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Research article

# Bases of resistance in maize against spotted stem borer, *Chilo partellus* (swinhoe)

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## Abstract

Spotted stem borer, *Chilo partellus* is the most ubiquitous and key pest of maize. Once the pest enters the plant tissue, it becomes almost impossible for biological control agents and pesticides to reach the target. Hence, keeping this in view, a search for biophysical and biochemical bases of resistance in maize against *C. partellus* was undertaken for two consecutive years, *i.e.*, *Kharif* 2018 and 2019 at Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut. Studies revealed that the genotypes with maximum leaf trichomes, leaf epidermal silica bodies, stem lignified vascular bundles, phenols, tannins, and with minimum sugars, proteins and chlorophyll content index had showed a negative impact on *C. partellus* damage parameters. Therefore, these biophysical and biochemical traits can be used as markers to identify maize genotypes with resistance to *C. partellus* and further these can be used in resistant breeding program.

**Keywords:** Bases of resistance, Biochemical traits, Biophysical traits, *Chilo partellus*, Damage parameters

## Introduction

Spotted stem borer, *Chilo partellus* is the most common and important pest of maize in *Kharif* season. It also infests bajra, sorghum, rice, millets, sugarcane and some other grasses. This pest has been reported to be the most damaging pest of maize during its early stages of growth around the world (Duale and Nwanze, 1999; Polaszek and Khan, 1998; Sharma and Sharma, 1987). The adult females of *C. partellus* lay eggs in batches parallel to the long axis of the underside of leaves. The first three larval instars feed initially by scrapping in the leaf whorls of growing plants, producing characteristic 'window-panning' and 'pin-holes' like symptoms. The period from egg hatching to the completion of third instar larval stage of *C. partellus* *i.e.* the time when the larva feed externally, lasts for about 10 days. Afterwards, the grown-up larvae bore inside the central shoot, resulting in the production of 'dead hearts' under severe infestation conditions and causing complete loss of the plant. *C. partellus* has been confirmed to cause maize yield losses of 4 to 97 percent in various countries around the world, according to various workers (Reddy and Walker, 1990). *C. partellus* has been reported to cause yield losses of 26.70 to 80.40% in maize in various agro-climatic zones of India (Panwar, 2005; Chatterji *et al*., 1969). Because of the nature of the pest's damage and behavior, it is extremely difficult to control with biological control agents and conventional insecticides. Once the pest has entered plant tissue, it is nearly impossible for pesticides and biological control agents to reach the target. Moreover, the indiscriminate use of pesticides has also caused many problems like the eradication of natural enemies and pollution of the environment along with the development of resistance in the pest. In view of the above constraints there was a need to develop alternative management strategies. Host plant resistance against various pests, including insects, has remained a reliable source for pest management since the advent of modern agriculture. The use of insect-resistant cultivars is an essential component of IPM, which offers an economic, stable, and ecologically sound approach to minimize the damage caused by *C. partellus*.

Variety of plant characteristics are known to render the cultivars unsuitable or less suitable for oviposition, feeding and growth of insect pests. These characteristics are broadly classified into two categories, namely biochemical and biophysical (Dhaliwal and Arora, 2001). In a plant defense mechanism, these biophysical and biochemical characteristics play a key role in *C. partellus* infestation in maize (Ali *et al*., 2015; Jyothi, 2016; Lokesh and Mehla, 2017; Rasool *et al*., 2017). The resistant mechanisms related to biophysical plant characteristics impair normal oviposition or feeding by insects or contribute to the action of other mortality factors are together called phonetic resistance. The biophysical characteristics of the host plant may also influence the nutrition of the insect by limiting the amount of feeding due to shape, color, or texture, which may limit the ingestion of the nutritive material and influence the digestibility and utilization of food by the insect (Kogan, 1994). The resistant mechanisms related to biochemical constituents, both in terms of quantities and proportions to each other in the host plant, have a great influence on the growth, development, survival and reproduction of insects. More importantly, the performance and abundance of herbivores are attributed to the variations in host plant quality being determined by nutritional composition (Dhillon and Chaudhary, 2015). Keeping this in view, an investigation was undertaken to identify the biophysical and biochemical traits of maize responsible for resistance to *C. partellus*.

## Materials and Methods

***Study site and design:*** A field experiment was conducted to screen maize genotypes against *C. partellus* damage under unprotected natural conditions during *Kharif* 2018 and 2019. Further, the biophysical and biochemical traits of maize genotypes were analyzed in the laboratory to understand the biophysical and biochemical bases of resistance against *C. partellus*. The maize genotypes were obtained from the ICAR-Indian Institute of Maize Research, New Delhi. The experiment was conducted in a randomized block design with three replications. Each genotype was planted in two rows. The length of each row was 6.0 m and the row-to-row and plant-to-plant distances were kept as 60 cm and 30 cm, respectively. All the recommended agronomic practices were adopted to raise good crops, except using any plant protection measures. For the current investigation, the field tests were led at the Crop Research Centre (CRC) and lab tests were directed at the College of Agriculture, Sardar Vallabhbhai Patel University of Agriculture and Technology.

***Damage parameters:*** Eighteen genotypes of maize were screened under field conditions and evaluated for their relative susceptibility to *C. partellus* (Swinhoe) during *Kharif* 2018 and 2019. Genotypic variation of relative susceptibility was assessed by using damage parameters such as leaf injury rating and stem tunnel length. Leaf injury rating was recorded for ten randomly selected plants individually in each genotype per replication on the rating scale of 1 to 9 at 45 days after sowing (Sarup *et al*., 1978). The mean leaf injury rating per plant was calculated by dividing the total number of plants. The mean of replication was taken as the overall reaction of the pest to a particular genotype. Based on leaf injury rating, the maize genotypes were further categorized into three distinct groups of susceptibility to *Chilo partellus, i.e.*, (i) least susceptible with mean leaf injury rating <3, (ii) moderately susceptible with mean leaf injury rating 3 to 6, (iii) highly susceptible with mean leaf injury rating >6 (Kumar *et al*., 2012).

Ten randomly selected plants per replication were also uprooted at the time of harvest from each genotype for recording data on stem tunnel length. The stems were split opened for recording the tunnel made by the larvae of *C. partellus*. Accordingly, the average stem tunnel length per plant was calculated. Based on the tunnel length caused by the larvae of *C. partellus*, different maize genotypes were grouped under the following 3 categories: (i) least susceptible with mean tunnel length ranges between 0 to 5 cm (ii) moderately susceptible with mean tunnel length ranges between >5 to 10 cm (iii) highly susceptible with mean tunnel length more than 10 cm (Lella and Srivastav, 2013).

***Biophysical traits:*** The observations on biophysical traits such as leaf epidermal silica bodies and stem lignified vascular bundles in each genotype were recorded following standard procedures (Johansen, 1940) on 45 days old crop during *Kharif* 2018 and 2019. The number of trichomes per square cm leaf area was counted by using a binocular compound microscope at 100 x magnification. These biophysical traits were recorded on five randomly selected plants of each genotype in each replication, and the average was calculated. The biophysical traits were correlated with the damage parameters of *C. partellus* to determine their role in resistance/susceptibility.

***Biochemical traits:*** To study the biochemical traits *viz*., phenol, tannin, sugar and protein, samples of the whole maize plants from each plot were collected 45 days after sowing during *Kharif* 2018 and *Kharif* 2019. These samples were taken into the laboratory, rinsed with distilled water, and left out in the open air for three hours in the shade. These samples were kept for 48 hours in a hot air oven at $35^0$C. The oven-dried samples were chopped up, grounded with a blender, sieved through a one mm sieve, and stored in zip-lock plastic bags in the refrigerator for further analysis. The phenol content, tannin content, protein content and sugar content in whole maize plants of different treatments were estimated as per the method developed by Malick and Singh (1980), Burns (1971), Lowry *et al*. (1951), and Hodge and Hofreiter (1962), respectively. The leaf chlorophyll content was estimated non-destructively by measuring leaf greenness using a handheld SPAD-502 Plus Chlorophyll Content Meter (Konica Minolta Optics, Inc. Japan). The biochemical constituents analyzed were correlated with the damage parameters of *C. partellus* to determine their role in resistance/ susceptibility.

***Statistical analysis:*** The data collected from different experiments on various parameters were statistically analyzed using the procedure described by Gomez and Gomez (1984). The 'F' test was applied at 5% level of significance. The data on correlation studies were analyzed by using SPSS software.

## Results and Discussion

### *Damage parameters*

***Leaf injury rating:*** During *Kharif* 2018, mean leaf injury rating score ranged from 1.97 to 7.13 (Table 1). Out of 18 genotypes screened, five genotypes *viz*., Vivek Hybrid 25 (1.97), Vivek Hybrid 9 (2.20), Wasc (2.57), HQPM 4 (2.87) and Vivek Hybrid 39 (2.83) were grouped under least susceptible category. The genotypes HQPM 8 (3.10), Vivek Hybrid 43 (3.40), HQPM 1 (3.53), Narmada Moti (3.77), Vivek Hybrid 27 (4.23), Shaktiman 3 (4.23), Vivek Hybrid 33 (4.67), HQPM 5 (4.90) and DHM 117 (5.53) were grouped under moderately susceptible category. However, four genotypes *viz*., African Tall (6.43), Shaktiman 5 (6.57), Parkash (6.87) and Shaktiman 2 (7.13) were grouped under the highly susceptible category.

In the succeeding year, *i.e*., *Kharif* 2019, the mean leaf injury rating score ranged from 1.83 to 6.87 (Table 1). Out of 18 genotypes screened, six genotypes *viz*., Vivek Hybrid 9 (1.83), Vivek Hybrid 25 (2.03), Wasc (2.33), HQPM 4 (2.70), Vivek Hybrid 39 (2.73) and HQPM 8 (2.93) were grouped under least susceptible category. The genotypes HQPM 1 (3.27), Vivek Hybrid 43 (3.43), Narmada Moti (3.57), Vivek Hybrid 27 (4.00), Shaktiman 3 (4.23), Vivek Hybrid 33 (4.57), HQPM 5 (4.77) and DHM 117 (5.03) were grouped under moderately susceptible category. However, four genotypes *viz*., African Tall (6.07), Shaktiman 5 (6.33), Parkash (6.70) and Shaktiman 2 (6.87) were grouped under the highly susceptible category.

The current findings are nearly identical to those of Kumar *et al*. (2017), who observed that leaf injury scores varied from 2.3 to 6.6 among different genotypes. Prasad *et al*. (2015) reported a leaf damage score of 4.7 to 8.3 in different genotypes. Rasool (2015) and Lella and Srivastav (2013) found leaf damage scores of 0.33 to 3.26, 0.60 to 7.26, 0.86 to 8.86, and 1 to 2.2, 1.4 to 4.2, 2.6 to 6.6 at 20, 30, 40 DAS and 20, 30, 60 DAS, respectively in different maize genotypes, which also supported our findings. The results showed that *C. partellus* had varying degrees of feeding pattern on the various maize genotypes; this might be due to the different specific biophysical and biochemical traits of the host-plant contributing towards the food preference levels of the pest.

***Stem tunnel length per plant:*** The data generated on the basis of mean stem tunnel length during *Kharif* 2018, ranged between 3.86 to 22.18 cm (Table 1). Wasc (3.86 cm), Vivek Hybrid 9 (4.82 cm) and Vivek Hybrid 25 (4.88 cm) were classified as the least susceptible genotypes. Whereas HQPM 4 (5.07 cm), HQPM 8 (5.15 cm), Vivek Hybrid 39 (5.96 cm), HQPM 1 (6.22 cm), Vivek Hybrid 43 (9.07 cm), Shaktiman 3 (9.34 cm), Narmada Moti (9.47 cm) and Vivek Hybrid 27 (9.78 cm) as moderately susceptible genotypes. However, Vivek Hybrid 33 (11.34 cm), DHM 117 (11.82 cm), HQPM 5 (12.24 cm), African Tall (16.44 cm), Shaktiman 2 (19.96 cm), Parkash (22.18 cm) and Shaktiman 5 (22.18 cm) were grouped in highly susceptible category.

During the next year, *i.e*., *Kharif* 2019, the stem tunnel length varied from 3.57 to 19.16 cm (Table 1). Wasc (3.57 cm), Vivek Hybrid 25 (3.96), Vivek Hybrid 9 (4.14 cm), HQPM 4 (4.25 cm) and HQPM 8 (4.77 cm) were classified as least susceptible genotypes. Whereas Vivek Hybrid 39 (6.12 cm), HQPM 1 (6.16 cm), Vivek Hybrid 43 (6.87 cm), Narmada Moti (7.63 cm), Shaktiman 3 (7.85 cm), Vivek Hybrid 33 (9.56 cm), Vivek Hybrid 27 (9.78 cm), DHM 117 (10.00 cm) as moderately susceptible genotypes. However, HQPM 5 (11.14 cm), African Tall (12.73 cm), Shaktiman 2 (18.32 cm), Parkash (18.85 cm) and Shaktiman 5 (19.16 cm) were grouped in a highly susceptible category.

These findings were consistent with those of Bhandari *et al*. (2016), who found that stem tunneling in different maize genotypes ranged from 3.2 to 22.5 cm and 4.2 to 20.4 cm on 0 to >10 cm scale for two consecutive years. Lella and Srivastav (2013), Rasool (2015) and Kumar *et al*. (2017) classified maize genotypes based on stem tunneling (0 to >10 cm scale) against *C. partellus*, resulting in significant variations.

### *Biophysical traits*

***Density of leaf trichomes:*** During *Kharif* 2018 and *Kharif* 2019 mean trichome density in various genotypes ranged from 37.71 to 78.96/cm$^2$ and 34.89 to 83.18/cm$^2$, respectively (Table 2). The relationship between trichome density and *C. partellus* damage parameters showed a highly significant negative correlation. Correlation coefficient values (r) for trichome density was -0.863 and -0.771 with leaf injury rating and -0.876 and -0.758 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. It indicated that resistance was increased with increasing trichome density in the majority of the genotypes. This finding was supported by the findings of Ali *et al*. (2015), Jyothi (2016), Nadeem *et al*. (2016), Rasool *et al*. (2017)

**Table 1.** Relative susceptibility of different maize genotypes to *C. partellus* on the basis of leaf injury rating (LIR) and stem tunnel length (STL)

| S. No | Genotypes | Leaf injury rating | | | | Stem tunnel length (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Kharif* 2018 | | *Kharif* 2019 | | *Kharif* 2018 | | *Kharif* 2019 | |
| | | LIR | Category | LIR | Category | STL | Category | STL | Category |
| 1 | African Tall | 6.43 | HS | 6.07 | HS | 16.44 | HS | 12.73 | HS |
| 2 | Narmada Moti | 3.77 | MS | 3.57 | MS | 9.47 | MS | 7.63 | MS |
| 3 | Wasc | 2.57 | LS | 2.33 | LS | 3.86 | LS | 3.57 | LS |
| 4 | DHM 117 | 5.53 | MS | 5.03 | MS | 11.82 | HS | 10.00 | MS |
| 5 | Parkash | 6.87 | HS | 6.70 | HS | 22.18 | HS | 18.85 | HS |
| 6 | HQPM 1 | 3.53 | MS | 3.27 | MS | 6.22 | MS | 6.16 | MS |
| 7 | HQPM 4 | 2.87 | LS | 2.70 | LS | 5.07 | MS | 4.25 | LS |
| 8 | HQPM 5 | 4.90 | MS | 4.77 | MS | 12.24 | HS | 11.14 | HS |
| 9 | HQPM 8 | 3.10 | MS | 2.93 | LS | 5.15 | MS | 4.77 | LS |
| 10 | Vivek Hybrid 9 | 2.20 | LS | 1.83 | LS | 4.82 | LS | 4.14 | LS |
| 11 | Vivek Hybrid 25 | 1.97 | LS | 2.03 | LS | 4.88 | LS | 3.96 | LS |
| 12 | Vivek Hybrid 27 | 4.23 | MS | 4.00 | MS | 9.78 | MS | 9.78 | MS |
| 13 | Vivek Hybrid 33 | 4.67 | MS | 4.57 | MS | 11.34 | HS | 9.56 | MS |
| 14 | Vivek Hybrid 39 | 2.83 | LS | 2.73 | LS | 5.96 | MS | 6.12 | MS |
| 15 | Vivek Hybrid 43 | 3.40 | MS | 3.43 | MS | 9.07 | MS | 6.87 | MS |
| 16 | Shaktiman 2 | 7.13 | HS | 6.87 | HS | 19.96 | HS | 18.32 | HS |
| 17 | Shaktiman 3 | 4.23 | MS | 4.23 | MS | 9.34 | MS | 7.85 | MS |
| 18 | Shaktiman 5 | 6.57 | HS | 6.33 | HS | 22.18 | HS | 19.16 | HS |
| SEM | | 0.17 | - | 0.22 | - | 0.70 | - | 0.72 | - |
| CD (P<0.05) | | 0.48 | - | 0.63 | - | 2.02 | - | 2.07 | - |
| CV (%) | | 6.80 | - | 9.26 | - | 11.53 | - | 13.65 | - |

LS: Least susceptible; MS: Moderately susceptible; HS: Highly susceptible

and Singh (2018), who reported a negatively significant correlation between trichome density and *C. partellus* infestation.

These results were also consistent with that of Rao and Panwar (2000), who found a significant negative correlation between trichome density and leaf injury score and reported that trichome density was the main factor of resistance in maize against *C. partellus*. Similarly, Kumar (1992) reported plant damage by herbivore insects generally decreases with an increase in trichome density and suggested that such maize cultivars could be of great practical utility in the breeding program of maize for the development of resistant varieties to *C. partellus.* Kumar (1997) also reported that *C. partellus* ovipositional non-preference for maize genotypes was due to the presence of maximum trichomes. Furthermore, War *et al.* (2012) reported that trichomes play an important role in plant defense against a variety of insect pests, with both deterrent and toxic effects. Trichome density had a negative impact on insect's feeding, ovipositional behavior and larval nutrition. Furthermore, dense trichomes had a mechanical effect on herbivory by interfering with the movement of insects on the plant surface, thereby limiting their ability to access the epidermis of the leaves.

***Density of leaf epidermal silica bodies:*** The data generated on density of leaf epidermal silica bodies of various maize genotypes during *Kharif* 2018 and *Kharif* 2019 ranged between 143.09 to 261.38 and 147.69 to 276.29, respectively (Table 2). A negative and significant correlation was observed between density of leaf epidermal silica bodies and *C. partellus* damage parameters. Correlation coefficient values (r) for density of leaf epidermal silica bodies was -0.757 and -0.695 with leaf injury rating and -0.749 and -0.723 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. The present study falls in line with Rao (1998) who reported a significant negative correlation between the

**Table 2.** Biophysical traits of different maize genotypes and their correlation with *C. partellus* damage parameters

| S. No | Genotypes | Trichome density ($cm^2$) | | Leaf epidermal silica bodies (per microscopic view) | | Lignified vascular bundles (per microscopic view) | |
|---|---|---|---|---|---|---|---|
| | | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 |
| 1 | African Tall | 51.33 | 46.31 | 207.89 | 212.73 | 25.60 | 23.20 |
| 2 | Narmada Moti | 62.53 | 71.00 | 184.36 | 191.36 | 26.20 | 29.33 |
| 3 | Wasc | 73.80 | 79.22 | 238.91 | 235.27 | 30.00 | 34.27 |
| 4 | DHM – 117 | 53.38 | 55.38 | 165.49 | 158.93 | 21.13 | 21.47 |
| 5 | Parkash | 37.71 | 40.91 | 157.29 | 172.76 | 15.07 | 17.07 |
| 6 | HQPM 1 | 66.40 | 58.27 | 238.67 | 253.56 | 30.20 | 34.00 |
| 7 | HQPM 4 | 78.96 | 83.18 | 236.96 | 248.40 | 34.60 | 37.13 |
| 8 | HQPM 5 | 46.40 | 39.56 | 143.09 | 155.49 | 19.33 | 17.53 |
| 9 | HQPM 8 | 76.62 | 75.24 | 254.93 | 270.71 | 32.60 | 31.20 |
| 10 | Vivek Hybrid 9 | 71.73 | 68.42 | 250.51 | 229.07 | 26.00 | 29.73 |
| 11 | Vivek Hybrid 25 | 68.51 | 76.11 | 223.46 | 221.33 | 27.53 | 33.40 |
| 12 | Vivek Hybrid 27 | 56.22 | 51.87 | 229.49 | 216.71 | 19.20 | 21.13 |
| 13 | Vivek Hybrid 33 | 48.86 | 34.89 | 168.22 | 173.62 | 20.07 | 21.47 |
| 14 | Vivek Hybrid 39 | 58.27 | 61.18 | 261.38 | 257.42 | 23.13 | 25.93 |
| 15 | Vivek Hybrid 43 | 73.11 | 75.31 | 254.13 | 276.29 | 21.67 | 25.00 |
| 16 | Shaktiman 2 | 46.75 | 44.71 | 171.38 | 177.33 | 13.60 | 16.40 |
| 17 | Shaktiman 3 | 62.07 | 70.36 | 233.73 | 241.13 | 21.27 | 25.60 |
| 18 | Shaktiman 5 | 42.02 | 49.93 | 165.76 | 147.69 | 15.73 | 14.07 |
| SEM | | 3.21 | 3.77 | 13.55 | 12.60 | 2.08 | 1.98 |
| CD (P<0.05) | | 9.23 | 10.83 | 38.94 | 36.23 | 5.99 | 5.70 |
| CV (%) | | 9.32 | 10.86 | 11.16 | 10.23 | 15.35 | 13.51 |
| Correlation coefficient (r) with leaf injury rating | | -0.863** | -0.771** | -0.757** | -0.695** | -0.744** | -0.851** |
| Correlation coefficient (r) with stem tunnel length | | -0.876** | -0.758** | -0.749** | -0.723** | -0.802** | -0.884** |

**($p < 0.01$)

density of leaf epidermal silica bodies and leaf injury score of *C. partellus*. Sharma and Chatterji (1971) in maize and Khurana (1980) in sorghum also found a negative relationship between *C. partellus* susceptibility to maize and silica content. Narwal (1973) and Abdalla (2015) also studied the density of silica bodies in the leaves of sorghum and maize against *C. partellus* infestation, respectively and reported that the genotypes with the highest densities of silica bodies were resistant to insect attack compared to that of susceptible check. The occurrence of silica bodies in the epidermis of leaves could offer mechanical resistance to *C. partellus* larval feeding through the destruction of mandibles. Kind (1954) found that high *silica* content might be an obstacle to utilizing plant nutrients by borers since the actions of trypsin, pepsin, amylase, acetyl choline esterase, urease and phosphatase are inhibited by dissolved silica. In this way the mechanism of antixenosis and antibiosis might act on the *C. partellus* larvae when they feed on genotypes with more leaf epidermal silica bodies.

***Density of stem lignified vascular bundles:*** In *Kharif* 2018 and *Kharif* 2019 the number of stem lignified vascular bundles per microscopic view at 100x magnification for all the genotypes varied from 13.60 to 34.60 and 14.07 to 37.13, respectively (Table 2). Correlation studies between a number of stem lignified vascular bundles and *C. partellus* damage parameters resulted in a significant and negative relationship. Correlation coefficient values (r) for stem lignified vascular bundles was -0.744 and -0.851 with leaf injury rating and -0.802 and -0.884 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. Rao (1998) also observed a significant negative correlation between stem-lignified vascular bundles and leaf injury score by *C. partellus*, indicating that resistant varieties had more stem-lignified vascular bundles compared to susceptible varieties. The presence of lignin in the cell walls of vascular bundles gives more strength and hardness to the stem. The presence of more lignified vascular bundles in resistant varieties might be obstructing the larval penetration into the stem.

## Biochemical traits

***Phenols:*** During *Kharif* 2018 and *Kharif* 2019 phenol content in various genotypes ranged from 236.87 to 697.84 mg/100 g and 252.25 to 706.58 mg/100 g, respectively (Table 3). Phenol content of various maize genotypes showed a highly significant negative correlation with *C. partellus* damage parameters, indicating that as phenol content increased, infestation by *C. partellus* decreased. Correlation coefficient values (r) for phenol content was -0.965 and -0.958 with leaf injury rating and -0.900 and -0.921 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. The results were consistent with those of Jyothi (2016) and Rasool *et al*. (2017) who reported that phenols are negatively correlated with *C. partellus* damage and are responsible for imparting resistance against pests. These findings were also consistent with the findings of Bergvinson (1993), Santiagoa *et al*. (2005) and Rios *et al.* (2011), who discovered that total phenols enhance resistance to the stem borer.

Praveen *et al.* (2013) conducted an investigation on biochemical changes during infestation of *C. partellus* on varieties of maize and noticed that phenol content was higher in resistant varieties compared to susceptible varieties during crop growth in vegetative parts of the plant. Lokesh and Mehla (2017) studied the antibiosis mechanism. They reported that the total life span of C. partellus increased with increase in phenol content of maize. Further, he observed that phenols exhibited negative and significant correlation with the per cent larvae completing life cycle. Dhillon and Chaudhary (2015) reported that phenolic acids *viz.*, p-coumaric acid and ferulic acid, had a significant negative correlation with *C. partellus* pupal period, and further suggested that maize plant defense towards *C. partellus* might be due to concentration of a specific biochemical substance or interaction with various biochemical compounds.

War *et al.* (2012) reported that plant phenols are one of the most prevalent and widespread groups of defensive chemicals in secondary metabolites, which plays an important role in the resistance of host plants to insects. Phenols protect plants not only from insects but also from competing plants and microorganisms. In response to insect attacks, there are quantitative and qualitative changes in phenols, as well as an increase in the activities of oxidative enzymes. Lignin, a phenolic heteropolymer, is important in plant defense against pathogens and insects. It increases the leaf toughness, which reduces insect feeding and decreases the nutritional content of the leaf. Peroxidase (POD) and polyphenol oxidase (PPO) catalyse the oxidation of phenols, which is a potential defence mechanism in plants against insects. Quinones, which are formed by the oxidation of phenols, bind to leaf proteins covalently and inhibit protein digestion in insects. In addition, quinones are directly toxic to insects. Phenol content has been shown to play a vital role in influencing a host's susceptibility or resistance to insect infestations. They are linked to insect feeding deterrence or growth inhibition. When phenolics are present in sufficient quantities, insect pests are deterred by direct toxicity and adults' preference for oviposition is reduced (Prasad and Anjani, 2001).

***Tannins:*** The data generated on tannin content of various maize genotypes during *Kharif* 2018 and *Kharif* 2019, ranged between 84.76 to 287.30 mg/100 g and 72.84 to 313.52 mg/100 g, respectively (Table 3). Tannin content and *C. partellus* damage parameters were found to have a negative and highly significant correlation. Correlation coefficient values (r) for tannin content was -0.903 and -0.948 with leaf injury rating and -0.846 and -0.902 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. Thus, from the present results it was clear that as the tannin content increased infestation by the *C. partellus* decreased. The findings of this study were similar to those of Praveen *et al.* (2013) and Khurana and Verma (1983), who investigated the function of tannins in *C. partellus* resistance on maize and sorghum, respectively. Tannins were also associated with repellency or deterrency and jointly contributed to the protection of plant along with other phytochemicals like phenols (Chiang and Norris, 1983).

***Sugars:*** In *Kharif* 2018 and *Kharif* 2019, the sugar content for all the genotypes varied from 1.07 to 3.41% and 1.22 to 3.37%, respectively (Table 3). Correlation studies between sugar content and *C. partellus* damage parameters established a significant and positive relationship. Correlation coefficient values (r) for sugar content was 0.599 and 0.678 with leaf injury rating and 0.514 and 0.612 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. This was in agreement with Kabre and Ghorpade (1999) who reported positive correlation of total sugars with stem borer infestation. These results also indicated that susceptibility to *C. partellus* increased with increased sugar content. This was consistence with the reports of Arabjafari and Jalali (2007), Praveen *et al.* (2013), Dhillon and Chaudhary (2015) and Lokesh and Mehla (2017), who reported that increased levels of sugars contributed to increase stem borer susceptibility in maize. Sugar is one of the most important nutrients for plants, and sugar contents reflects the metabolic state of the maize tissue, so differences in relative sugar amounts between genotypes with different

**Table 3.** Biochemical traits of different maize genotypes and their correlation with *C. partellus* damage parameters

| S. No | Genotypes | Phenol content (mg/100 g) | | Tannin content (mg/100 g) | | Sugar content (%) | | Protein content (%) | | Chlorophyll content index (CCI) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 | *Kharif* 2018 | *Kharif* 2019 |
| 1 | African Tall | 345.83 | 372.14 | 158.87 | 129.89 | 3.22 | 3.37 | 9.75 | 10.08 | 49.74 | 52.11 |
| 2 | Narmada Moti | 562.41 | 537.83 | 144.31 | 162.56 | 1.46 | 1.45 | 11.03 | 12.78 | 52.38 | 49.52 |
| 3 | Wasc | 667.69 | 674.22 | 253.00 | 304.28 | 1.91 | 1.76 | 8.53 | 9.87 | 42.74 | 47.20 |
| 4 | DHM – 117 | 309.31 | 332.24 | 127.96 | 115.93 | 2.15 | 2.39 | 11.28 | 11.45 | 58.26 | 58.77 |
| 5 | Parkash | 277.69 | 291.93 | 100.57 | 81.06 | 2.74 | 3.18 | 12.35 | 12.04 | 62.16 | 56.73 |
| 6 | HQPM 1 | 444.92 | 465.15 | 219.57 | 242.60 | 1.98 | 1.84 | 10.75 | 10.91 | 49.16 | 51.60 |
| 7 | HQPM 4 | 591.45 | 622.64 | 235.11 | 255.57 | 2.54 | 2.56 | 11.63 | 13.22 | 52.24 | 52.68 |
| 8 | HQPM 5 | 382.24 | 368.74 | 123.12 | 138.14 | 3.41 | 3.11 | 12.61 | 14.26 | 60.45 | 55.43 |
| 9 | HQPM 8 | 602.18 | 584.95 | 188.74 | 214.17 | 1.97 | 2.08 | 10.69 | 10.37 | 43.93 | 50.48 |
| 10 | Vivek Hybrid 9 | 697.84 | 694.35 | 258.54 | 286.49 | 1.52 | 1.60 | 8.26 | 10.46 | 44.58 | 45.60 |
| 11 | Vivek Hybrid 25 | 688.27 | 706.58 | 287.30 | 313.52 | 1.40 | 1.22 | 12.72 | 13.69 | 51.63 | 50.36 |
| 12 | Vivek Hybrid 27 | 476.28 | 483.88 | 195.19 | 184.00 | 1.57 | 1.71 | 10.84 | 11.76 | 47.08 | 47.53 |
| 13 | Vivek Hybrid 33 | 443.70 | 438.52 | 132.43 | 147.86 | 1.77 | 1.85 | 12.44 | 13.84 | 52.46 | 50.31 |
| 14 | Vivek Hybrid 39 | 618.97 | 609.59 | 242.93 | 234.23 | 1.52 | 1.36 | 9.37 | 9.14 | 44.27 | 47.76 |
| 15 | Vivek Hybrid 43 | 545.48 | 558.78 | 235.43 | 220.17 | 1.07 | 1.41 | 9.68 | 8.73 | 46.76 | 43.43 |
| 16 | Shaktiman 2 | 236.87 | 252.25 | 84.76 | 87.00 | 2.32 | 2.13 | 11.90 | 11.88 | 55.81 | 53.32 |
| 17 | Shaktiman 3 | 529.12 | 544.18 | 151.45 | 155.79 | 1.63 | 1.57 | 10.81 | 10.64 | 51.32 | 51.90 |
| 18 | Shaktiman 5 | 284.86 | 268.97 | 102.27 | 72.84 | 2.27 | 2.63 | 10.96 | 10.16 | 48.79 | 50.45 |
| SEM | | 14.56 | 12.75 | 8.31 | 7.59 | 0.07 | 0.10 | 0.21 | 0.36 | 2.76 | 3.27 |
| CD (P<0.05) | | 41.85 | 36.65 | 23.88 | 21.82 | 0.21 | 0.28 | 0.62 | 1.04 | 7.94 | 9.38 |
| CV (%) | | 5.22 | 4.51 | 7.99 | 7.07 | 6.35 | 8.14 | 3.42 | 5.48 | 9.43 | 11.12 |
| Correlation coefficient (r) with leaf injury rating | | -0.965** | -0.958** | -0.903** | -0.948** | 0.599** | 0.678** | 0.382$^{NS}$ | 0.087$^{NS}$ | 0.612** | 0.580* |
| Correlation coefficient (r) with stem tunnel length | | -0.900** | -0.921** | -0.846** | -0.902** | 0.514* | 0.612** | 0.383$^{NS}$ | 0.074$^{NS}$ | 0.580* | 0.478* |

**(P<0.01); *(P< 0.05); NS: Non-significant susceptibilities suggested that these substances could act as phagostimulants to *C. partellus* when it feeds on maize.

***Proteins:*** Protein content of various genotypes during *Kharif* 2018 and *Kharif* 2019, varied between 8.26 to 12.72% and 8.73 to 14.26%, respectively (Table 3). Protein content had showed a non-significant positive correlation with *C. partellus* damage parameters. The correlation coefficient values (r) for protein content was 0.382 and 0.087 with leaf injury rating and 0.383 and 0.074 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. Thus, it was clear that protein content of tested genotypes did not play any role in offering resistance or susceptibility with *C. partellus* infestation. However, Kabre and Ghorpade (1999), Rao and Panwar (2002), Ali *et al*. (2015) and Jyothi (2016) reported a positive and significant correlation between proteins and *C. partellus* infestation. The acceptability and utilization of maize genotypes with higher protein content by *C. partellus* might be limited due to the presence of high levels of phenols and tannins. This might have been the reason for the differences between the results of present and earlier investigations.

***Chlorophyll content index:*** During *Kharif* 2018 and *Kharif* 2019 chlorophyll content index in various genotypes ranged from 42.74 to 62.16 and 43.43 to 58.77, respectively (Table 3). The chlorophyll content index of various maize genotypes showed positive correlation with *C. partellus* damage parameters. Correlation coefficient values (r) for chlorophyll content index was 0.612 and 0.580 with leaf injury rating and 0.580 and 0.478 with stem tunnel length during *Kharif* 2018 and *Kharif* 2019, respectively. The results of the present study could be supported by the findings of Rao and Panwar (2002), Abdalla (2015) and Dhillon and Chaudhary (2015), who found that the chlorophyll content was distinctly low in resistant cultivars compared to susceptible ones. The lower amount of chlorophyll in the leaves of resistant genotypes turns them yellowish green and probably makes them unattractive for oviposition to *C. partellus*. This might be the reason for the decreased infestation of *C. partellus* in genotypes with less chlorophyll content.

## Conclusion

From the results of the biophysical and biochemical basis of resistance, it was inferred that the genotypes with maximum leaf trichomes, leaf epidermal silica bodies, stem lignified vascular bundles, phenols and tannins, and with minimum sugars and chlorophyll are not chosen by *C. partellus* for food, shelter or oviposition because of either the absence of desirable characters in that plant like texture, taste, flavor, or presence of undesirable characters. Further the absence of desirable characters or presence of undesirable characters in host plant results in reduced fecundity, decreased size, long life cycle, failure of larva to pupate or failure of adult emergence and increased mortality of insects. Indirectly, these biophysical and biochemical traits might result in increased exposure of the insect to its natural enemies and help in the improvement of tritrophic interactions. Therefore, these biophysical and biochemical traits can be used as markers to identify the resistance sources of maize with different mechanisms of resistance against *C. partellus*. This finding can be used very effectively in *C. partellus* resistant breeding program.

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