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RESISTANCE OF *SACCHARUM* SPP. AGAINST *CHILO SACCHARIPHAGUS INDICUS* (KAPUR) (LEPIDOPTERA: CRAMBIDAE) IN INDIA

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SUMMARY

Accessions of four *Saccharum* spp. from the world collection of sugarcane germplasm maintained at the ICAR-Sugarcane Breeding Institute Research Center, Kannur, Kerala State, India, were screened against *Chilo sacchariphagus indicus* (Kapur) (Lepidoptera: Crambidae), commonly known as internode borer. Observations on the progression of borer attack in the most susceptible *Saccharum officinarum* indicated that the incidence began in the first fortnight of July, increased in the next 2 months and reached its peak in September. Thereafter, the incidence decreased in the next 2 months but reached its overall peak in December. Simple correlation coefficients between mean monthly weather parameters and borer incidence were not significant. Percent of canes attacked was significantly lower in 2011 than in 2012 for *S. officinarum*, *Saccharum barberi* and *Saccharum sinense* but did not differ between the years for *Saccharum robustum*. Amongst the four *Saccharum* spp., *S. robustum* showed the lowest borer incidence whereas *S. officinarum* recorded the lowest attack intensity. Whilst infestation index showed the same trend as percent canes attacked, percent deadhearts did not differ amongst the four *Saccharum* spp. Considering the 171 accessions evaluated, 29 (16.9%) accessions were resistant, 39 (22.8%) moderately resistant and 103 (60.2%) susceptible to internode borer. Out of the 39 accessions of *S. officinarum*, none occupied the resistant category whereas 17.9% were in the moderately resistant category. In *S. robustum*, whilst nearly half (44.5%) the accessions emerged as resistant, a considerable number occupied the moderately resistant category. In *S. barberi*, no accession was resistant to the borer. In *S. sinense*, only one accession each represented resistant and moderately resistant categories. Plant morphological characters, yield and quality parameters did not show clear-cut relationship with the three infestation parameters.

INTRODUCTION

Of more than 200 species of insect pests reported to attack sugarcane during different growth phases of the crop in India (David and Nandagopal, 1986), lepidopteran borers are considered most detrimental in both tropical and sub-tropical sugarcane fields. Amongst the borers, *Chilo sacchariphagus indicus* (Kapur) (Lepidoptera: Crambidae), commonly known as internode borer, has remained a major pest in peninsular India. It generally attacks the crop from internode formation to harvest, causing estimated crop losses of 10–35% (Yalawar *et al.*, 2010). When the borer injury extends to three or more internodes per cane, or more than 10% of the total length of the cane, canes suffer significant deterioration in juice quality. Although

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known to bore the top four to five formative internodes, the borer destroys the apical meristem in young and weak shoots producing deadhearts (David, 1986), with axial bud sprouting and bunchy top formation leading to crop losses (Mukunthan and Rakkiyappan, 1989). Larvae often enter from the top to either feed only on the spindle above the meristem or reach and injure the meristem, both of which produce deadhearts often coupled with axial bud germination and injury to the germinated buds (Srikanth and Kurup, 2011).

Insecticides are generally not effective against the borer due to its internal tissue feeding habits and plant canopy structure (Ananthanaryana and David, 1986). Biological control and sex pheromone traps are known to minimize infestation levels but suffer from specific limitations (Mukunthan, 2006; Srikanth *et al.*, 2013). Host plant resistance provides an effective platform for breeding varieties resistant to important borer pests such as *C. sacchariphagus indicus*. Cultivars were screened against borers such as *C. sacchariphagus indicus* in India (Albert *et al.*, 2007), *Diatraea saccharalis* (Fabr.) (Lepidoptera: Crambidae) (Coburn and Hensley, 1972) in Louisiana, Mexican rice borer *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae) in Texas (Reay-Jones *et al.*, 2003; Wilson *et al.*, 2015) and other moth borers in Papua New Guinea (Korowi and Samson 2013; Korowi *et al.*, 2011) to identify their resistance. The ICAR-Sugarcane Breeding Institute Research Center (ICAR-SBI RC), Kannur, Kerala State, India, currently maintains the world's largest collection of sugarcane germplasm. This vast germplasm with diverse genetic makeup includes assemblages of *Saccharum* spp. accessions. Interspecific crosses involving *Saccharum officinarum*, *Saccharum barberi*, *Saccharum robustum* and *Saccharum spontaneum* were carried out and the progenies evaluated for identifying superior hybrids. These hybrids were intercrossed, back crossed and crossed with the commercial varieties to develop genetic stocks and new varieties (Nair, 2011). Besides, *Saccharum* spp. also serve as sources of resistance against pests and accessions resistant to some emerging pests have been identified amongst those maintained at the research centre (Mahesh *et al.*, 2013, 2014, 2015a, b).

In preliminary observations, the germplasm collection at the centre showed 1.2–23.5% incidence of *C. sacchariphagus indicus* in *Saccharum* spp. and exotic and Indian hybrids (Anonymous, 2008). In studies conducted elsewhere with clones of *Saccharum* spp., a few were identified as resistant to *C. sacchariphagus indicus* (Jayanthi, 1988). As *Saccharum* spp. serve as important parental material, identification of sources of resistance against *C. sacchariphagus indicus* would strengthen the breeding programme for resistance against the borer. However, no screening studies were conducted with the large collection of *Saccharum* spp. accessions maintained in the world sugarcane germplasm at the ICAR-SBI RC. Hence, the present study was taken up to screen accessions of four *Saccharum* spp. against *C. sacchariphagus indicus*.

MATERIALS AND METHODS

Study site and field layout

Sugarcane germplasm maintained at ICAR-SBI RC, Kannur, Kerala State, India (11°52′ N, 75°25′ E, 11 m MSL), constitutes a crop island as Kerala State in general

Table 1. Experimental details of screening *Saccharum* spp. against *Chilo sacchariphagus indicus* at ICAR-SBIRC, Kannur, Kerala State, India, in 2011 and 2012. As injury parameters, proportions (%) of bored internodes and deadheart were evaluated.

Saccharum spp.	No. of accessions	Planting	Borer assessment	Sucrose estimation
S. officinarum	39	02/13/2011	01/09-10/ 2012	01/2012
		01/30/2012	12/22-23/2012	12/2012
S. robustum	63	02/14/2011	01/11-13/2012	01/2012
		01/31/2012	12/22-24/2012	12/2012
S. barberi	39	02/14/2011	01/14-15/2012	01/2012
		01/31/2012	12/24-25/2012	12/2012
S. sinense	30	02/14/2011	01/16-17/2012	01/2012
		01/31/2012	12/27-28/2012	12/2012

and Kannur in particular lack large-scale or commercial sugarcane cultivation. The germplasm collection includes four species of *Saccharum*, *viz. S. officinarum, S. robustum, S. barberi* and *Saccharum sinense*. Each accession of the four species was planted in a 2 m row with 90 cm spacing between rows and 10 cm between plants (Table 1). Recommended agronomical practices were followed but no insecticides were applied for pest control.

Infestation parameters

The attack of *C. sacchariphagus indicus* begins at fifth month age of the crop and extends almost until harvest. Larvae, after feeding on the leaf tissue for 7–8 days, typically bore into the top internodes egesting out wet frass from the bore holes, which indicates fresh attack. The presence of large bore holes, often blackened by the growth of saprophytes, in the lower internodes characterizes old attack (See supplementary Figure S1 available online at http://dx.doi.org/10.1017/S0014479716000697). Grown-up larvae emerge out of the tunnel and pupate in dry leaf sheaths. Occasionally, young canes that produce deadhearts remain stunted and fail to produce millable canes (David, 1986).

Three types of injury were considered to assess the borer incidence in terms of direct or derived parameters, as follows:

$$\text{Percent incidence} = \frac{\text{Number of injured canes}}{\text{Total number of canes}} \times 100, \quad (1)$$

$$\text{Percent intensity} = \frac{\text{Number of injured internodes}}{\text{Total number of internodes}} \times 100, \quad (2)$$

$$\text{Infestation index} = \frac{\text{Percent incidence} \times \text{Percent intensity}}{100}. \quad (3)$$

The usefulness of deadhearts as an independent infestation parameter was assessed by computing its occurrence separately as follows:

$$\text{Percent deadhearts} = \frac{\text{Number of canes with deadhearts}}{\text{Total number of canes}} \times 100. \tag{4}$$

Progression of borer attack

Progression of *C. sacchariphagus indicus* was examined in 39 accessions of *S. officinarum*, which is highly prone to the borer attack, during 2012 crop season. Percent of borer incidence on the basis of fresh injury was assessed at monthly intervals beginning in July (120 days after planting) and ending in December. The total number of canes and number of canes with fresh injury were recorded and percent incidence was calculated for each observation.

Borer status in Saccharum *spp.*

Adequate number of trained personnel, familiar with symptoms of injury, was deployed to assess the incidence levels of the borer in 171 accessions of the four *Saccharum* spp. in 2011 and 2012. As the observations were done at harvest, all three types of injury symptoms and parameters were considered. For each accession, after counting the total number of canes, individual canes were cut at the base and examined for the presence of injury symptoms and the affected cane number recorded. In the infested canes, the total number of internodes and number of injured internodes were recorded and the three injury parameters were computed.

Categorization of accessions

Accessions of the four *Saccharum* spp. were grouped into three categories of resistance/susceptibility based on percent incidence (Mukunthan, 2001). For each accession, the datasets from the two study years (2011–2012) were compared and the dataset with higher incidence was selected to account for the variation between the 2 years and avoid the possibility of escapes under low natural infestation.

Morphological characters vs. borer incidence

Selected morphological traits such leaf length, leaf width, sheath hair and nature of leaf sheath clasping were recorded in 9-month old plants as per the descriptor classes and descriptor states adopted for sugarcane germplasm (Artschwager and Brandes, 1958). Yield traits such as cane thickness, cane length and sucrose percentage in healthy canes were recorded in 12-month old plants.

Meteorological data

Daily weather data during the experimental period were recorded by the Meteorological Observatory of the Center, with monthly averages for air temperature and relative humidity, and monthly totals for rainfall being calculated.

Statistical analyses

Non-parametric analysis was applied to the data of infestation parameters. Friedman ANOVA by ranks and Kendall concordance coefficient test for multiple dependent samples were applied to the monthly data (July–December 2012), with sugarcane accessions as blocks and months as treatments. *Post-hoc* analysis was carried out using Wilcoxon matched pairs rank test with a Bonferroni correction that sets a significance level of $P < 0.0033$ for the 15 2-month comparisons. Simple correlation coefficients were calculated between mean monthly (July–December 2012) weather parameters and mean and rank values of *C. sacchariphagus indicus* incidence in *S. officinarum*. Wilcoxon matched pairs rank test for two dependent samples was used to compare the percent incidence data of the two study years (2011 and 2012) for individual *Saccharum* spp. Kruskal–Wallis ANOVA by ranks and multiple comparison tests were applied to the accession data selected on the highest value of percent infestation taking the four *Saccharum* spp. as treatments. Box plots were used for graphical depiction of means from the four *Saccharum* spp. For assessing the relationship between morphological characters and infestation parameters, simple correlation coefficients were computed for quantitative parameters and Mann–Whitney U test was applied for qualitative parameters with two categories. The analyses were performed using StatSoft Inc. (2004).

RESULTS

Progression of infestation

Progression of the borer in *S. officinarum* assessed from July to December on the basis of freshly attacked canes showed significant differences amongst months by Friedman ANOVA ($\chi^2 = 75.965$, $N = 135$, df $= 5$, $P < 0.00001$; Kendall coefficient of concordance = 0.113). Borer attack began in the first fortnight of July with 4.5% mean incidence amongst the accessions, increased in the next 2 months and reached its peak in September with 12.5% infestation (Figure 1). Thereafter, the incidence decreased in the next 2 months but reached its overall peak (14.8%) in December, i.e. at harvest. Wilcoxon matched pairs rank test with a Bonferroni correction indicated significant differences amongst months. Simple correlation coefficients between mean monthly (July–December 2012) weather parameters and mean and rank values of borer incidence were not significant for any parameter (See supplementary Table S1 available online at http://dx.doi.org/10.1017/S0014479716000697).

Borer attack rates in Saccharum *spp.*

Comparison of *C. sacchariphagus indicus* attack rates by Wilcoxon matched pairs rank test indicated significant differences between the 2 years for percent of canes attacked in the four *Saccharum* spp. Percent incidence of the borer was significantly higher in 2012 than in 2011 for *S. officinarum* ($Z = 5.39$; $P < 0.0001$), *S. barberi* ($Z = 5.34$; $P < 0.0001$) and *S. sinense* ($Z = 4.19$; $P < 0.0001$). However, borer incidence did not differ significantly ($Z = 0.64$; $P = 0.525$) between the 2 years for *S. robustum*.

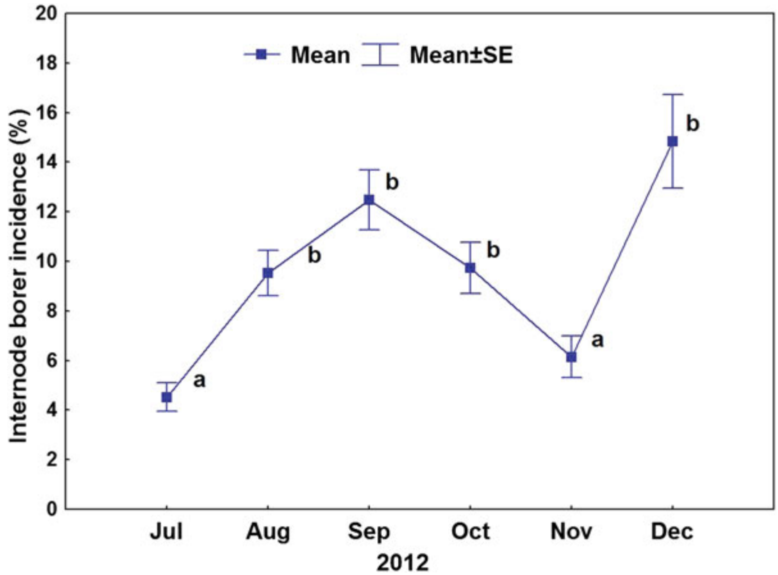

Figure 1. Pattern of *Chilo sacchariphagus indicus* incidence during July–December 2012 in *Saccharum officinarum*. Means with the same letter are not significantly different by Friedman ANOVA and Wilcoxon matched pairs rank test with a Bonferroni correction.

The accessions of *S. robustum* showed the lowest mean (Figure 2a) and range of *C. sacchariphagus indicus* incidence (Table 2). Amongst the four species, the lowest incidence (3.0%) was observed in the accession IM 76-255 (*S. robustum*) and the highest (96.3%) in UB 1 (*S. officinarum*). Mean percent intensity in affected canes was the lowest in *S. officinarum* (Figure 2b) whereas the range was the highest in *S. robustum* with the minimum (3.4%) being found in IJ 76-535 and the maximum (18.2%) in NG 77-108. The Infestation index was the lowest in *S. robustum* (Figure 2c) reflecting the trend observed in incidence.

Canes with deadhearts that were visibly shorter and thinner than healthy canes and dried deadhearts could be pulled out easily; the canes that produced deadhearts often featured axial bud germination (Figure S1). The mean and range of percent

Table 2. Comparative *Chilo sacchariphagus indicus* attack rates in accessions of four *Saccharum* spp. sorted on highest percent incidence in two study years (2011 and 2012).

	Incidence (%)		Intensity (%)		Infestation index		Deadhearts (%)	
Saccharum spp.	Range	Mean rank*	Range	Mean rank	Range	Mean rank	Range	Mean rank
S. officinarum	20.5–96.3	110.83a	3.8–8.6	55.63b	1.05–8.14	92.90b	0.0–18.8	93.76a
S. robustum	3.0–52.0	40.63b	3.4–18.2	85.72a	0.24–5.84	46.17c	0.0–13.3	81.83a
S. barberi	15.2–90.9	109.01a	4.1–15.0	97.26a	0.81–7.80	112.64ab	0.0–6.7	91.96a
S. sinense	13.7–77.3	119.08a	3.8–15.7	111.43a	0.57–9.42	126.03a	0.0–8.7	76.92a

*Mean ranks followed by the same letter are not significantly different ($P > 0.05$) by Kruskal–Wallis ANOVA and multiple comparisons test.

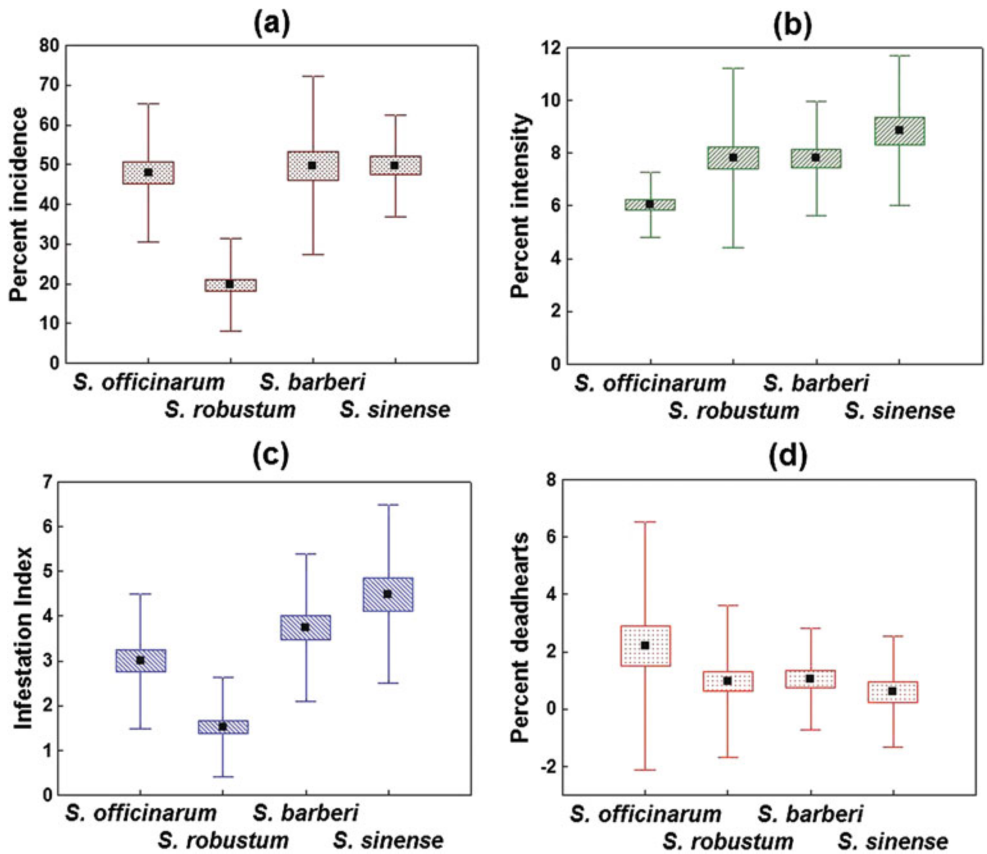

Figure 2. Infestation parameters of *Chilo sacchariphagus indicus* amongst accessions of four *Saccharum* spp.: (a) incidence, (b) intensity, (c) infestation index and (d) deadhearts. Markers represent mean, boxes indicate mean ± SE and whiskers display mean ± SD.

deadhearts was the highest in *S. officinarum* followed by *S. robustum*, *S. sinense* and *S. barberi* (Table 2; Figure 2d). The lowest overall mean deadheart (0.6%) was observed in *S. sinense* and the highest (2.2%) in *S. officinarum*. When all 171 accessions were considered together, 21.6% accessions showed deadheart symptoms.

Kruskal–Wallis ANOVA by ranks showed significant differences amongst the four *Saccharum* spp. for incidence ($\chi^2 = 84.56$; df = 3; $N = 171$; $P < 0.0001$), intensity ($\chi^2 = 24.61$; df = 3; $N = 171$; $P < 0.0001$) and infestation index ($\chi^2 = 72.43$; df = 3; $N = 171$; $P < 0.0001$) but not for percent deadhearts ($\chi^2 = 5.86$; df = 3; $N = 171$; $P = 0.118$). Multiple comparison z' and P values established *S. robustum* as the species harbouring significantly lowest incidence amongst the four species; the other three showed no differences amongst them (Table 2). Intensity was, however, significantly lowest in *S. officinarum* whilst the other three species had similar intensity. Infestation index showed the same trend as percent canes attacked in that it was significantly lowest in *S. robustum* and highest in *S. sinense; S. barberi* showed overlapping differences

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with *S. officinarum* and *S. sinense*. Percent deadhearts did not differ amongst the four *Saccharum* spp.

Categorization of accessions

All accessions showed borer attack in at least one experimental year. The 171 accessions were grouped broadly into three different categories following the grading suggested by Mukunthan (2001) based on the higher incidence level between the two study years. Of the 171 accessions from the four *Saccharum* spp., 29 (17.0%) were placed in resistant category, 39 (22.8%) in moderately resistant category and 103 (60.2%) in susceptible category (Table 3).

Out of the 39 accessions of *S. officinarum*, none was placed in the resistant category (Table S2). Whilst 17.9% accessions were in the moderately resistant category, a large majority (82.1%) showed susceptible reaction. In *S. robustum*, whilst nearly half (44.5%) the accessions emerged as resistant to *C. sacchariphagus indicus*, a considerable number occupied the moderately resistant category. The reaction of *S. barberi* accessions was similar to that of *S. officinarum* in that none was resistant to the borer; considerable percentage (76.9%) of accessions remained susceptible to the borer. *Saccharum sinense* occupied the last position with 28 accessions (93.4%) emerging as susceptible. Only one accession each, namely KHADYA with 13.7% borer incidence and PANSAHI with 28.6% borer incidence represented resistant and moderately resistant categories, respectively.

Morphological characters vs. borer incidence

Amongst the morphological characters examined, leaf length showed non-significant correlations with incidence, intensity and infestation index in all four *Saccharum* spp. (Table S3). Leaf width showed non-significant correlations for all parameters and species except for a significant negative correlation with infestation index in *S. sinense*. For cane thickness, the only significant relationship was the positive correlation with incidence in *S. officinarum*. Cane height showed significant negative correlations with infestation index in *S. officinarum*, and incidence and infestation index in *S. barberi*. Sucrose content in cane showed significant negative correlation with intensity in *S. officinarum*; significant negative correlations with incidence and infestation index in *S. robustum*; significant negative correlation with

Table 3. Categorization of *Saccharum* spp. accessions on the basis of higher percent incidence of *Chilo sacchariphagus indicus* in 2 years (2011 and 2012).

		No. of accessions			
Infestation (%)	Category	*S. officinarum*	*S. robustum*	*S. barberi*	*S. sinense*
0–15	Resistant	0 (0.0)*	28 (44.5)	0 (0.0)	1 (3.3)
15–30	Moderately resistant	7 (17.9)	22 (34.9)	9 (23.1)	1 (3.3)
>30	Susceptible	32(82.1)	13 (20.6)	30 (76.9)	28 (93.4)

*Numbers in parenthesis are percent values for each species.

incidence but significant positive correlation with intensity in *S. barberi*; significant positive correlations with incidence and infestation index in *S. sinense*.

Mann–Whitney U test carried out for sheath hair character indicated that in *S. officinarum*, incidence and infestation index ranked significantly higher in accessions with sheath hair than those without it. In *S. barberi*, incidence ranked significantly higher but intensity ranked significantly lower in accessions with sheath hair. Nature of leaf sheath clasping generally showed non-significant impact on borer infestation parameters. In *S. barberi*, however, tight leaf sheath showed significantly lower rank for incidence but significantly higher rank for intensity than loose leaf sheath.

DISCUSSION

Chilo sacchariphagus indicus, a major borer pest of sugarcane restricted to tropical Indian states, is known to be active from June to December in the sugarcane monoculture belts with peak activity during June and July, albeit with minor variations in different locations (David, 1986). Under mild or favourable climatic conditions that facilitate year-round plantations, the borer and its natural enemies remain active throughout the year (Srikanth *et al.*, 1999). In the present study site, where the sugarcane germplasm is maintained as a crop island from January to December, the onset of *C. sacchariphagus indicus* activity in July could be due to two reasons: (i) suitability of 6-month old crop for first attack and (ii) harvest in June of the previous season crop, generally maintained for an additional 6 months to ensure emergency seed material in the event of germination failure, leading to dispersal of the borer to the current season crop. The increase in borer attack rates in the next 2 months appeared to be more due to suitability of the crop stage and general favourable conditions of moderate air temperature and humidity than the influence of any specific weather parameter as the non-significant correlations between monthly weather data and borer attack for the short 6-month period indicated. Although crop maturity may have led to the decrease in borer incidence rates during September–November, attack of side shoots in deadheart canes and water shoots may have contributed to the higher attack rate in December. Such higher incidence of the borer observed late in the season justified the assessment of the *Saccharum* spp. accessions on the basis of cumulative incidence of the borer at harvest.

Significant differences in attack rates in 2011 and 2012 observed for pink stem borer *Sesamia inferens* (Walker) (Lepidoptera: Noctuidae) and leaf miner *Aphanisticus aeneus* Kerremans (Coleoptera: Buprestidae) were suggested to be independent of climatic factors. Differential response of individual accessions or directional location of the germplasm collection in the Research Centre was suggested to be partly responsible for such variation (Mahesh *et al.*, 2014, 2015a). Higher *C. sacchariphagus indicus* incidence in 2012 than in 2011 observed for *S. officinarum*, *S. barberi* and *S. sinense* could also be due to the same reasons. However, assuming the possibility of higher borer activity in 2012, the absence of significant difference in attack rates for *S. robustum* suggested that this species responded similarly under differential intensity of the borer thus emerging as a source of resistance.

Amongst the three parameters used for assessing the borer injury, higher ranges of incidence than intensity values for all four *Saccharum* spp. indicated higher between-plant than within-plant dispersal of the borer. The infestation index, developed from the percent incidence and percent intensity, gave a trend similar to that of incidence parameter both in terms of range and mean ranks. Whilst assessing the resistance of commercial and experimental sugarcane cultivars to the Mexican rice borer *E. loftini*, Wilson *et al.* (2015) used a relative resistance ratio calculated from relative resistance rankings based on proportion of bored internodes and relative survival, the latter based on adult emergence holes developed by Bessin *et al.* (1990). Since larvae of *C. sacchariphagus indicus* often display cane-to-cane dispersal and pupate outside the cane, assessment of relative survival rate is infeasible. Instead, intensity was assessed from the number of bored internodes and total internodes in affected canes. However, due to the non-significant correlation coefficients between incidence and intensity obtained for the four species, only incidence was used as a rapid and low sampling-cost method to assess the resistance status of the four *Saccharum* spp. against *C. sacchariphagus indicus*.

Chilo sacchariphagus indicus is known to cause deadhearts (Mukunthan and Rakkiyappan, 1989; Srikanth and Kurup, 2011) in commercial varieties, particularly in young and weak shoots (David, 1986). Apparently, this is due to the mismatch between larval development and plant growth rates leading to the larvae reaching the meristem in the course of vertical feeding. A similar mechanism would have operated in the four *Saccharum* spp. Although the range of percent deadhearts in the accessions showed some variation, the non-significant differences in the mean ranks indicated that the four species responded similarly or provided identical conditions required for the production of deadhearts. Also, since percent incidence included deadhearts whose intensity was far lower than that of internode injury, as was also observed earlier in commercial varieties in growers' farms (Srikanth and Kurup, 2011), deadheart injury was ignored as a separate parameter.

Categorization of accessions on the basis of higher incidence between the 2 years not only accounted for the year-to-year variation but also avoided erroneous grouping due to the possibility of escape in the low infestation year. The categorization adopted in the present study (Mukunthan, 2001) with lower ranges of infestation in each category was more stringent than other systems of classification (Radadia and Shinde, 2013) in vogue. Despite such rigorous classification, about 40% of accessions of the four *Saccharum* spp. showed resistance to moderate resistance against internode borer. Amongst the four species, *S. robustum* emerged clearly as the source with the highest resistance whereas the other three species showed more or less similar categorization. The susceptible status of *S. officinarum* and resistance status of *S. barberi* accessions to the borer were indicated in an earlier study based on infestation index (Jayanthi, 1988). In another study on sugarcane early shoot borer *Chilo infuscatellus* (Snellen) (Lepidoptera: Crambidae), despite the far fewer number of *Saccharum* spp. accessions used, the highest resistance was observed in *S. spontaneum* and *S. robustum* whilst the other species showed susceptible entries (Kumar *et al.*, 2002). In our earlier studies with the pink stem borer *S. inferens* in accessions of the four *Saccharum* spp., *S. robustum* emerged as the resistant species and *S. officinarum* as the susceptible species (Mahesh *et al.*, 2014). All these studies indicated that *S. robustum* and *S. officinarum* showed similar resistance and susceptibility status, respectively to *C. sacchariphagus indicus*, *C. infuscatellus* and *S. inferens* which suggested common mechanisms of resistance to all these borers in the four *Saccharum* spp.

Amongst the morphological characters selectively examined for their relationship with *C. sacchariphagus indicus* infestation parameters, leaf length and width are expected to impart typical canopy architecture with a bearing on visual attraction for oviposition. On the other hand, greater thickness and lesser height can enhance the suitability of the cane for entry of young larvae. However, the general lack of significance in correlation analysis indicated the weak influence of these plant morphological characters on borer activity. Presence or absence of sheath hair can potentially interfere with movement and entry of young larvae into the tender top internodes. Varieties with close-fitting leaf-sheaths showed higher incidence than the loose-fitting and self-detrashing varieties apparently because the newly hatched borer larvae generally remain inside the leaf-sheaths in the initial stages before feeding their way slowly into the cane, and grown-up larvae usually pupate underneath the leaf-sheath (David, 1986). Coburn and Hensley (1972) reported that tightness of leaf-sheaths was partially responsible for the resistance to *D. saccharalis*. However, these two characters did not seem to affect *C. sacchariphagus indicus* activity as evidenced from the general lack of significance in Mann–Whitney U test of ranks for accessions in each of the four *Saccharum* spp.

Association studies of selected biochemical nutrients in different hosts and levels of *E. loftini* infestation showed that plant species with relatively high levels of fructose supported elevated levels of the borer consistently (Showler and Moran, 2014). However, such possible impact of carbohydrates on borer levels was not evident in the present study as indicated by the variable relationship between sucrose content and *C. sacchariphagus indicus*. A similar absence of relationship between selected cane yield or quality parameters and infestation parameters of stalk borer *Chilo auricilius* Dudgeon (Lepidoptera: Crambidae), a borer with predominance in subtropical India and feeding habits similar to *C. sacchariphagus indicus*, was observed in sugarcane genotypes, including subtropical, exotic and interspecific and intergeneric hybrids (Pandey *et al.*, 2014). These trends suggested the possible significant role of plant biochemical factors rather than morphological or nutritional characters for resistance against borers in sugarcane.

With no commercial cultivation of sugarcane either for sugar or jaggery for several kilometres around, the world collection of sugarcane germplasm established in the late 50s represents a crop island intended to serve as a fail-safe measure against pest incursion. However, over the decades, the germplasm had been colonized by a few pests, including *C. sacchariphagus indicus*, whose populations rose to considerable levels in the recent years. The high 96.3% infestation rate of the borer observed in an *S. officinarum* accession adequately justified the screening of *Saccharum* spp. at the present study site. Around 60% of accessions from all four *Saccharum* spp. rated as susceptible can be rejected straight away since they showed more than 30%

incidence. The accessions classified as moderately resistant and resistant, particularly of *S. robustum* which contributed significantly to these two categories, need to be re-evaluated under more stringent conditions of natural infestation or artificial inoculation of the borer before selecting them as potential donors in resistance breeding programmes.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S0014479716000697

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