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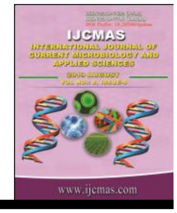

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Sorghum - *Chilo partellus* Interaction: A Biochemical Perspective

Tanmaya Kumar Bhoi and Ipsita Samal*

Division of Entomology, ICAR-Indian Agricultural Research Institute, New Delhi, India

**Corresponding author*

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A B S T R A C T

Sorghum is an essential crop in the semi-arid tropics being attacked by nearly 150 species of insects, out of which *Chilo partellus* is the more devastating pest. Based on the foliar damage the resistance and susceptible genotypes of sorghum can be screened. For further understanding of the host plant resistance relationship between sorghum and stem borer the orientation behaviour and larval establishment behaviour can be studied. The host plant resistance in sorghum to *C. partellus* can be either morphological or biochemical. Plant morphological characters such as hairs on upper leaf surface, trichome length and density have been reported to affect the orientation, settling and feeding behaviour of insects. Among the biochemical factors under consideration, some are constitutive and some may be induced in response to attack by insects. Morphological, allelochemical and biochemical character decide the host plant preference of the insect. Moreover, the expression of resistance to a particular insect is not governed by a single biochemical factor rather the interaction of diverse biochemical constituents lead to differential levels of host plant resistance to a single or a diverse array of insects. Among the biochemical factors, proteins, total lipids, total sugars, total tannins, total flavonoids, different amino acids and lipophilic compounds play a significant deciding role in determining in resistance\susceptibility. Furthermore, various enzymes such as catalase, peroxidase, superoxide dismutase etc. also impart significant resistance or susceptibility to diverse array of insects. The study of biochemical factors influencing resistance or susceptibility may be further open up new ways for developing new biochemical markers which could be further helpful in developing resistant varieties. Moreover, the elite genotypes can be screened to devise a resistant variety by eliminating the susceptibility related genes.

Sorghum crop

Sorghum (*Sorghum bicolor* Moench) is an essential crop of semi-arid tropics (SAT). It provides livelihood to millions of people in Asia, Africa, USA, Latin America and Australia. It is a fifth major cereal crop after rice, wheat, maize and barley (Sharma *et al.*, 2003). According to FAOSTAT (2014), sorghum is grown on 45 million ha area with production of 68.9 million tons of grains around the world. In India, it is cultivated on 5.65 million ha with annual production of 4.41 million tones (ASG, 2016). It is mainly used for livestock and poultry feed, malt industry and for human consumption (Chapke *et al.*, 2011). Sorghum adapts well to harsh weather conditions, particularly drought which makes it high value crop worldwide. It is mainly cultivated for feed, fodder and ethanol industry. Apart from these, it also has additional health and pharmaceutical benefits such as slow digestibility, reduction in cardiovascular disease, cholesterol reduction and anticancer properties (Rooney and Awika, 2004, 2005). Productivity of sorghum is quite low (500–800 kg/ha) under Indian subsistence farming conditions due to biotic and abiotic factors. *Chilo partellus* (Swinhoe) is most devastating pest of sorghum in Asia and Africa (Sharma *et al.,* 2003, 2007).

Spotted stem borer, *Chilo partellus*

Sorghum is damaged by 150 insect species, of which 10 species cause economic damage, and *C. partellus* is the most devastating for this crop (Dhillon *et al.,* 2014). It is the most destructive pest of sorghum and maize in South East Asia, Central and East Africa and also distributed to Mediterranean region. In India, it is a serious pest of sorghum in Rajasthan, Delhi and Haryana, while it causes serious damage to maize in Central and Northern regions. The insect breeds actively from March-April to October, and for the rest of the year it remains in hibernation as full grown larvae in sorghum stubbles, stalks or unshelled cobs. The pest usually attacks the plant at vegetative stage or before harvest resulting in economic loss of the crop. The whole life cycle of *C. partellus* vary according to temperature and other factors and usually takes about 3-4 weeks (Anne *et al.,* 2011). Conventional management strategies like insecticides and biocontrol agents prove to be ineffective against this pest due to its internal feeding nature. To counteract this problem, we need to develop some alternative strategies including tolerant varieties. As per the background of Integrated Pest Management strategies, development and deployment of insect resistant varieties offer a more holistic approach to minimize losses caused by spotted stem borer, *C. partellus*.

Description and biology of *Chilo partellus*

The eggs of *C. partellus* are flat, oval, yellowish and lay about 20 eggs in cluster on underside of leaves of sorghum in overlapping clusters. A female lay over 300 eggs during its life span and hatches in 4-5 days. Maximum mating and oviposition occurs during first night after emergence and mating, respectively. After hatching, neonates disperse and enter the leaf whorl where they feed and cause damage to the leaves. Neonates also feed inside the leaf sheath and ear husk (Kumar, 1992). Extensive larval feeding in the leaf whorl results in 'deadheart' formation (Kumar and Asino, 1993). The older larvae leave the leaf whorl and enter the stem causing tunneling and ear damage. The larvae become full fed in 14-28 days, passing through six instars, it pupates inside the stem/stubbles. The larvae pupate in March and moth emerges in early April. Siddalingappa *et al.,* (2010) studied the biology of *C. partellus* and recorded observations on total life cycle, incubation period, larval instars, mean duration of each larval instar, total larval period, premating and mating period, oviposition period, fecundity rate and adult male and female life span under laboratory conditions. Earlier studies reported slow development of *C. partellus* on wild gramineous plants than on cultivated cereal crops (Mohammed *et al.,* 2004).

Assessment of damage done by *C. partellus*

The resistant and susceptible genotypes can be distinguished based on foliar damage, number of egg masses, entry and exit holes, stem tunneling length and stalk breakage due to *C. partellus* damage (Ampofo *et al.,* 1986). The parametric ratios for the test cultivar computed against the susceptible check, and overall resistance/susceptibility index (ORSI) have been derived. Based on ORSI value, resistance to *C. partellus* has been established. However, such methods are un-reliable for speedy screening of maize germplasm. Besides, both primary and secondary damage parameters important to use in such insect resistance evaluation.

Kumar and Asino (1993) distinguished resistance genotypes based on leaf feeding score, dead heart and stem damage.

Oviposition and feeding behaviour

The oviposition behavior can be studied under natural conditions in the field by growing the resistant and susceptible genotypes (Ampofo, 1985; Kumar, 1988) or by exposing the genotypes to the ovipositing females in the specially constructed cages (Kumar and Saxena, 1985b). Field tests by Ampofo (1985) revealed differences in maize stem borer oviposition on the resistant and susceptible genotypes. They suggested that certain conditioning stimuli were central to larvae acceptance or rejection of the plant on which eggs were laid (Ampofo, 1985; Ampofo and Nyangiri, 1986). Their analysis indicated that different chemical characteristics play a certain role in larvae acceptance of the plant. Kumar and Saxena (1985) made similar observations on the ovipositional responses to the susceptible and resistant sorghum cultivars. Saxena (1987) employing techniques specially developed to test the role of cultivars in oviposition reported remarkable differences in oviposition of the susceptible, IS 18363, and the resistant, IS 1044, cultivars. The number of eggs laid as well as the ovipositional preference were high for IS 18363, while the number of eggs as well as the ovipositional preference were low and medium respectively for IS 1044. Other workers show that w-hexane and/or acetone extracts of susceptible and resistant cultivars of sorghum (IS 18363, IS 1044) exhibit deferent levels of oviposition stimulation and/or inhibition.

Orientation behavior

This response of insect determines its establishment on the plant in two ways: (i) an insect may be attracted to a plant or repelled from it because of certain attractants or repellents. (ii) the larvae emerging from the eggs laid on the leaves may continue to stay on the plant and succeed in reaching the feeding sites in the leaf whorls or may depart from the plant during their movements from oviposition site (basal leaves) to the feeding site (leaf whorl). This is being ascribed to various morphological and biochemical factors. The attraction/repulsion could be for feeding in the case of larvae or oviposition in the case of adults (Saxena, 1985).

Egg production and viability

The egg production and viability can be studied by rearing *C. partellus* neonates on diverse resistant and susceptible sorghum genotypes. Number of eggs laid can be determined by releasing single pair of adults obtained from diverse resistant and susceptible sorghum genotype fed *C. partellus* larvae in the oviposition cages until its death. Fewer eggs were laid by *C. partellus* females which were reared on the resistant Antigua Group 1 in comparison to the susceptible Basi Local (Sharma and Chatterji, 1971; Durbey and Sarup, 1984). On the other hand, Sekhon and Sajjan (1987) did not find any difference in the fecundity of *C. partellus* reared on these two genotypes.

Larval establishment behavior

Larval movement in *C. partellus*is guided through four phases:

Ballooning of newly hatched larvae moving towards whorl

Ballooning of first and second instars to depart the plant whorl

Walking prior to stem penetration, and

Walking after stem penetration

Such differences were clearly observed in movement of *C. partellus* larvae on sorghum and maize (Berger, 1992). Larval behaviour is mainly acceptance or rejection to host or establishment of larvae in whorl, where it usually starts feeding and guided by stimuli and chemical characteristics of the host plant (Ampofo and Nayangiri, 1985).

The host - pest relationship

The survival, development and damage by pests on crop plants is directly related with interaction between insect and host plant for feeding, oviposition and orientation of the pest. Several genotypes have been reported to differ in their levels of susceptibility or resistance to insect pests in cereals (Jotwani and Davis, 1980; Jotwani, 1981; Dabrowski and Kidiavai, 1983; Singh *et al.*, 1983). The factors determining colonization and establishment of the insect on test plant to determine level of resistance or susceptibilitycan be illustrated through the method given by Saxena (1985):

Determination of insects arrival and avoidance of plant is depend on its orientation

Feeding

Utilization of ingested food

Development of larvae

Fecundity of adults, and

Oviposition

These studies revealed that lower the insect response to any of these categories to a cultivar the greater will be the plant resistance to pest, thus, reduces the insect preference to the cultivar. Preferably, this leads to reducing the insect's three major behavioral responses namely feeding, orientation and oviposition.

Plant resistance to insects

The considerable damage due to *C. partellus* larvae and other insect pests on host plants affect the grain or crop yield, which promote the scientists to concentrate on screening for identifying and developing resistant varieties. Efforts to identify sources of resistance to *C. partellus* in various sorghum cultivars are already in progress in many research institutions. Four factors are mainly known to affects the expression and stability of resistance in cultivar are morphological, genetic, biochemical and environmental factors (Singh, 1978; Ampofo, and Nyangiri, 1986). Biochemical factors are taken into consideration to this research. In nature, every plant is inherently resistant to herbivory attack due to certain chemicals present in the plant. Therefore, resistant cultivars may develop defense mechanism to survive in a given habitat. The chemical resistance factor present in plant (allelochemicals) mainly affects the behavioral and metabolic processes of the insect pests. Several chemicals have been reported which are proved essential or prohibitive to the development of insect pests in various crops (Smith *et al.*, 1979; Sagawa and Pathak., 1970; Torto *et al.*, 1990; Woodhead and Bemays, 1978). Allelochemicals imbalance in a genotype affects the susceptibility level of the cultivar (Auclair *et al.*, 1957; Maxwel *et al.*, 1976; Ampofo and Nyangiri, 1986).

Basis of resistance to spotted stem borer, *C. partellus*

The *C. partellus* neonates accept or reject the plant and choose appropriate site for their settlement (Khan, 1997; Kumar, 1997; Van den Berg and Van der Westhuisen, 1997). Morphological, allelochemcial and biochemical characteristics of a plant determine its quality and host suitability (Beck, 1965; Norris and Kogan, 1980;

Agrawal, 2011). Plant morphological characters interfere with insect behavior activities such as mating, oviposition, feeding and ingestion. Trichome length and density adversely affect oviposition preference of *C. partellus* (Durbey and Sarup, 1982; Ampofo, 1985; Kumar and Saxena, 1985). Pubescence hairs on upper leaf surface also impart oviposition non-preference to *C. partellus* (Kumar, 1992; Van den Berg, 2006).

To measure orientation and settling behavior of *C. partellus*, various choice tests have been developed and used for such studies (Smith *et al.*, 1994; Khan, 1997). No choice tests have been performed to determine level of antibiosis in various maize hybrids (Davis *et al.*, 1989) and fodder grasses (Wiseman *et al.*, 1982). Biochemical characteristics of plant adversely affect the feeding behavior of *C. partellus* by producing toxic substances which ultimately prevent metabolic processes (Kumar and Saxena, 1985; Kumar, 1994a, b, c). However, expression of resistance in host plant not only governed by single constitutive factor, but is the result of interaction between all the constitutive biochemical factors (Dhillon *et al.*, 2005; Dhillon and Chaudhary, 2015, 2018; Dhillon and Kumar, 2017).

Biochemical factors of insect resistance

Host plant quality can be determined by specific allelochemicals, nutrients and anatomical factors present in the host plant (Agrawal 2001; Baldwin *et al.*, 2001). Various morphological characteristics such as plant height, trichrome, pubescence hair, stem hardiness, leaf texture, glossiness and tassel ratio have been reported to impart resistance against insect pests in maize (Durbey and Sarup, 1982; Kumar, 1997; Rao and Panwar, 2000, 2001). Several nutritional and anti-nutritional biochemical characteristics have also been found to govern resistance to insect pests in maize (Kumar and Saxena, 1985; Karbe and Ghoarpade, 1999; Bhanot *et al.*, 2004; Yele, 2014; Dhillon and Chaudhary, 2015). The constitutive and/or induced plant metabolic compounds govern the insect-plant interaction, which ultimately leads to plant defense against insects (Sharma, 2009). The sum of all the morphological, biochemical and anatomical plant features contribute to durable resistance against insect pests (Dhillon *et al.*, 2005; Huang *et al.*, 2013). Anti-nutritional factors like lignin and phenolic compounds also play a major role in plant defense against herbivores (Rasool *et al.*, 2017). The plant chemicals influence the resistance/susceptibility to insect pests in several ways: (i) determining the orientation, feeding and oviposition behaviour of the insects. (ii) determining the metabolism of insects, which could be either helpful in normal metabolic processes resulting in insect's normal growth and survival or production of plant toxins interfering developmental biology. The plant volatiles from resistant and susceptible maize genotypes in response to damage by spotted stem borer have been reported to be equally effective in eliciting oviposition by *C. partellus* (Kumar and Saxena, 1985; Kumar, 1994b). After arrival on the host plant, leaf surface wax of the resistant genotype, Mp704 was found less effective than those on the susceptible genotype, Inbred A to elicit oviposition by *C. partellus*. Alcoholic and hexane extracts of resistant maize genotype, Mex 17 were found to adversely affect the growth and development of *C. partellus* (Durbey and Sarup, 1988).

Qualitative or quantitative alteration in phenols and enhanced activity of oxidative enzymes in response to herbivore attack is general phenomenon (Barakat *et al.*, 2010). It plays major role in plant defense against insect pests (Howe and Jander, 2008; Sharma, 2009). The induced plant defense chemicals adversely affect growth, development, feeding and survival of insect and overcome damage by the herbivores (Howe and Jander, 2008; Chen *et al.,* 2009; Sethi *et al.,* 2009; Wu and Baldwin, 2010; Karban, 2011; War *et al.,* 2011). In plant defense against herbivores, reactive oxygen species (ROS) play a major role. It acts as secondary messenger for signaling various defense reaction pathways in plants (Low and Merida, 1996; Asada, 2006). They promote beneficial oxidation to generate energy and kill microbial invaders. But in excess, they cause pigment co-oxidation, lipid peroxidation, membrane destruction, protein denaturation, and DNA mutation (Mittler, 2002). In order to prevent oxidation, plant itself develop important ROS scavenging mechanism (Howe and Schilmiller, 2002). Antioxidative enzymes are the most important components in the scavenging system of ROS, and are involved in defense against herbivores. Induced resistance in host plants is also regulated by various antioxidative defense enzyme (Gulsen *et al.,* 2010; Usha Rani and Jyothsna, 2010; War *et al.,* 2011, 2012).

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