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Identification and Analysis of Host Plant Resistance in Leading Maize Genotypes Against Spotted Stem Borer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae)

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Abstract: Twenty six popular varieties of maize in Karnataka state (India) were screened for resistance to *Chilo partellus* (Swinhoe). In field trial, varieties CM132, CM137 and PMZ103 showed the highest level of resistance, respectively. While the varieties GK3014, HY4642 and DK984 had the lowest level of resistance, respectively. In glasshouse trial, the varieties CM137 and HY4642 had the highest and lowest level of resistance. A positive correlation equal to +0.111 (in field) and +0.521 (in glasshouse) was found between the Leaf Injury Score (LIS) and Stem Diameter (SD). Meanwhile, negative correlation equal to -0.432 (in field) and -0.896 (in glasshouse) was found between Leaf Injury Score (LIS) and Internodal Distance (InD). Results of the studies on major nutritional elements on resistant variety CM137 and susceptible variety HY4642 indicated higher percentage of P, K, Fe and Si in stem tissues of the variety CM137, while the variety HY4642 had higher percentage of N and Sugar, highlighting the role of these elements in conferring resistance and susceptibility to *C. partellus*. Studies on the impact of resistance factors on biological events of *C. partellus* revealed significant differences between percentage survival of larvae, percentage of pupation, pupal weight and pupal period (females only) on two varieties CM137 and HY4642. But there was no significant difference in the percentage of moth emergence on two varieties.

Key words: Spotted stem borer, *Chilo partellus*, maize, host plant resistance, stem diameter, internodal distance

INTRODUCTION

Maize is attacked by more than 140 insect species causing different degrees of damage, but only about 10 species impose serious and economic damage. These infest maize from the time of sowing to harvest and even in storage places. The damage may be caused by certain insects attacking roots (rootworms, wireworms, white grubs and seed-corn maggots), leaves (aphids, armyworm, stem borers, thrips, spider mites and grasshoppers), stalks (stem borers, termites), ears and tassels (stem borers, earworms, adult rootworms and armyworm) and grain during storage (grain weevils, grain borers, Indian meal moth and the Angoumois grain moth). Insect damage can occur at any stage of maize production and storage. Its severity depends on germplasm used, cultivation practices, levels of pest infestation, control strategies used and climate.

The Spotted Stem Borer (SSB), *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae) is an important pest of maize in several countries of Asia and Africa.

Siddiqui and Marwaha (1993) have mentioned India, Afghanistan, Bangladesh, East Africa, Iraq, Japan, Indonesia, Nepal, Malawi, Pakistan, Sudan, Taiwan, Thailand and Uganda as distribution areas of *C. partellus*.

The losses due to this pest have been reported to vary from 24 to 75% (Latif *et al*., 1960; Chatterjee *et al*., 1970).

Besides maize and sorghum, finger millet, sugarcane, Johnson grass, *Saccharum* sp. Job's tears (*Coix lachrymal-jobi*), *Polytoca burbata*, *Eragrostis* sp., *Eleusine verticilliata* and *Trianthema monogyma* have been recorded as host plants of *C. partellus* (Fletcher, 1919; Rahman, 1940; Trehan and Butani, 1949; Vishakantaiah and Gowda, 1974).

The nature of damage and the behavior of this insect makes it very difficult to be managed by using conventional chemical insecticides and biological methods. Because once the larvae enter the plant tissue, they would be out of reach of most insecticides and biological control agents. Chemicals can be effective only for a very short period, when the first instar larvae feed on leaf surface, Egg hatching in a field is not synchronized and neonate larvae can be seen almost any time during the growing season. Consequently, a full chemical control on the pest demands spraying for every 3-4 days which is costly, harmful and practically impossible.

Keeping in view above mentioned obstacles, the use of resistant varieties of maize for management of Spotted Stem Borer, *Chilo partellus* seems to be the most

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acceptable option. Hence, it was proposed to identify and analyze host plant resistance components in the leading maize genotypes against this dreaded pest. Further, this approach, from the farmer's point of view is most economical and sustainable in addition to being highly acceptable ecologically and environmentally. Hence, many entomologists in collaboration with other scientists are working in this line recently.

Several workers have tried to find mechanisms conferring resistance to maize plants. The role of trichomes in inhibiting oviposition by *C. partellus* has been experimentally demonstrated by Kumar and Saxena (1985).

The mechanisms and bases of resistance in maize to spotted stem borer, *C. partellus*, in India were reported by Sekhon *et al*. (1997).

Songa *et al*. (2001) reported that plants with good physical characteristics had significantly more resistance to spotted stem borer, resulting in increased grain yield.

Economic benefits occur because crop yields are saved from loss due to insect pests and money is saved by not applying insecticides that would have been applied to susceptible varieties. In most cases, seeds of insect-resistant cultivars are affordable by farmers, as the cost is just the same or little more, than for susceptible cultivars. Ecological and environmental benefits arise from increasing in species diversity in the agro ecosystem, in part because of reduced use of insecticides. Increases in species diversity increase ecosystem stability which promotes a more sustainable system far less polluted and detrimental to natural resources.

Realizing the importance of stem borer, *Chilo partellus* (Swinhoe) in India and neighboring countries, an attempt has been made to find out important mechanisms of resistance in leading maize varieties in Bangalore and Karnataka and the impact of resistance on the biological events during the life time of *C. partellus*, with following objectives:

- To screen the most popular varieties of maize for resistance or susceptibility to *C. partellus* (Swinhoe).
- To study mechanisms of resistance in terms of major nutritional elements and some morphological traits.
- To study the impact of resistance on different stages of life cycle of *Chilo partellus* (Swinhoe).

MATERIALS AND METHODS

Screening of maize varieties was undertaken during the years 2004 and 2005 at Main Research Station (MRS), Hebbal and UAS, Bangalore, Karnataka. Laboratory studies were conducted in different laboratories in UAS; Project Directorate of Biological Control (PDBC), Bangalore and Indian Institute of Horticulture Research Hessaraghatta, Bangalore, Karnataka. Studies on the biology of *C. partellus* were carried out at Department of Entomology, UAS, Bangalore. *C. partellus* larvae were collected from maize at military farm, Bellary Road, Bangalore and other adjoining fields.

Screening: Field trial- A total number of 26 popular maize varieties were collected from Bangalore. These varieties were used in a 2-staged screening procedure for resistance and susceptibility to *C. partellus.* All 26 varieties were used at this stage. The experiment was laid out in randomized complete block design. Uniform cultural practices were followed in all plots. The varieties were: PMZ-103, C-111, AB- 2001, Premier, PAC-9714, MMH-3818, Kaveri-235, Bioseed-9681, CM-132, CM-13, CM-212, Godavari-989, PMH-2203, PMH-2244, DHM-103, HY-4642, Kanak, Swarna, NLD, GK-3014, GK-3015, DK-984, SMH-42, Seed Tech-740, Seed Tech-940 and PEMH-2. The experiment was conducted in a 40×32.5 m plot, divided into 5 blocks; each of them was 40×6.5 m as one replication. From each entry, 20 seeds were sown in each block in 2 rows (10 plants in each row). Row to row distance was 75 cm and plant to plant was 60 cm, in accordance with most previous experiments in this field. All experimental plots were treated with N, P, K at the rate of 100, 75, 40 kg ha^{-1} at the time of sowing and two weeks later crop was top dressed with 50 kg N ha^{-1}. Three weeks after sowing, neonate larvae were taken to farm and 10 larvae were released on whorl leaves of each plant, using a camel's hair brush. This method has been recommended for cases where few plants are to be screened and an exact number of insects is required Four weeks after releasing the larvae, plants were assessed for the extent of damage and scored on 1-9 ratting scale was used to measure the damage according to Chatterji *et al.* (1970) and Sarup *et al*. (1978).

One variety (CM-212) failed in the field during the experiment because of drought and hence studies were conducted on 25 varieties.

Results were subjected to statistical analysis (ANOVA) and processed by using SAS program version 6.12.

Screening: Glasshouse trial- This part of experiment was conducted in the glasshouse of Department of Agricultural Entomology, UAS, GKVK. The statistical design was drawn as CRD with 6 entries and 8 replications. Varieties were used: CM-132, CM-137, PMZ-103, HY-4642, GK-3014 and DK-984. These varieties were selected according to results from earlier screening trial conducted in field. Maize plants were grown in separate pots. Each pot was treated as a replication and 8 replications were considered for each variety. To prevent the damage by other insects in glasshouse, the pots were covered with a cotton cloth mesh and plants were irrigated for every 3 days and maintained in good condition. Production of larvae and artificial infestation of maize plants were carried out in the same way as in field experiment. Visual assessment of the extent of damage was conducted 4 weeks after releasing the larvae and plants were given scores 1 to 9 on the basis of the extent of damage to each plant. Collected data were subjected to statistical analysis procedures (here GLM) and processed by SAS program version 6.12 to select the most resistant and the most susceptible variety.

Rearing and releasing of *C. partellus* : The larvae were produced in the laboratory at PDBC, Hebbal, Bangalore. For this purpose, larvae in late instars were collected from military farm in Bangalore and transferred to laboratory where they were put on artificial diet to complete their life cycle. We used the artificial diet developed earlier at ICRISAT Centre for mass rearing of *C. partellus* (Taneja and Leuschner, 1985b), but little change was made in formula when sorghum leaf powder was substituted with maize leaf powder. Late instar larvae collected from farm, were introduced into this diet (3-4 larvae in each vial). Pupae were collected from these vials and placed in small petries and then put in oviposition cage. As male moths generally emerge earlier than female moths, male pupae (smaller in size) were collected and stored for a couple of days in low temperature (14-15°C) in order to obtain simultaneous emergence of both sexes.

Freshly emerged moths of both sexes were kept in an oviposition cage lined with creased waxed paper as a substrate for oviposition. The creases simulate areas of concavity within the leaf, which are the preferred sites for oviposition. Pieces of cotton wetted with distilled water and a drop of honey were provided for the moths as food. Oviposition cage was a cylinder shape container (16 cm high and 10 cm diameter) made of transparent polyethylene. Ten pairs of pupae were put in a cage mated and emerged moths lay their eggs on creased waxed paper within 2-3 days. The paper with eggs then was removed and egg masses were collected and put in vials closed with cotton. After 5-7 days, newly hatched larvae were ready to be released on experimental plants.

Studies on resistance factors

Nutritional constituents: To investigate the possible role of plant's nutritional elements in conferring resistance, an estimation and comparison of N, P, K, Si, Fe and sugar in two varieties, CM-137 which was found as resistant and HY-4642 as the most susceptible variety, was conducted at two ages of 4 and 6 weeks after germination. Samples used in this study were taken from the part of stem located between 4th and 5th leaves from top, the same location where stem diameter (SD) and internodal distance (InD) were measured. These samples were put in an oven at 40°C for 4 days to get dry materials and then were removed from the oven for conducting studies on major nutritional components. Measurements on N, P, K and Fe were done at Chemical analysis lab, Soil science section, Indian Institute of Horticulture Research, Hessaraghatta Lake Post, Bangalore, following standard laboratory procedures as detailed by Jackson (1973). Sugar content and Silica quantities were estimated at Department of Entomology, UAS, GKVK, Bangalore, as in the procedure explained by Sadasivam and Manickam (1996).

Morphological traits: Two morphological characters, Stem Diameter (SD) and internodal distance (InD) were studied in an attempt to establish any possible relation between these attributes and the extent of resistance to *C. partellus* in experimental varieties.

SD was measured both in field and glass house at the age of 4 weeks after germination (5 weeks after sowing). For the sake of uniformity, on all experimental plants, the diameter at a specific point, 2 cm below the 4th node from top was measured. Measurement was conducted by a digital clipper with 2 decimal places and recorded in mm. InD, the part of stem located between two nodes, was measured on experimental plants in both field and glass house at the age of 4 weeks after germination. The internode located between 4th and 5th leaves from top was selected for this measurement and recorded in cm.

In the glass house trial, the variety HY-4642 was missed due to dead heart on all 8 replications before measurements on SD and InD. Records were later analyzed using SAS program 6.12 to find out possible relation between these two factors and resistance or susceptibility.

Studies on the biology of *C. partellus* on resistant and susceptible varieties: To find out the effects of resistance components on different biological events of *C. partellus*, following factors were investigated in this experiment:

1-Percentage survival of larvae, 2-Larval period. 3-Percentage of pupation 4-Pupal weight, for both sexes. 5-Pupal period. 6-Growth index value 7-Percentage of moth emergence. 8-Average developmental period from larva to adult 9-Average number of eggs laid per female. 10-Percentage viability of eggs. 11-Ovipositional preference and non-preference. Two varieties selected from screening procedure, CM-137 as resistant and HY-4642 as susceptible, were used for this experiment. One hundred plants from each variety were grown in 100 separate pots. At the age of 3 weeks, each maize plant was artificially infested with 10 neonate larvae in the same way as done in previous experiment. Ten plants from each variety were picked every week and taken to lab for measurements on biological factors.

In weekly intervals, 10 plants at random from each variety were taken to lab where the larvae occurred in each plant were counted and average larvae survived up to that stage were determined. This evaluation was continued for 5 weeks when all larvae had become pupa and results for 5 weeks and for 2 varieties were arranged and tabulated. To find out larval period, the date when larvae released on maize plants and the date when each larva turned into pupa and collected as pupa was recorded as larval period. Further, the average larval period for all collected pupae on two varieties was calculated. On 6th week all remaining plants (50 plants) were removed and the number of pupae collected from these plants were used to calculate the percentage of pupation.

Male and female pupae were separated and the average weight for each group was determined by digital balance with 4 decimal places.

Pupae in separate glass vials were kept at 25±2°C in laboratory and the average numbers of days required for the emergence of moths were recorded every day at 10 am.

The growth index value was calculated by dividing the percentage (n) of the larvae becoming pupae with the average developmental period (p).

The number of moths obtained from each group was used to calculate the percentage of moth emergence from both initial number of larvae released and initial number of pupae collected.

The average larval period was added to the average pupal period to calculate the total developmental period from larva to adult.

To find the average number of eggs laid per female, 20 pair of moths (20 males and 20 females) from the emerged adults on each variety were selected. Each pair of moths were transferred to an oviposition cage and left for 4 days and egg masses were collected from butter papers and counted for the number of egg masses and the average number of eggs in each mass.

Collected eggs from each cage were kept in a separate glass vial in lab condition (25±2°C) for the period of one week and the number of larvae emerged, were recorded to calculate the viability of eggs for each group.

To find out the probable effect of resistance factors on the ovipositional preference of *C. partellus* moths, two experiments were designed to investigate the issue in both with choice and no-choice conditions. The objective of this test is to determine if any significant difference exist between two varieties of maize in terms of attracting or deterring moths at the time of oviposition. Or, in other words, the attempt has been made to find out whether there is any role for anti-xenosis in conferring resistance to resistant variety, here CM-137. The test was conducted in two cases: with choice and no-choice.

In with choice test, insect can select between any of resistant and susceptible varieties. While, in no-choice test, insect has access to only one variety.

Twenty identical cages were used for this test. In 10 of them, variety CM-137 as resistant and in 10 other cages, HY-4642 as susceptible variety were kept. Experimental plants were grown earlier in plastic pots, so that their handling was easy. One pair (1 male and 1 female) of just-emerged moths were released to each cage and they were left for 4 days. In 5th day, plants were removed from the cages and egg masses and total number of eggs laid on each plant was recorded.

Ten identical cages were used for this test. In each cage one plant from resistant variety CM-137 and another plant from susceptible variety HY-4642 were kept as host plant for *C. partellus*.

Like previous test, one pair (1 male and 1 female) from just-emerged moths were released to each cage and they were left for 4 days. On the 5th day, plants were removed from the cages and egg masses and total number of eggs laid on each plant was recorded.

RESULTS

Field trial: For 25 varieties measured on this criterion, the mean values of Leaf Injury Scores (LIS) ranged from 2.05 for variety CM-132 to 8.75 for variety GK-3014 (Table 1). It is evident from the mean values that none of those varieties have showed complete resistance (immunity) to *C. partellus*. But on the other hand, variety GK-3014 has shown high level of susceptibility, though the correspondent mean value for leaf injury score still remains less than 9. Meanwhile, small amount of standard errors for two mentioned varieties, 0.114 for CM-132 and 0.123 for GK-3014 indicated that the uniformity among individuals of any of those varieties. This point naturally increases the reliability of mean values obtained.

The scores 1 and 9 would represent complete resistance and susceptibility, however, all other scores in the Table 1, shows the fact of varied extent of resistance or susceptibility among the entries.

Table 1: Descriptive analysis of Leaf Injury Score (LIS), Stem Diameter (SD) and Internodal Distance(InD) on 25 varieties in field

	LIS					SD					InD				
Varieties	Mean	SE	Min	Max	Range	Mean	SE	Min	Max	Range	Mean	SE	Min	Max	Range
C111	4.55	0.33	2.00	7.00	5.00	11.40	0.45	8.30	16.83	8.53	11.62	0.23	10.00	13.10	3.10
AB 2001	3.00	0.23	1.00	5.00	4.00	10.56	0.24	8.00	12.51	4.51	12.28	0.19	10.20	14.00	3.80
Bioseed 9681	3.55	0.23	1.00	5.00	4.00	12.16	0.65	7.98	17.02	9.04	11.86	0.28	9.40	14.50	5.10
CM-132	2.05	0.11	1.00	3.00	2.00	11.13	0.51	8.52	15.65	7.13	13.68	0.30	12.10	15.90	3.80
CM-137	2.50	0.22	1.00	4.00	3.00	10.65	0.26	9.14	14.08	4.94	14.04	0.31	11.60	17.10	5.50
DHM 103	5.75	0.26	4.00	9.00	5.00	10.90	0.51	7.00	14.03	7.03	10.92	0.27	9.00	12.90	3.90
DK 984	6.95	0.29	5.00	9.00	4.00	10.76	0.42	7.57	14.63	7.06	9.82	0.18	8.40	11.50	3.10
GK 3014	8.75	0.12	7.00	9.00	2.00	12.18	0.46	8.54	17.00	8.46	9.59	0.29	5.80	11.10	5.30
GK 3015	3.70	0.23	2.00	6.00	4.00	11.78	0.48	7.00	15.00	8.00	12.02	0.35	9.30	13.90	4.60
Godavari 989	5.00	0.29	3.00	7.00	4.00	10.89	0.85	7.92	16.67	8.75	10.31	0.55	7.30	12.50	5.20
HY-4642	7.75	0.35	5.00	9.00	4.00	12.59	0.41	10.55	17.50	6.95	9.76	0.26	8.00	12.40	4.40
Kanak	3.50	0.17	2.00	5.00	3.00	9.83	0.39	7.30	13.54	6.24	11.39	0.23	9.30	13.10	3.80
Kaveri 235	6.00	0.51	2.00	9.00	7.00	11.60	0.49	7.63	15.12	7.49	10.97	0.30	9.10	12.70	3.60
MMH 3816	4.00	0.16	3.00	5.00	2.00	11.83	0.38	8.13	14.07	5.94	12.23	0.26	10.30	13.70	3.40
NLD	4.50	0.21	3.00	7.00	4.00	11.24	0.49	8.43	15.59	7.16	11.09	0.28	8.90	13.30	4.40
PAC 9714	4.40	0.20	3.00	7.00	4.00	10.76	0.32	8.61	14.93	6.32	11.89	0.28	9.80	13.60	3.80
PEMH 2	4.90	0.23	3.00	7.00	4.00	12.33	0.25	10.37	14.64	4.27	11.32	0.33	8.50	14.20	5.70
PMH 2203	6.10	0.41	4.00	9.00	5.00	11.08	0.47	7.05	14.13	7.08	11.05	0.37	8.80	14.60	5.80
PMH 2244	6.30	0.23	5.00	8.00	3.00	11.32	0.58	7.78	15.50	7.72	11.11	0.31	8.70	13.80	5.10
PMZ 103	2.70	0.18	1.00	4.00	3.00	9.96	0.36	7.56	13.43	5.87	13.59	0.17	11.90	15.20	3.30
SeedTech 740	4.60	0.22	3.00	7.00	4.00	11.22	0.40	7.36	14.22	6.86	11.06	0.25	9.70	13.10	3.40
SeedTech 940	4.60	0.30	3.00	7.00	4.00	12.32	0.46	9.37	16.65	7.28	10.49	0.26	8.20	12.90	4.70
SMH 42	3.15	0.18	2.00	5.00	3.00	12.76	0.53	9.30	16.88	7.58	11.24	0.29	8.60	13.60	5.00
Swarna	5.20	0.42	1.00	8.00	7.00	10.38	0.39	8.15	14.03	5.88	10.81	0.24	9.3	13.2	3.9
LSD	1.97					1.96					1.96				
F-test	0.0001					1E-04					0.0001				

Table 2: Descriptive analysis of Leaf Injury Score (LIS), Stem Diameter (SD) and Internodal Distance (InD) on 6 varieties in glass house

	LIS					SD					InD				
Varieties	Mean	SE	Min	Max	Range	Mean	SE	Min	Max	Range	Mean	SE	Min	Max	Range
CM-132	3.375	0.375	2	5	3	10.69	0.503	9.16	12.62	3.46	14.625	0.261	13.4	15.5	2.1
CM-137	2.361	0.324	1	4	3	9.68	0.331	8.75	11.46	2.71	14.875	0.363	13.5	16.0	2.5
DK-984	8.125	0.295	7	9	2	9.90	0.776	6.96	13.46	6.50	7.62	0.516	6.0	9.2	3.2
GK-3014	6.625	0.565	4	9	5	11.67	0.636	8.64	13.99	5.35	10.114	0.241	9.0	11.0	2.0
HY-4642	9.00	0.00	9	9	0	.	.	.	.	.	.	.	.	.	.
PMZ-103	3.25	0.313	2	4	2	11.58	0.634	9.58	14.64	5.06	14.40	0.226	13.2	15.0	1.8
LSD	1.009					1.70					2.04				
F-test	0.0001					0.069					0.0001				

Glasshouse trial: When six varieties were used in glasshouse screening trial, measurements on Leaf Injury Score (LIS) showed the maximum possible of damage, dead heart, (LIS equal to 9±0.00), in variety HY-4642, while the variety CM-137 showed the maximum resistance with the mean value of LIS equal to 2.36.

The mean LIS of variety CM-137 at ($p<0.05$) was significantly different from two other resistant varieties CM-132 and PMZ-103. (LSD = 1.009), while CM-132 and PMZ-103 had no significant difference. Meanwhile, the mean LIS of three susceptible varieties HY-4642, DK-984 and GK-3014 were significantly different from each other at this level of probability.

Results obtained from data on measurements of extent of damage to experimental varieties have been summarized in Table 2. On the basis of these results, variety CM-137 and HY-4642 were selected as most resistant and most susceptible varieties, respectively.

Nutritional constituents

Sugars: In an attempt to relate sugar content for resistance or susceptibility in two maize varieties, variety HY-4642 which was rated as susceptible in both the field and glasshouse screening programs, was found to contain significantly higher percentage of sugar (1.535%±0.488) as compared to variety CM-137 (with 1.333%±0.223) which showed resistance in the same trials. Similarly, these two varieties showed significant difference in terms of resistance and susceptibility in two different ages. In variety CM-137, the quantity of sugar has reduced as the age increased. By contrast in variety HY-4642 the plant had more sugar content at the age of six weeks compared with that of four weeks.

Nitrogen: Quantitative analysis was carried out to find out the percentage of nitrogen in two maize varieties. The estimation of nitrogen showed relative relationship with the degree of damage where susceptible variety HY-4642 contained higher (Mean = 1.187%±0.352), while resistant variety CM-137 contained low level (Mean = 0.752%±0.134) of nitrogen. These results suggest that higher percentage of nitrogen may confer of susceptibility to stem borer *C. partellus* in maize varieties.

Phosphorus: The percentage of phosphorus was higher (0.241%±0.070) in resistant variety CM-137 in comparison with susceptible variety HY-4642 (with 0.125%±0.090) and difference was significant at ($p<0.05$). On the other hand, the percentage of phosphorus is significantly different in two different ages of plant. The older plants (6 weeks) recorded higher percentage of phosphorus (Mean±SE = 0.272±0.056) compared to younger ones (4 weeks) which recorded lower percentage of phosphorus (Mean±SE = 0.094±0.004).

Iron: The quantity of Iron (Fe) found to be less in susceptible variety HY-4642 (29.950±0.969 ppm) compared to resistant variety CM-137 (53.300±11.248 ppm) indicating the positive correlation between the quantity of iron and degree of resistance to *C. partellus*. The difference was significant at $p<0.05$. Meanwhile, in comparison between two different ages, the findings of this study revealed that maize plants have less amount of Iron (30.100±0.853 ppm) at the age of 4 weeks in comparison with those of 6 weeks (53.150±11.31 ppm). The difference was significant at $p<0.05$.

Potash: Findings of present study showed that percentage of potash in the resistant variety CM-137 is relatively more (5.800±1.521) in comparison to the susceptible variety HY-4642 (5.000±0.537) and difference was found to be significant at $p<0.05$.

On two different ages of plant, it was found that plant at the age of 4 weeks has less quantity of potash (3.100±0.313) when compared with the age of 6 weeks (7.700±0.674) and difference was significant at $p<0.05$.

Silica: Silica content was found to be relatively more in the resistant variety CM-137 (2.388±0.112) as against the susceptible variety HY-4642 (1.361±0.297) and their difference was significant at $p<0.05$.

In comparison of two ages, this study showed higher percentage (2.320±0.138) of silica in 6 weeks-age plant when compared with that of 4 weeks-age one (1.430±0.382). This difference was significant at $p<0.05$.

Morphological traits

A. Stem diameter (SD)

Field trial: Measurements of SD on 25 varieties ranged from a minimum of 9.83±0.39 mm in variety Kanak followed by 9.96±0.36 for variety PMZ 103, 10.38±0.39 for variety Swarna, 10.56±0.24 for variety AB 2001 and 10.65±0.26 for variety CM-137 and a maximum of 12.76±0.53 for variety SMH 42 which is followed by 12.59±0.41 for variety HY-4642, 12.33±0.25 for variety PEMH2, 12.32±0.46 for variety SeedTech 940 and 12.18±0.46 for variety GK 3014. Correlation between LIS and SD was found to be + 0.111 which indicated a positive relation between these two parameters.

Glasshouse trial: The variety HY-4642 was missed due to dead heart before SD was measured. Among five the remaining varieties, CM-137 was found to have the least SD, 9.68±0.331 while, variety GK 3014 showed to have greatest SD,11.67±0.636 (Table 2).

Correlation between LIS and SD was found to be + 0.521 which indicated a strong positive relation between these two parameters.

B. Internodal distance (InD)

Field trial: It is evident from these data that InD has a range of mean values from 9.59±0.29 to 14.04±0.31 cm. The variety GK-3014 was found to have the lowest internodal distance with mean value equal to 9.59±0.29 cm followed by HY-4642 with 9.76±0.26 and DK-984 with 9.82±0.18 and among the highest mean values of InD, the first is that of the variety CM-137 with 14.04±0.31 which is followed by variety CM-132 with 13.68±0.30 and then variety PMZ-103 with 13.59±0.17 (Table 1).

Analysis of data showed a significant negative correlation between Leaf Injury Score (LIS) and Internodal distance (InD) to be -0.432 which indicates a relatively strong relation between these two parameters.

Glasshouse trial: It was found from the measurements on InD on 6 varieties at glasshouse trial that variety CM-137 has the highest InD (14.875±0.363) followed by CM-132 (14.625±0.261) and PMZ-103 (14.4±0.226). Meanwhile the variety DK-984 was found to have the lowest InD (7.62±0.516) then followed by GK-3014 (10.114±0.241). The variety HY-4642 was missed due to dead heart before InD was measured.

Analysis of data collected revealed a high significant negative correlation between InD and LIS which was found to be equal to -0.896. It can be suggested that the extent of resistance has increased when InD has increased. This relation was significant at $p<0.01$.

Studies on the biology of *C. partellus* on resistant and susceptible varieties

Percentage survival of larvae: A study was carried out on resistant variety CM-137 and susceptible variety HY-4642. Samples were collected at 7-day intervals starting from day 7 after releasing of the larvae on experimental plants and continued for a period of 5 weeks. The percentage survival of larvae was higher in all samples on variety HY-4642 in comparison to variety CM-137, though the difference was not statistically significant for the first and second weeks, but it was significant in 3rd and 4th weeks at $p<0.05$ and in 5th week at $p<0.01$.

Larval period: Figure 1 shows the number of larvae that successfully pupated in the days 21 to 32 after hatching on each of two varieties CM-137 and HY-4642. On variety CM-137, the first pupation happened on day 21 after hatching and last larvae went to pupation on day 32. While on variety HY-4642, pupation started on the day 22 and ended on the day 30. In other words, the larvae fed on CM-137 went to pupation in a wider period compare to those fed on HY-4642.

Total pupae harvested on variety CM-137 and HY-4642 were 34 and 47, respectively. The average larval period was 26.67 days on variety CM-137 and 25.64 days on variety HY-4642.

Percentage of pupation: The percentage of pupation was calculated on the basis of total number of larvae turned to pupae during a period of five weeks after hatching. This percentage was found to be 34.0±4.0 for the larvae fed on variety CM-137 and 47.0±4.23 for those fed on variety HY-4642. Further, the statistical analysis revealed a significant difference at $p<0.05$ between the percentages of pupation of two groups.

Pupal weight, for both sexes: Pupal weights for both sexes were studied in 25 male and 19 female pupae. The pupae were harvested from the larvae fed on CM-137. Moreover, from the larvae fed on the variety HY-4642, 22 male and 25 female pupae were collected. The mean weight of male and female pupae on variety CM-137 was 34.736±0.815 and 73.9±2.63 mg, respectively.

On the variety HY-4642, same measurements showed the mean weight of male and female pupae 40.09±1.060 and 102.07±1.188 mg, respectively. The difference in the weight of male and female pupae on two varieties were statistically significant.

Pupal period: Differences between pupal period of male insects in the resistant and susceptible varieties were non-significant. But the pupal period for female was significantly different at $p<0.05$ indicating that female pupae harvested from the variety CM-137 had longer period of pupal stage compared to those harvested from variety HY-4642.

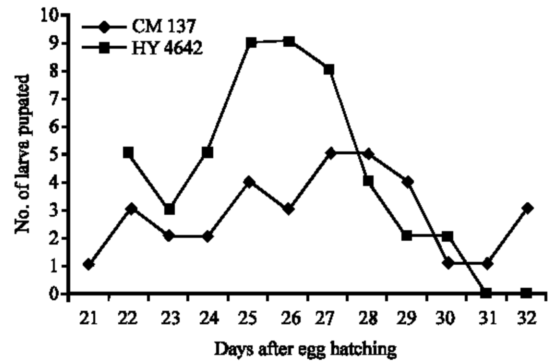

Fig. 1: Larval period on CM-137 and HY-4642

Percentage of moth emergence: Neither the percentage emergence of males nor that of females was significantly different on resistant variety CM-137 and susceptible variety HY-4642. Besides, the results indicated more percentage of male moths emerged on susceptible variety, while by contrast, the percentage emergence of females was higher on resistant variety in comparison to susceptible one, but none of them was statistically significant.

Average developmental period from larva to adult: This parameter was simply calculated by adding the average larval period to average pupal period.

On the basis of results, developmental period from larvae to the emergence of moths on two varieties were too close and hence, it can suggest that there has been no difference between this parameter on these varieties.

Average number of eggs laid per female: Results of the present study showed no significant difference between the average number of eggs laid per female on resistant variety CM-137 and those laid on susceptible variety HY-4642.

Percentage viability of eggs: Data obtained on the viability of eggs laid in two different varieties indicated that the percentage of viability of eggs is not significantly different on two varieties. But Incubation period, was found to be significantly higher in variety CM-137 compared to variety HY-4642 at $p<0.05$.

Ovipositional preference and non-preference

No choice test: When *C. partellus* moths were subjected to no-choice test, mean number of egg masses laid on variety CM-137 was significantly lower than those laid on variety HY-4642. Statistical analysis on the collected data of this test showed mean value for number of egg masses on CM-137 to be 1.4±0.339 while on variety HY-4642 it was found to be 2.70±0.86 and difference was significant at $p<0.05$.

Meanwhile, the total number of eggs/female was significantly higher on the susceptible variety HY-4642 when compared the number of eggs/female on resistant variety CM-137. Mean values were found to be 63.10±17.0 on Hy-4642 and 19.8±6.23 on CM-137. Further, a comparison carried out between eggs/mass on two varieties showed mean values were 20.1 and 17.9 on CM-137 and HY-4642, respectively and difference was not significant.

With choice test: This test indicated no significant difference on ovipositional preference on two varieties. The mean values for the number of egg masses in variety CM-137 was 5.1±1.131, slightly higher than that on variety HY-4642 which was found to be 4.5±1.118.

Moreover, the mean value for the total number of eggs/female laid on CM-137 was found 97.4±22.91 and on HY-4642 was 103.60±29.1. Neither the number of egg masses nor the total number of egg/female were significantly different when subjected to statistical analysis.

DISCUSSION

Although none of the varieties used in the current study have been evaluated for resistance by earlier workers, however cultivars under the series identified as CM lines such as CM-202 and CM-205 have been studied earlier (Sarup *et al.*, 1978). Similarly, CM-500 and CM-110 (Sarup *et al.*, 1978) have been studied thoroughly and later introduced as resistant varieties. The variety CM-500, also known as Antigua Gr 1, has been utilized in almost all previous works in India as a source of resistance to *C. partellus* (Chatterji *et al.*, 1966, 1970; Sharma and Chatterji, 1971a; Panwar and Sarup, 1985). Thus, the results of this research may suggest yet another confirmation on the resistance in this group. In the present study, varieties such as CM-132, CM-137 and CM-212 were initially used in field screening. However, the variety CM-212 was later found to be very susceptible to drought and consequently it was omitted from the field trial experiment, but other two varieties, CM-132 and CM-137, showed high level of resistance to *C. partellus* and accordingly both along with the variety PMZ-103 were selected for the second phase of screening procedure which was conducted in glass house. The variety CM-137 again showed the highest level of resistance. Meanwhile vulnerability to drought condition may remain as a demerit of this group of maize varieties and it may necessitate separate mode of research work on this aspect in field conditions. It highlights the fact that in any IPM program, resistance or susceptibility to any factor must be regarded as a component within a complex combination of affecting factors.

Resistance and morphological traits: The possible relation between two morphological characters, stem diameter (SD) and internodal distance (InD) in maize varieties with resistance and susceptibility to *C. partellus* were investigated and results of this study in field and glasshouse showed a positive correlation equal to 0.111(in field study) and 0.521 (in glasshouse study) between Leaf Injury Score (LIS) and Stem Diameter (SD). In other words, varieties with greater stem diameter have shown less resistance to stem borer. This may be related to the point that plants with greater stem diameter, can provide more food and shelter for early stage larvae so that they prefer to remain at the same location where they have entered after hatching and impose more severe damage to plant. In field collections of larvae, it was frequently observed that those plants having thicker stems usually harbored more number of larvae in single internodes, sometimes exceeding to 20 larvae and these plants later show more damage symptoms because of intense feeding of larvae at a specific point. While in the plants with thinner stems, larvae are usually scattered on different internodes or even some of them prefer to migrate to neighboring plants. Sharma and Chatterji (1971a, b) evaluated the relationship of some plant characters with resistance. According to them, the germplasms having vigorous plants, compact whorl, soft stem and long internodes were more susceptible. Though there is no direct mention to the stem diameter in that report, but as normally stems with small diameter are softer than those with greater diameter, so it seems that the findings of current study is not in conformity with that report. But on the other hand, in the study of relation between internodal distance and the extent of resistance to stem borer, the current research has come to the same conclusion as that of Sharma and Chatterji (1971a, b). We found a negative correlation equal to -0.432 (in field) and -0.896 (in glasshouse) between InD and LIS as an indicator that longer internodes resulted in more resistance and less damage. It might be related to the fact that genotypes with longer internodes have inheritable vigor of growth which in turn can negatively affect larval activities inside maize stems. This conclusion needs to be examined trough further studies.

Resistance and nutritional constituents

Reducing sugars: The reducing sugars are considered to be an essential component in insect nutrition. As reducing sugars are imperative for the normal growth and development of insects, their concentration in host plant is positively correlated with feeding behavior of insects. Findings of the current study showed that reducing sugar was lower (1.33 %) in resistant variety CM-137 and higher (1.53 %) in susceptible variety HY-4642. The result was in accordance with reports of Kalode and Pant (1967) and Sharma and Chatterji (1971d). These results also indicated a reduction in sugar content when the age of plant increases. Analysis of data showed 1.863% sugar content in the plants at the age of 4 weeks while only 1.005% in the plants at the age of 6 weeks. This may elucidate a reason that younger plants are more perfect attractants for stem borer moths at the time of oviposition.

Silica: It has been demonstrated that increasing concentration of Silica leads to functional enhancement in the plant tissues (Ma, 2002) and this may suggest that Silica can improve the resistance to stem borers through a mechanical mechanism rather than chemical. This hypothesis becomes more likely when results shows increasing in Silica content in older plants compare to younger ones and the existence of more resistance in older plants. In current study, a comparison between Si content at two different ages of plant (4 weeks and 6 weeks age) indicated significant higher concentration of Si in six weeks age (2.32%) compare to 1.43% in the plants with 4 weeks age.

Nitrogen (N): The results in this study is in conformity with the results of Kalode and Pant (1967), Sharma and Chatterji (1971c) and the report of Uma kanta and Sajjan (1989) which also reported that resistance to *Chilo partellus* was associated with lower nitrogen content. Nevertheless, Sharma and Chatterji (1971d) believe that antibiosis in maize or in other words resistance is not primarily governed by any of chemicals *viz* nitrogen, phosphorus, iron and silica in whorl or stem, but it is possible that they might be interacting with some other mechanisms responsible for resistance. Meanwhile, on the basis of findings in the current research, concentration of nitrogen was higher (1.505%) at the age of six weeks when compared to (0.434%) at the age of four weeks, which may give some confusing conclusion as resistance increases in later ages. One possible interpretation may suggest that in later ages of plant, the function of nitrogen in terms of resistance or susceptibility to insect is undermined by stronger role of other elements such as increasing silica or reducing sugar content or changes in the proportion of other elements.

Phosphorus (P) and Potash (K): Studies on the possible role of phosphorus in resistance to *C. partellus* showed higher percentage (0.241%) of this nutrient in resistant variety CM-137 compared to (0.125%) in susceptible variety HY-4642. This result was in contrast with the report of Sharma and Chatterji (1971c) who reported lower content of phosphorus associated with resistance to spotted stem borer. The (5.8%) of potash as observed in resistant variety CM-137 in comparison to (5.000%) in susceptible variety HY-4642, was in contrast with the report of Sharma and Chatterji (1971c) who reported lower percentage of potash to be associated with more resistance to *C. partellus*. In comparison of K and P content in different ages, current investigation showed an increase in K and P content when the age increases. Measurements indicated 0.272% at the age of six weeks, while only 0.094% at four weeks age. Likewise, plants with six weeks age had 7.7% of K and 3.100% at the age of four weeks.

Iron (Fe): Higher concentration of iron in resistant germplasms compared to susceptible ones had been reported previously (Sharma and Chatterji, 1971c; Kalode and Pant, 1967). Current study also showed the results indicating higher percentage of Fe in resistant variety CM-137 (53.3 ppm) when compared with that of susceptible variety HY-4642 with 29.95 ppm. Meanwhile, in the investigation on the Fe content in two ages of plant, it was revealed that Fe concentration has increased at higher ages. These measurements showed 30.1 ppm of Fe in the plants with 4 weeks and 53.5 ppm in those with 6 weeks age.

Biology of *C. partellus* on resistant and susceptible varieties: Investigations on various biological parameters of *C. partellus* such as percentage survival of larvae, larval and pupal period, percentage of pupation, pupal weight, percentage of moth emergence, average developmental period from larva to adult, average number of eggs laid by a female and percentage viability of eggs on both resistant and susceptible varieties indicated significant impact of resistance factors on those parameters. Thus a lower percentage of larval survival, 82.0, 70.0, 57.0, 41.0 and 31.0% at days 7, 14, 21, 28 and 35 days after artificial infestation was recorded for the larvae fed on resistant variety CM-137 and the values were higher, 94.0, 79.0, 75.0, 60.0 and 56.0% in the same periods for those fed on the susceptible variety HY-4642. This indicated that susceptible variety HY-4642 was more suitable for feeding by *C. partellus* than resistant variety CM-137. The larval period indicates the period of time since the egg hatching till the full growth of larvae when they pupate. The results of studies on larval period revealed that larvae fed on variety HY-4642 had lower larval period and higher larval period was recorded with the larvae fed on variety CM-137 which was determined in field and glass house trials as resistant variety. This can be an indication that variety HY-4642 has provided more nutritional requirements for larvae of *C. partellus* in order to complete the larval stage in a shorter period of time. This finding was in good agreement with the report of Kumar (1993) who indicated that percentage of larvae recovered from the resistant varieties MP-704, V-37 and Poza Rica 7832 at 15 days after infestation was significantly lower than the susceptible inbred A. Further, most of the larvae collected from the susceptible variety, were in fourth instar and a few had entered to the fifth instar. On the resistant varieties, the percentage of larvae in fourth instar was significantly lower and they were mostly in second and third instars. Several other workers in Asia also have studied the survival and development of *C. partellus* in the laboratory (Sharma and Chatterji, 1971a, 1972; Lal and Pant, 1980; Durbey and Sarup, 1984; Sekhon and Sajjan, 1987). According to them, survival, growth and development of *C. partellus* on Antigua Gr 1, was lower than the susceptible check varieties.

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