, b)
Tytthus mundulus (Breddin)	Miridae	Hemiptera	Eggs	Australia Fiji USA (Hawaii) -	Swezey (1936) Swezey (1936) Williams (1931); Swezey (1936); Usinger (1939); Zimmerman (1948); Verma (1954, 1955); Napompeth (1973) Carnegie and Harris (1969)
Tytthus parviceps (Reut.)	Miridae	Hemiptera	Eggs	-	Carnegie and Harris (1969)
Xiphidiopsis lita Hebard [Syn: *Chrysotus pallidipalpus*van Duzee]	Tettigonidae	Orthoptera	Adults & nymphs	USA (Hawaii)	Swezey (1936); Napompeth (1973)
Zelus renardii Kolenati	Reduvidae	Hemiptera	Adults & nymphs	USA (Hawaii)	Fullaway (1918); Swezey (1936); Zimmerman (1948); Napompeth (1973)

positive correlation was observed between chlorophyll index and potash, whereas negative correlation was observed between nitrogen and phosphorus with shoot bug population density and shoot bug plant damage.

Chikkarugi and Balikai (2011c) studied the physical causes of resistance against shoot bug (*P. maidis*) in 131 genotypes of *rabi* sorghum and reported that significant and positive correlation for plant height and leaf area, a significant and negative correlation for number of leaves per plant and non-significant positive correlation for distance between two leaves and leaf angle with shoot bug damage was observed.

Management practices

Biological control

The various parasitoids and predators, their order, family and reported author are given in Tables 3 & 4. Andrea *et al* (2007) reported 17 isolates from 5 fungal species *Beauveria bassiana*, *Lecanicillium muscarium* (Petch) Zare & W. Gams, *Metarhizium anisopliae*, *Isaria farinosa* (Holmsk.: Fr.) Fr. and *I. fumosorosea* and were tested for preliminary screening assays. After 7 days of post-inoculation, significant differences were observed among treatments. Percentages of fungal infection were 18.5 to 69.8%, although mortalities exceeded 20% in the majority of isolates tested. The three most effective isolates against *P. maidis* were *B. bassiana* CEP 147, CEP 150 and CEP 189, all of whose cumulative mortalities exceeded 50%. *Beauveria bassiana* CEP 147 (cumulative mortality of 69.8±6.4%) was selected for comparative pathogenicity tests against *P. maidis*. Proportionally more females than males were infected, but the differences were not statistically significant. Mortality percentages were similar for males (31.0 ± 3.3%) and females (35.0 ± 3.4%).

Chemical control

Effective control of *P. maidis* with increased yields was achieved with demeton-S-methyl, monocrotophos (Gandhale *et al*, 1986), carbaryl (sevin) and phosphamidon (Malaguti and Naranjo, 1963), dimethoate 0.03%, quinalphos 0.05% and endosulfan 0.05% (Chaudhari *et al*, 1994). Use of thiamethoxam 70 WS seed treatment @ 2 g/kg seed or dressing with carbosulfan 25 DS (@ 40 g/kg seed) or whorl application of phorate 10 G (@ 10 kg/ha) resulted in higher profit than the other chemicals (Vijay Kumar, 2004) and imidacloprid 70 WS @ 2 g/kg seed treatment was effective in reducing the population of shoot bug, which was on par with its higher dose (@ 5 g/kg seed) and also recorded low incidence of maize streak virus disease (Bheemannna *et al.*, 2003). The best knockdown effect was realized with endosulfan and malathion (Tsai *et al,* 1990). However, the persistence of oxydemeton-methyl was shorter (3 days) (Tsai *et al,* 1990) and sevin, malathion, parathion, BHC, endrin, chlordane, isodrin, DDT, aldrin (Sarup *et al,* 1960), phosphamidon, endrin (Rathore *et al,* 1970) and carbaryl persisted for longer times (10-15 days) (Tsai *et al,* 1990). In addition, botanicals such as seed extracts of taramira oil (*Eruca sativa*), and leaf and shoot oil extracts of artemisia oil (*Artemisia kurramensis* Qazilb.) alone or in combination with DDT have increased toxicity (Khan, 1984). Similarly, the seed extracts of custard apple (*Annona squamosa* L.) (Yasin and Syamsuddin, 1999), and cucurbitacins (Tallamy *et al,* 1997), when sprayed, showed antixenosis for oviposition and/or feeding by *P. maidis.*

Balikai and Bhagwat (2009) reported that, four treatments *viz*., intercropping of chickpea (2:2) + seed treatment with thiamethoxam 70 WS @ 3 g/kg seed, seed treatment with thiamethoxam 70 WS @ 3 g/kg seed + spray of NSKE @ 5% at 45 days after emergence of crop (DAE), seed treatment with thiamethoxam 70 WS @ 3 g/kg seed + spray of endosulfan @ 0.07% at 45 DAE and seed treatment with thiamethoxam 70 WS @ 3 g/kg seed alone were effective in reducing the shoot fly, shoot bug and aphid incidence and thereby harnessed higher sorghum grain equivalent yield, fodder yield and net returns. Intercropping of sorghum with chickpea (2:2 row proportions) was not a good option from the point of insect pest suppression and higher returns.

Balikai (2011) reported that, the seed treatment with thiamethoxam 70 WS @ 3 g/kg seed proved highly effective in reducing the sorghum stripe disease incidence (5.2%) and significantly superior over rest of the treatments except seed treatment with imidacloprid 70 WS @ 5 g/kg seeds (8.2%). Seed treatment with thiamethoxam 70 WS @ 3 g/kg seed recorded highest grain yield (22.5 q/ha) and fodder yield (54.3 q/ha) and followed by seed treatment by imidacloprid 70 WS @ 5 g/kg seeds (21.7 and 52.1 q/ha grain and fodder yield, respectively) and thiamethoxam 70 WS @ 2 g/kg seeds (20.4 and 51.3 q/ha grain and fodder yield, respectively) and were on par with each other.

Anaji and Balikai (2007b, 2012) reported that, among the different seed dressers tested the lowest shoot bug population (18.53/5 plants) was recorded by thiamethoxam 70WS @ 3 g/kg seed and was at par with imidacloprid 70WS @ 5 g/kg seed, carbosulfan 25DS @ 20 g/kg seed which recorded 21.33 and 23.40 shoot bugs per five plants, respectively. Carbosulfan 25DS @ 20 g/kg seed and thiamethoxam 70WS @ 2 g/kg seed recorded almost similar reaction in respect of sorghum stripe disease expression (7.3 and 8.97%, respectively). The thiamethoxam 70WS @ 3 g/kg seed was very effective in hindering the disease incidence (2.57%) which was the lowest among the insecticides tested. Next best was imidacloprid 70WS @ 5 g/kg seed treatment by recording 4.33 per cent disease. The seed treatment by thiamethoxam 70WS @ 3 g/kg seed resulted in higher net profit of Rs. 15902/ha which was on par with the seed treatment by carbosulfan 25DS @ 20 g per kg seed (Rs. 15772/ha), imidacloprid 70WS @ 5 g/kg seed (Rs. 15437/ha), imidacloprid 70 WS @ 2 g/kg seed (Rs. 14663/ha) and thiamethoxam 70WS @ 2 g/kg seeds (Rs. 14573/ha).

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