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# Components of host plant resistance to insect pests with specific emphasis on spotted stem borer, *Chilo partellus* in maize

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**Abstract**
The spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) is an important pest of maizein Asia. Host plant resistance is one of the effective way to minimise crop losses due to insect pests. Various morphological and biochemical factors of host plant lead to the development of resistance/ susceptibility in insects. The host plant resistance can be studied through the establishment and orientation behaviour which may be constitutive or induced.Biochemical constituents both in terms of quantities and proportions to each other in host plant have a great influence on growth, development, survival and reproduction of insects. More importantly, the performance and abundance of herbivores is attributed to the variations in host plant quality being determined by nutritional composition, allele chemistry and specific anatomical features The ROS react with wide range of molecules leading to membrane destruction, lipid peroxidation, causing pigment co-oxidation and membrane destruction. In order to compensate oxidation burst due to production of ROS, plants have evolved complex protective mechanism for scavenging ROS, which include small molecular antioxidants and enzymatic components. In this series there are several naturally occurring plant cell antioxidants/enzymes like catalases, ascorbic acid oxidase, ascorbic acid peroxidase, phenyl ammonia lyase and tyrosine ammonia lyase; and constitutive plant defense compounds such as phenolics, flavonoids, tannins, chlorophyll and carotenoid derivatives which could be potential plant defence factors against herbivores.

**Keywords:** *Chilopartellus,* maize, host plant resistance

## Introduction

Maize (*Zea mays* L.) is one of the most important cereal crop among the cereals occupying third rank globally in area and production next to rice and wheat. Maize grain is used for various purposes including food, feed, green cobs, popcorn, baby corn, sweet corn, fodder, starch and several industrial products, depending on the socioeconomic conditions and regions of the population (Kumar *et al.,* 2014). It has very high yield potential, there is no cereal on earth which has so immense potentiality and that is why it is called ‘queen of cereals’.It is grown on an area of 8.85 million ha with annual production of 22.84 million tones in India (ASG, 2016), 75% of which is being used as poultry feed and human food, and rest 25% for animal feed and industrial purposes (Dhillon and Gujar, 2013) [19].

The grain yields of traditional maize genotypes under subsistence farming conditions are quite low (2.17 t/ha) in India because of several biotic and abiotic stresses. Among the biotic stress, most important constraints responsible for low yield is damage by various insect pests. The insect pests damage the maize crop from sowing to till harvesting and even in storage. Maize is damaged by 139 species of insects during different growth stages, of which only 10 insect species cause economic damage (Dhillon *et al.*, 2014) [20]. Based on the insect feeding habit and crop growth stage, these can be categorized into various categories such as roots (wire worms, white grub and root worm), leaves (stem borer, thrips, spider mites, army worm, grasshopper and aphids), stalks (stem borer and termites), ears and tassels (stem borer, army worm, and ear worm), grain during storage (grain weevil, grain borer and Indian meal moth) damaging insect pests. Among the stalk feeding insects, spotted stem borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) pose a great challenge to increase productivity potential of this crop (Kanta *et al.*, 1997; Dhillon *et al.*, 2014) [20]. The spotted stem borer, *C. partellus* is an important pest of maize in several Asian and African continents. It causes yield loss of about 18 to 25% under different agro-climatic conditions in Asia and Africa (Dhaliwal *et al.*, 2015; Dhillon and Chaudhary, 2015) [18]. This pest remains active in the field from March to November, and maximum damage is experienced in the month of August.

The insect breeds actively from March-April to October under North Indian conditions and for the rest of the year it remains in hibernation as a full-grown larva in maize and sorghum stubbles, stalks or unshelled cobs under North Indian conditions (Dhillon *et al.,* 2017). However, under South Indian conditions, it undergoes aestivation during April to June (Dhillon and Hasan, 2017a, b). The young larvae first feed on the leaves, making a few shot holes, which then enters the central whorl resulting in damage on the central growing point causing drying of the central two leaves known as "dead heart" formation. The damaged plants remain stunted in growth and produce no grain. Maximum damage is caused in month of August, wherein some times more than one larvae are found in a plant. They females are active during night, when they mate and lay eggs on the underside of the leaves of various host plants, particularly the early sown maize crop for fodder purpose. The eggs are flat, oval, yellowish and are laid in overlapping clusters each containing up to 20 eggs. A female lays over 300 eggs during its life-span of 2-12 days, and the eggs hatch in 4-5 days during Summer. The larva passes through six stages, completing larval during in 14-28 days, which then pupates inside the stem and/or stubbles. In general, *C. partellus* completes the life cycle in 3 to 4 weeks, but it varies according to agro-climatic conditions. Five or more successive generations can be completed under favorable climatic conditions (Anne *et al.,* 2011) [7].

Several management strategies including crop rotation, field sanitation, biological control agents and synthetic pesticides have been recommended for the control of *C. partellus,* but none of these have been found effective for its control particularly when the larvae enter inside the stalks (Kfir *et al.*, 2002; Sharma *et al.*, 2007). Under such situations, host plant resistance could be one of the most effective mean of minimizing losses due to this pest. Host plant resistance refers to heritable qualities of a cultivar to counteract the activities of insects so as to cause minimum reduction in yield as compared to other cultivars under similar conditions (Dhaliwal *et al.*, 1993). Since plant resistance is the result of interaction between the plant and the insect, four resistance characteristics *viz.*, heritable, relative, measurable and variable are important to compare the performance of particular genotype for resistance to target insect (Panda and Khush, 1995). All the three mechanisms of resistance *viz*., antixenosis/non-preference, antibiosis and tolerance/recovery are operational against spotted stem borer, *C. partellus* in sorghum (Dhillon and Kumar, 2017). However, maize crop has no mechanism to recover from stem borer damage, antibiosis and antixenosis mechanisms are rewarding for developing stem borer-resistant maize genotypes. Antixenosis mechanism of resistance inhibits feeding by *C. partellus* larvae on the host plant (Kumar, 1997). The neonate larvae choose appropriate substrate whether to accept or reject the plants (Kumar, 1997; Van den Berg and Van der Westhuisen, 1997), and then orient towards suitable host and get settled. Antixenosis mechanism of resistance influence larval orientation, settling and feeding response due to presence of chemical and/or morphological factors (Khan, 1997) [32]. This behavioral response could be used as a tool for the management of stem borers in maize. Antibiosis mechanism of resistance affects biology of the insect, and the most commonly observed adverse effects are in terms of nutritional physiology including consumption, assimilation, utilization and subsequent allocation of food resources for reproduction. This is manifested by larval death in first few instars, abnormal growth rates, disruption in conversion of ingested food, decline in size and weight of larvae, prolongation of larval period, restlessness and abnormal behaviour in the larvae, failure in emergence of adults from pupae, decrease in fecundity and reduction in fertility (Panda and Khush, 1995). These symptoms may appear due to various physiological processes like presence of toxic substances, absence or insufficient amount of essential nutrients, nutrient imbalances, presence of anti-metabolites and enzymes adversely affecting food digestion and utilization.

Furthermore, there is complex interplay of signals between the insect pest and host plant in response to damage by the herbivore, which ultimately determines the resistance/ susceptibility reaction of the host plant. Biochemical constituents both in terms of quantities and proportions to each other in host plant have a great influence on growth, development, survival and reproduction of insects. More importantly, the performance and abundance of herbivores is attributed to the variations in host plant quality being determined by nutritional composition, allelochemistry and specific anatomical features (Dhillon and Choudhury, 2015). Several maize genotypes with resistance to *C. partellus* have been identified (Kanta *et al*., 1997; Rakshit *et al*., 2008; Dhillon and Gujar, 2013) [57, 51, 19], and many morphological and anatomical plant characters (Kumar, 1997; Sharma *et al*., 2007; Dhillon and Gujar, 2013) [13] and biochemical factors (Kumar and Saxena, 1985; Kumar, 1997; Rao and Panwar, 2002; Yele, 2014; Dhillon and Chaudhary, 2015; Samal, 2017) [20, 18, 74] have been found associated with resistance to *C. partellus* in maize. Apart from these biochemical constituents, free radicals are also generated in plant biological system, which are capable of independent existence, usually promoting beneficial oxidation to generate energy and defend against herbivores. However, excess release of these free radicals cause harmful oxidation that can damage cell membrane and even cell death, while antioxidants play important role in scavenging these excess free radicals. The most common mechanism in the plant defence system is the production of reactive oxygen species (ROS), an early event of plant defence in response to different stresses and act as a secondary messenger to signal subsequent defence reaction in plants (Low and Merida, 1996; Asada, 2006) [46, 8]. The ROS react with wide range of molecules leading to membrane destruction, lipid peroxidation, causing pigment co-oxidation and membrane destruction. In order to compensate oxidation burst due to production of ROS, plants have evolved complex protective mechanism for scavenging ROS, which include small molecular antioxidants and enzymatic components (Howe and Schilmiller, 2002). In this series there are several naturally occurring plant cell antioxidants/enzymes like catalases, ascorbic acid oxidase, ascorbic acid peroxidase, phenyl ammonia lyase and tyrosine ammonia lyase; and constitutive plant defense compounds such as phenolics, flavonoids, tannins, chlorophyll and carotenoid derivatives which could be potential plant defence factors against herbivores. Apart from biochemical mechanisms of resistance, oviposition and feeding behaviours also plays crucial role in devising strategies for the management of insect pest.

**Biology of *C. partellus***

The eggs of *C. partellus* are flat, oval, yellowish and lay about 20 eggs in cluster on underside of leaves of maize 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). Because of the extensive feeding by the larvae in the leaf whorl, the central shoot dries up, plant killed and showing 'dead heart' symptoms (Kumar and Asino, 1993). The older larvae leave the leaf whorl and bore into the stem causing stem 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) [64] 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 of maize stem borer under laboratory conditions. Studies conducted on behaviour and biology of *C. partellus* on maize and wild gramineous plants revealed that the larval growth and development was significantly faster on maize in comparison to other plants (Mohammed *et al*., 2004).

**Assessment of damage done by *C. partellus***

To distinguish between resistant and susceptible maize genotypes, Ampofo *et al.* (1986) [6] investigated parameters like foliar damage, number of egg masses, number of entry and exit holes, percentage of stem length tunneled and stalk breakage due to *C. partellus* damage. The ratios of each of these parameter values for a test cultivar against the susceptible check were computed. The relative ratios of all the parameters for each genotype were then averaged to calculate overall resistance/susceptibility index (ORSI). The lower the ORSI value of a genotype, the greater would be the resistance to *C. partellus* and vice-versa. However, such methods are not suitable for rapid screening of maize germplasm for selecting resistant genotypes in a breeding program. Besides, the secondary damage parameters like entry holes or stalk breakage are considered at par with the primary damage parameters. Kumar and Asino (1993) [40] suggested leaf damage, dead heart and stalk damage on maize by *C. partellus* to clearly distinguish the resistant and susceptible genotypes. More detailed studies can be undertaken with various other damage parameters to confirm resistance to maize genotypes against spotted stem borer.

**Ovipositional responses**

The oviposition behavior can be studied under natural conditions in the field by growing the resistant and susceptible genotypes (Ampofo, 1985; Kumar, 1988) [4, 5] or by exposing the genotypes to the ovipositing females in the specially constructed cages (Kumar and Saxena, 1985b) [41]. Field tests by Ampofo (1985) [4, 5] revealed differences in maize stem borer oviposition on the resistant and susceptible genotypes. Durbey and Sarup (1982) [23, 24] reported ovipositional non-preference mechanism for certain resistant genotypes. Kumar and Saxena (1985) [43] showed that the differential ovipositional preference of *C. partellus* to different susceptible and resistant maize genotypes compared in field or greenhouse under controlled conditions are only due to plant characters. These studies demonstrated that variation in the humidity stimuli in the vicinity of the plants influence oviposition by *C. partellus*, wherein fewer eggs laid by the females on the resistant maize genotypes due to contact-perceivable characters (surface waxes, trichomes, etc.) than distance-perceivable characters (hygro, visual and olfactory stimuli). However, Kumar (1994b) reported that the differences between the resistant and susceptible genotypes under field conditions could also be because of certain non-plant characters apart from plant characters, which influence *C. partellus* orientation and subsequent oviposition by the females.

**Feeding response**

After entry of *C. partellus* larvae in the leaf whorls, their establishment would depend on larval feeding. Feeding responses of *C. partellus* on plants can bestudied in the laboratory as well as under field conditions. Using laboratory bioassays, Kumar (1993a, b) [35] demonstrated that food ingested by maize stem borer larvae on Mp704, Poza Rica 7832 and V 37 genotypes was less in comparison to the susceptible genotype, Inbred A. In the field experiments, Kumar and Saxena (1992) reported significantly less feeding by *C. partellus* on resistant Mp 704, Poza Rica 7832 and V 37 genotypes than the susceptible genotype.

**Survival, growth and development**

The methods to measure survival, growth and development of *C. partellus* on maize have been described by Kumar (1993a, b) [35]. They reported that the percentage of larvae recovered from resistant genotypes Mp704, V 37 and Poza Rica 7832 were significantly lower than the susceptible genotype. Most of the recovered larvae from the susceptible genotype were in the fourth instar and some had advanced to fifth instar stage. On the other hand, the percentage of the larvae recovered from resistant cultivars was less in the fourth instar in comparison to the recovered larvae from susceptible genotypes. These results demonstrated that antibiosis was the mechanism of resistance operating within the resistant genotypes. Similarly, several studies on survival and development of *C. partellus* under laboratory conditions have also been done from Asia (Sharma and Chatterji, 1971, 1972; La1 and Pant, 1980; Durbey and Sarup, 1984; Sekhon and Sajjan, 1987) [62, 25, 58]. The survival, growth and development of *C. partellus* have also been studied through impregnation of dry leaf powders of resistant and susceptible maize genotypes in the artificial diet under laboratory conditions (Kumar, 1993a) [35].

**Orientation behavior**

This response of insect determines it's 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, and (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) due 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) [43]. The role of larval orientation in determining resistance/susceptibility of maize genotypes has not been studied, but *C. partellus* adults have been reported to be attracted equally to the resistant and susceptible genotypes for oviposition (Kumar and Saxena, 1985; Kumar, 1994b) [43]. Kumar (1993a, b) [35] compared four maize genotypes for larval orientation from oviposition to feeding sites. The maize genotypes Mp704 and Poza Rica 7832 seems to possess morphological characteristics which suppress the movement of larvae from oviposition to the feeding sites, thus indicating a non-preference type of mechanism of resistance in these genotypes to *C. partellus*.

**Egg production and viability**

This aspect can be studied by rearing *C. partellus* neonates on the susceptible and resistant genotypes. Single pair of adults emerging from the pupae reared on these genotypes are confined in the oviposition cages to determine the number of eggs laid by the female until it dies. 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) [23, 24]. On the other hand, Sekhon and Sajjan (1987) [62, 58] 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: (i) ballooning of newly hatched larvae moving towards whorl, (ii) ballooning of first and second instars to leave the plant whorl, (iii) walking prior to stem penetration, and (iv) walking after stem penetration. Such differences were clearly observed in movement of *C. partellus* larvae on maize and sorghum (Berger, 1992) [13]. 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) [4, 5, 43]. The studies on dispersal and establishment behavior of *C. partellus* larvae in different maize cultivars revealed that the larval dispersal increased two fold on resistant (ICZ2-CM) surrounded by susceptible genotype (Inbred A), while reverse was the trend when Inbred A was surrounded by genotype, ICZ2-CM (Ampofo, 1985) [4, 5, 43]. But ultimately, more larvae were settled on susceptible (Inbred A) than the resistant genotype, ICZ2-CM.

**Host plant resistance to insects**

The resistance to spotted stem borer, *C. partellus* is expressed as antixenosis, antibiosis and tolerance. Additive gene action determines the resistance to *C. partellus* (Sharma *et al*., 2007). In addition, environmental factors also play a key role in development of resistance to a particular genotype, wherein differential performance of a genotype varies according to environmental conditions, thus making genotype, phenotype and their interaction very crucial for selection of a resistant genotype. Therefore to select a novel insect resistant genotype, it is equally important to rationally expose the test genotypes to varying environmental conditions in addition to optimum insect pressure.

**Sources of spotted stem borer, *C. partellus* resistance**

A more sustainable approach towards controlling insect pests is host plant resistance which can be served as a long term ecofriendly measure (Luginbill, 1969) [47]. Most of the maize varieties released for cultivation shows high degree of susceptibility to *C. partellus* (Kumar, 1997). It has been found that very few genotypes are showing low to moderate resistance to this pest (Chavan *et al*., 2007; Rakshit *et al*., 2008; Sekhar *et al*., 2008) [57, 51, 15]. However, recently several new genotypes of maize have been found with high level of resistance to this pest (Dhillon and Gujar, 2013) [51, 19].

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

All three mechanism of resistance to *C. partellus* are reported to be functional in maize *viz*., non-preference, antibiosis and tolerance (Saxena, 1969) [55]. Various experiments were performed which shows that larval mortality, larval weight and pupal weight were adversely affected on maize genotypes *viz*., Antigua Group 1, Mex 17, Population 590, Population 390 and Ganga 5 when *C. partellus* larvae were reared on these genotypes as compared to susceptible genotypes like Basil Local and Vijay Composite. Some sources of resistance to *C. partellus* have also been reported in the recent past (Kumar and Asino, 1994; Kumar, 1994c; Dhillon and Gujar, 2013) [19]. Larval establishment and damage by *C. partellus* at the time of anthesis in maize has been studied by Kumar (1992b). In context of insect pest management, tolerance is an important form of resistance, but this mechanism of resistance is not operational maize against *C. partellus* (Ampofo, 1986; Kumar, 1994a, b, c) [4, 5, 6].

**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) [32]. Morphological, allele chemcial and biochemical characteristics of a plant determine it's 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 have been found to adversely affect the oviposition preference of *C. partellus* in different maize genotype (Durbey and Sarup, 1982; Ampofo, 1985; Kumar and Saxena, 1985) [23, 24, 4, 5, 43]. Pubescence hairs on upper surface of maize plant also impart oviposition non-preference to *C. partellus* (Kumar, 1992; Van den Berg, 2006). Kumar (1992) developed an inbred line, ICZ-T having trichomes on both the leaf surfaces and found effective in inhibiting oviposition by *C. partellus* females.

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) [32]. No choice tests have been performed to determine level of antibiosis in various maize hybrids (Davis *et al.*, 1989) [17] 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) [43]. The feeding potential of first instar larvae of European corn borer, *Ostrinia nubilalis* (Hubner) on young seedlings of resistant maize genotypes was found reduced due to biochemical factor, 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA). The concentration of DIMBOA in maize plant decreases with plant age (Beck, 1965). 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).

**Biochemical factors of insect resistance**

Apart from various morphological characteristics such as plant height, trichrome, pubescence hair, stem hardiness, leaf texture, glossiness and tassel ratio (Durbey and Sarup, 1982; Kumar, 1997; Rao and Panwar, 2000, 2001) [24, 25, 52], biochemical characteristics *viz.*, tannin, phenol, flavonoids, chlorophyll, carotenoids, protein, sugar, starch have also been reported to be effective for imparting resistance to various insect pests in maize (Kumar and Saxena, 1985; Karbe and Ghoarpade, 1997, 1999; Bhanot *et al.*, 2004; Yele, 2014; Dhillon and Chaudhary, 2015) [14, 43, 20, 74, 18]. The constitutive and/or induced plant metabolic compounds govern the insect-plant interaction, which ultimately leads to plant defense against insects (Sharma, 2009). Host plant quality can be determined by specific allelochemicals, nutrients and anatomical factors present in the host plant (Agrawal 2001; Baldwin *et al*., 2001) [10, 73]. 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) [28]. Anti-nutritional factors like lignin and phenolic compounds also play a major role in plant defense against herbivores (Dhillon *et al.*, 2015; Rasool *et al*., 2017) [54]. The plant chemicals influence the resistance/susceptibility to insect pests in several ways: (i) determining the orientation, feeding and oviposition behaviour of the insects; and (ii) determining the metabolism of insects, which could be either helpful in normal metabolic processes resulting in insect's normal survival, development and egg production or production of plant toxins interfering with survival, development and egg production. 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) [43]. 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) [25].

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) [27, 16, 59, 73, 1]. In plant defense against herbivores, reactive oxygen species (ROS) play a major role and act as secondary messenger for signaling various defense reaction pathways in plants (Low and Merida, 1996; Asada, 2006) [46, 8]. 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 regulated by various antioxidative defense enzyme such as peroxidases (PODs), polyphenol oxidases (PPO), phenylalanine ammonia lyase (PAL), superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase (Gulsen *et al*., 2010; Usha Rani and Jyothsna, 2010; War *et al*., 2011, 2012) [26, 66, 70, 71]. Qualitative or quantitative alteration in phenols and enhanced activity of oxidative enzymes in response to herbivore attack is general phenomenon (Barakat *et al*., 2010) [11], and play major role in plant defense against insect pests (Howe and Jander, 2008; Sharma, 2009) [27].

## Conclusion

The biology, survival, ovipositional response, feeding response could have further implications in understanding the host plant resistance in maize against *C. partellus*. Furthermore, understanding of various induce defense system including antioxidative defense enzyme such as catalase (CAT), tyrosine ammonia lyase (TAL), phenylalanine ammonia lyase (PAL), superoxide dismutase (SOD), ascorbate peroxidase (APX) and catalase can open up new path for the development of resistant/tolerant varieties through molecular breeding approaches by using these enzymes as markers. Metabolic pathways leading to the development of induced resistance can be traced out and upregulation and downregulation of respective genes can be done for the development of resistance varieties which is helpful in ecofriendly approaches of host plant resistance.

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