Resistance Mechanisms of Sugarcane to Mexican Rice Borer (Lepidoptera: Pyralidae)

B. L. MEACHER, JR.,1 J. E. IRVINE, R. G. BREENE,2 R. S. PFANNESTIEL1 AND M. GALLO-MEACHER3

Texas Agricultural Experiment Station, 2415 East Highway 93, Weslaco, TX 78596

ABSTRACT
Larval anesthetics and adult and larval nonsuppression studies were compared with field screening studies to determine the sugarcane characters and mechanisms that may cause resistance against the Mexican rice borer, E. lioptini (Dyar). Larval anesthetics results of diet incorporation bioassays suggest the presence of antinutritional components or allelochemicals in some genotypes. Differences in adult disposition among genotypes in laboratory, greenhouse, and field studies were slight; therefore, repulsion preference is probably not important in conferring resistance. Laboratory experiments indicated that differences in larval establishment could be an important resistance character. Field results confirmed earlier research that sugarcane genotypes vary in their level of injury to this pest. However, field results did not always compare favorably with laboratory results, suggesting that several mechanisms of resistance may be important in this sugarcane--stalkborer system.

KEY WORDS: E. lioptini, Saccharum, plant resistance, anesthetics, nonsuppression, stalkborers

TWO STALKBORING PLAGUES, Mexican rice borer, E. lioptini (Dyar), and sugarcane borer, D. saccharalis (F.), are serious economic pests of sugarcane in the Lower Rio Grande Valley of Texas (Meagher et al. 1992). E. lioptini was first detected in the Lower Rio Grande Valley in 1980 (Johnston and van Leerden 1981) and has replaced D. saccharalis as the primary insect pest of sugarcane (Krueger et al. 1994). Insecticidal control of E. lioptini has been generally unsatisfactory (Meagher et al. 1994). Classical biological control has also been unsuccessful (Brown and Melton 1987, Smith et al. 1987, Plannenet et al. 1992).

Two lines of evidence suggest that the importance of the sugarcane--stalkborer system has led to increased interest in plant resistance.

1 Current address: Department of Entomology, University of Minnesota, St. Paul, MN 55108-8128.
2 Current address: P.O. Box 8104, South Padre Island, TX 78597.
3 Current address: Tree Fruit Research Center, Washington State University, 1500 N. Waverly Avenue, Wenatchee, WA 98801.
4 Current address: Department of Agronomy and Plant Genetic, University of Minnesota, St. Paul, MN 55108.

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Lack of success with these pest management strategies has led to increased interest in plant resistance. Plant resistance has been an important management strategy for stalkboring plagues in many sugarcane-growing regions of the world (Mathers and Charpentier 1969, Nuss and Atkinson 1983). In Louisiana, plant resistance has been a component of the sugarcane integrated pest management program against D. saccharalis for many years and has been a successful management strategy when used alone or in combination with other strategies (Long et al. 1981, Bessin et al. 1990, White et al. 1993).

In Texas, the relative susceptibility of sugarcane progenitors and clones to stalk injury by E. lioptini has been measured in field studies under natural infestation conditions. Results suggested large variability in bored internodes among progenitors such as Missetanus fortitulus (Lahill) Wach., E. benthami (Bentz), B. bennariensis (Bentz), and E. fruini (Haack), Saccharum spontaneum L. and S. officinarum L. (Bing and Browning 1990). Modern sugarcane is a complex polyploidy clone consisting of aneuploids developed as tri- and quadranspecific hybrids of Saccharum (White et al. 1993). Screening of commercial (cultivar) and noncommercial sugarcane clones showed variability in E. lioptini injury (Plannenet and Meagher 1961). Field evaluation of sugarcane germplasm for internodes bored by E. lioptini has continued since 1989 (B.L.M., unpublished data). Mathers and Charpentier (1969) classified components associated with stalkborer resistance as (1) unsusceptibility of plants to adults for oviposition, (2) plant characters unfavorable for larval establishment in the plant, (3) plant characters that inhibit or retard larval development, and (4) plant tolerance (Painter's definition) (Painter 1951). Life history characteristics of stalkborders can provide further evidence for resistance factors in sugarcane germplasm (for review of life history characteris-tics, see Smith et al. 1993). The objectives of this
research were to compare laboratory measures of larval resistance and adult and larval nonpreference studies with results of field injury so that mecha-
nizations involved in conferring plant resistance to E. lophysi can be determined.

Materials and Methods

Antioxidant Bioassays. Sugarcane leaf sheaths at

tached to the 5th leaf below the apical meristem were collected from mature plants of each cultivar and

cut and stored at ~20°C. Fresh leaf sheaths were then placed in a lyophilizer (Dura-

day Condenser Module, FTS Systems, Stone Ridge, NY) for 6 h. Lyophilized tissue was passed through a 40-mesh screen using a Thomas Wiley Intermediate Mill (Thomas Scientific, Swedesboro, NJ). The remaining powder was placed in a sealed plastic bag and stored at ~20°C. During meridic

diet preparation (Martinez et al., 1996), the powder was added in the final steps at the rates of 5, 10, or 12 g/100 ml diet (=50, 100, 120 mg tissue per milliliter of diet). As additional 10.0, 39.2, and 47.0 mg of distilled water, respectively, was added to

improve blending capability.

The meridic diet plus tannin was added to 25 diet
cups (195.5 ml, Fill-Rite, Newark, NJ), and 1 E. lophysi larva was added per cup. Larvae from an E. lophysi culture collected from the Lower Rio Grande Valley and <1 yr old were used in all bioassays. Cups were placed in a growth chamber (Percival, Boone, IA) at 30°C and a 14:10 (L:D) h photoper-

iod. Larvae were weighed (Dexter A106, Dexter Instrument, Arvada, CO) after 14 d. After 21 d, cups were checked daily for pupal formation, and surviving pupae were weighed and their sex deter-

mined. The experiment was arranged as a random-

ized complete block design with 3 replications. A replicate consisted of a mean of 25 larvae.

Analysis of variance (ANOVA) (PROC GLM, SAS Institute 1987) was used to compare the 3 dependent variables larval weight, pupal weight, and days to pupation among leaf sheath tissue amounts added to meridic diet. The ANOVA mod-

el contained sample (leaf sheath) as a block. ANOVA (CP 65-

350, CP 70-321, CP 70-324, CP 72-1210, CP 80-1827, CP 87-6215, CP 87-1130, NC 3105, TCP 81-3505, TCP 83-3135, TCP 83-3346, TCP 85-3647, and TCP 85-6076), tissue amount (0, 50, 100, 120 mg/ml), sex (2), and all 2- and

3rd-order interactions. ANOVA also was used to compare the same dependent variables among

clones. However, measurements of larval weight, pupal weight, and days to pupation measurements

from the diet tissue amounts (0 mg/ml) were com-
mbed, and included as a “control” clone.

Nonpreference Bioassays. Oviposition: Labo-

ratory Choice and No-Choice Experiments. Three 

separate tests were conducted to compare the ovip-

osition preference of moths with 2 standard sugarcane cultivars grown in Texas. Female E. lophysi oviposited cryptically on the dried plant material

near the base of the stalks by inserting the egg mass into folded leaf crevices (van Leerdom et al., 1994, 1995). To create this effect, dried sugarcane leaves were soaked in water for 5 min. One leaf edge was folded ~7 mm inward while the entire leaf stem was pressed with heat (iron). Four
dried leaves of NC 310 and CP 70-321 each, all 10.6 cm long, were alternated posteriorly in a circle in soil inside oviposition chambers (cardboard containers, 17 cm diameter, 17 cm deep). Test 1 contained 1 female and 2 male moths in the chambers (31 replications), and test 2 con-
tained 5 female and 5 male moths (8 replications). Test 3 was a no-choice test in which 5 leaves of either cultivar were placed in the chamber with 5 females and males (5 replications). The chambers were placed in darkened incubators at 30°C. After

72 h, the leaves were removed, and the number of eggs on the 2 cultivars were recorded. Mexican rice borer females deposit eggs in masses ranging in number from 5 to 146; therefore, the number of eggs deposited was recorded rather than the number of egg masses (van Leerdom et al., 1995). For each test, a t-test for significant differences was performed (PROC T-TEST, SAS Institute 1987).

Oviposition: Greenhouse Experiments. Two tests

were conducted during 1986 in large cages (1.8 m high, 1.8 m wide, 2.4 m long) within a greenhouse (fin and cooling pad design, a clear plastic cover-

ing, no shade cloth). The cages had contiguous wooden frames and were covered with white or-

gard cloth. Scaans and joints of the cages were sealed with caulk to prevent the escape of E. lophysi. Test 1 was a choice test to compare oviposi-
tion among 6 cultivars. Four young plants (at or nearly at the grand growth stage, ~1.4 m tall) of each cultivar (CP 65-357, CP 70-321, CP 70-

324, CP 71-1038, NC 310, TCP 81-3058) were placed randomly within the greenhouse, and 15 male moths were released in the cage by placing pupae (sex determined) on a tray that was hung in the middle of the cage. Plants were sam-

pled for eggs and number of dead, brown leaves 72 h after introduction. The test was repeated 3 times for a total of 4 trials. Data were analyzed using an ANOVA (PROC GLM, SAS Institute 1987) with trial, plant, and cultivar as class vari-

ables.

For test 2, 2 individually compared NC 310 versus CP 70-321, NC 310 versus CP 70-324, and CP 70-321 versus CP 70-324. Five plants of each cul-

tivar were randomly placed within each cage, and 30 females and 15 males were released. Three sep-

arate trials were conducted. Eggs and brown leaves were counted after 72 h. Data were analyzed using

the tests (PROC T-TEST, SAS Institute 1987).

Oviposition: Field Cage Experiment. Field 

plots were used to compare oviposition on 2 cultivars. In late 1989, NC 310 and CP 70-321 were plant-
ed in alternating rows on the Texas Agronomic Experiment Station, Weslaco, using standard sug-
arsenic planting procedures. Large cages (3.0 by 2.4 by 3.4 m) were placed over the top of the two rows during May and September 1990 and May and August 1991. For each separate test, 25 female and 20 male moths were released per cage. The test was replicated 4 times by moving cages to different areas of the field. Sugarcane plants were sampled for E. lobii and brown leaves 72 h after infestation. Data were analyzed using t-tests (FPROC T-TEST, SAS Institute 1987).

Larvae: Laboratory Experiments. Sugarcane leaf whole and leaf sheath tissue were used in choice tests to compare larval preference and establishment. The leaf whole tissue test consisted of 5 cross sections (2 mm) of the standard cultivars NCO 310 or CP 70-7321, and 5 pieces of a test cultivar placed alternately along the perimeter of a petri dish (9 cm diameter, 1.5 cm deep). The test-cultivars were CP 85-357, CP 70-321, CP 70-324, CP 71-1036, LCP 81-10, and TCP 81-3058. Petri dishes were filled with 2% (w/v) agar for moisture retention. Ten neonates were gently brushed onto the center of each petri dish and placed in a darkened incubator at 30°C. The number of larvae present on the sugarcane pieces was recorded 1, 3, 6, and 24 h after infestation (15 replications). Data were analyzed using t-tests (FPROC T-TEST, SAS Institute 1987).

In the test of leaf sheath tissue, tissue from the 1st-4th leaf sheaths (counting from stalk bottom upward) and leaf roll tissue =1 mm above the apical meristem was used. Leaf roll tissue is that part of the apparent stem that consists of leaf tissue. It exists from the terminal bud to the collar of the youngest fully expanded leaf. The outer layers are primarily leaf sheath tissue and the inner portion is mostly leaf tissue. Three 5-mm cross sections of NCO 310 and CP 70-321 were placed alternately along the perimeter of a petri dish (9 cm diam.). Dishes were filled with 2% (w/v) agar for moisture retention. Twenty neonates were positioned in the dish center, and dishes were placed in a darkened incubator at 30°C. The number of larvae present was recorded 1, 4, and 24 h after infestation (5 replications). Data were analyzed using t-tests (FPROC T-TEST, SAS Institute 1987).

Field Susceptibility. A comparison of 12 cultivars and one control (Rice Industries Standard cultivar NCO 310) was completed using accelerated breeding line evaluations from the 1998-1999 to 1994-1995 field tests (R.L.M., unpublished data). Methods used to evaluate cultivars and clones are described in the Menn et al. (1991). Briefly, field plantings with 16-22 cultivars and clones were evaluated for agronomic performance and stinkhopper injury in plots with 4 rows (0.9 m long) on a 1.5-m row spacing. Field layout was a completely block design with 4 replications, and plantings were replicated across several Lower Rio Grande Valley locations. To evaluate stinkhopper injury, 15-20 stalks were removed from the outer 2 rows of each plot at harvest.

Table 1. Growth and developmental parameters for E. lobii fed meristic diet containing different sugarcane clone leaf sheath tissue

<table>
<thead>
<tr>
<th>Tissue amount</th>
<th>Wt. mg</th>
<th>No. days to pupation</th>
</tr>
</thead>
<tbody>
<tr>
<td>right</td>
<td>100</td>
<td>241</td>
</tr>
<tr>
<td>left</td>
<td>90</td>
<td>21.1</td>
</tr>
<tr>
<td>85</td>
<td>16.5</td>
<td>0.5</td>
</tr>
<tr>
<td>80</td>
<td>15.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

For each variable, means ± SE followed by the same letter are not significantly different (P = 0.05, Waller-Duncan k ratio t-test). ANOVA for larval weight F = 23.7; P = 3.200; F < 0.0001; for pupal weight F = 29.6; P < 0.0001; for days to pupation F = 52.1; P = 3.200; F < 0.0001.

*Significant of sugarcane tissue per milliliter of meristic diet.

Results

Antibiosis Bioassay. Adding increasing amounts of leaf sheath tissue to the meristic diet affected growth and development of E. lobii negatively. Larval and pupal weights were lower and days to pupation were longer when leaf sheath tissue was added to the diet (Table 1). Female larvae and pupae were heavier than those of the male (female larvae 20.1 ± 0.8 mg, male 18.0 ± 0.7 mg, P = 0.024; female pupae 28.9 ± 0.6 mg, male 25.7 ± 0.3 mg, P < 0.0001, respectively) and took longer to develop than males (female 25.7 ± 0.3 d, male 24.2 ± 0.2 d, P < 0.0001). The only interaction that was significant was diet amount x sex for pupal weight (P < 0.0001). This interaction can be explained by smaller differences between female and male pupal weights as increasing amounts of sugarcane tissue were added to the diet.

Clones expressed genotypic differences in larval and pupal weights and days to pupation (all P < 0.0001). Larvae fed on meristic diet (control) and the number of immatures from TCP 80-4078 and NCO 310 were significantly heavier than larvae fed diet mixed with sugarcane leaves. (Table 1). Resulting pupae from the control diet were heavier than other genotypes (Table 1). Resulting pupae from the control diet were heavier than other genotypes. (Table 1). Resulting pupae from the control diet were heavier than other genotypes. (Table 1). Resulting pupae from the control diet were heavier than other genotypes. (Table 1). Resulting pupae from the control diet were heavier than other genotypes. (Table 1). Resulting pupae from the control diet were heavier than other genotypes.
Table 2. Responses of E. leitana larvae after feeding on meristemic tissue containing various amounts of different sugarcane clone times.

<table>
<thead>
<tr>
<th>Clone</th>
<th>Wt. ng</th>
<th>No. d. population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>24.7 ± 1.3</td>
<td>37.7 ± 4.6</td>
</tr>
<tr>
<td>TCP 90-4078</td>
<td>25.6 ± 2.35</td>
<td>39.7 ± 4.09</td>
</tr>
<tr>
<td>NCO 310</td>
<td>25.0 ± 2.3</td>
<td>22.3 ± 2.8</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>19.4 ± 1.85</td>
<td>32.4 ± 1.36</td>
</tr>
<tr>
<td>TCP 60-3346</td>
<td>19.2 ± 2.35</td>
<td>31.8 ± 1.79</td>
</tr>
<tr>
<td>TCP 01-3058</td>
<td>19.1 ± 1.75</td>
<td>28.3 ± 1.74</td>
</tr>
<tr>
<td>TCP 60-3346</td>
<td>19.1 ± 2.32</td>
<td>26.3 ± 1.39</td>
</tr>
<tr>
<td>TCP 01-3213</td>
<td>15.8 ± 2.32</td>
<td>29.5 ± 1.81</td>
</tr>
<tr>
<td>CP 72-1501</td>
<td>15.3 ± 0.64</td>
<td>27.3 ± 2.02</td>
</tr>
<tr>
<td>TCP 89-157</td>
<td>15.7 ± 1.41</td>
<td>29.5 ± 2.16</td>
</tr>
<tr>
<td>CP 70-324</td>
<td>14.4 ± 0.55</td>
<td>30.7 ± 1.16</td>
</tr>
<tr>
<td>CP 60-200</td>
<td>13.3 ± 0.65</td>
<td>30.7 ± 1.28</td>
</tr>
<tr>
<td>CP 67-415</td>
<td>12.9 ± 0.54</td>
<td>30.3 ± 1.16</td>
</tr>
<tr>
<td>LAP 81-101</td>
<td>11.8 ± 1.0</td>
<td>28.1 ± 1.75</td>
</tr>
</tbody>
</table>

For each variable, means ± SE followed by the same letter are not significantly different (P > 0.05; Waller-Duncan K ratio t-test). ANOVA for larval weight: F = 4.84, df = 12, 150, P = 0.006; for pupal weight: F = 4.1, df = 12, 119, P = 0.005; for days to pupation: F = 7.3, df = 12, 150, P = 0.006.

Nutritional factors and allelochemical analysis of leaf tissue has not been investigated thoroughly in sugarcane as it has in other crops (Woodhead and Tanjea 1987). Our study represents the first use of a diet incorporation bioassay to determine antibacte- rials of sugarcane tissue. Larval weight and days to pupation were not affected by the addition of leaf tissue of sugarcane tissue from the known susceptible genotype (NCO 310) compared with the meristemic diet. Therefore, it appears the differences between the resistant genotypes (CP 70-321, CP 72-1210, and TCP 90-3168) and the susceptible genotypes were a result of allelochemicals in the tissue rather than from varying textures in the treatment diets (Bong et al. 1996). Allelochemical variables analyzed, pupal weight explained the most variation in the models, followed by days to pupation and larval weight (r² = 0.822, 0.630, 0.480, respectively). It is not known why larval weight measured at 14 d was erratic. Even in the control or meristemic diet, many larvae of the same sex were quite variable in weight but had similar pupal weights and develop- mental periods. Further experimentation into the physiological and behavioral requirements of E. leitana larvae may help to explain this variation.

Nonpreference Bioassays, Outcross: Laboratory Choice and No-Choice Experiments. No sig- nificant differences were found in eggs per leaf in comparisons between NCO 310 and CP 70-321 in either choice test (test 1, t = 0.14, df = 31.3, P = 0.86; test 2, t = 0.72, df = 11.0, P = 0.48). In choice test 1, individual females laid 5.8 ± 1.4 eggs on NCO 310 leaves compared with 6.14 ± 3.1 eggs on CP 70-321. In choice test 2, 6.4 ± 1.9 eggs were laid per female per leaf on NCO 310 compared with 4.1 ± 1.0 eggs on CP 70-321. In the no-choice tests, females laid more eggs on CP 70-321 leaves than on NCO 310 leaves (10.4 ± 2.8 versus 2.9 ± 1.0, respectively, t = 3.02, df = 62, P = 0.006).

Table 4. Orpistoplos responses of E. leitana females to different sugarcane cultivars in a greenhouse test.

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>No. egg/plant</th>
<th>No. brown leaf/plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCO 310</td>
<td>28.9 ± 8.4a</td>
<td>6.2 ± 0.5b</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>14.6 ± 0.4a</td>
<td>6.0 ± 0.5a</td>
</tr>
<tr>
<td>NCO 310</td>
<td>13.3 ± 1.0a</td>
<td>6.0 ± 0.5b</td>
</tr>
<tr>
<td>CP 70-324</td>
<td>27.3 ± 0.3a</td>
<td>8.0 ± 0.5a</td>
</tr>
<tr>
<td>CP 72-1501</td>
<td>20.2 ± 1.6a</td>
<td>8.1 ± 0.5a</td>
</tr>
<tr>
<td>CP 70-324</td>
<td>30.2 ± 0.3a</td>
<td>8.7 ± 0.5a</td>
</tr>
</tbody>
</table>

For each variable within each cultivar comparison, means ± SE followed by the same letter are not significantly different (P > 0.05, t-test). ANOVA for NCO 310 versus CP 70-321, eggs t = 1.83, df = 33, F = 0.077, brown leaves t = 2.20, df = 36, F = 0.037, eggs for NCO 310 versus CP 70-324, eggs t = 1.14, df = 26, F = 0.215, brown leaves t = 3.95, df = 36, F = 0.007, eggs for CP 70-321 versus CP 70-324, eggs t = 1.37, df = 36.3, F = 0.716, brown leaves t = 0.73, df = 37.8, F = 0.47.
Fig. 1. Oviposition responses of E. lobi ifinis females on different sugarcane cultivars in individual comparisons in field cage tests. *t*-tests for spring 1990, eggs \( t = -3.30, df = 4.2, P = 0.7385 \), brown leaves \( t = -1.10, df = 5.4, P = 0.3506 \); t-tests for summer 1990, eggs \( t = 1.33, df = 5.9, P = 0.1939 \), brown leaves \( t = -0.16, df = 4.9, P = 0.8795 \); t-tests for spring 1991, eggs \( t = -0.46, df = 5.6, P = 0.8976 \), brown leaves \( t = -1.31, df = 4.4, P = 0.2186 \); t-tests for fall 1991, eggs \( t = 0.01, df = 2.1, P = 0.9331 \), brown leaves \( t = 0.62, df = 3.0, P = 0.6766 \).

Fig. 2. Larvae of E. lobi ifinis found on sugarcane leaf whorl tissues from NCo 310 compared with other cultivars in laboratory choice tests. * \( P < 0.05 \), ** \( P < 0.01 \), *** \( P < 0.001 \).

Leaf sheaths and leaf roll contained similar numbers of larvae on both cultivars \( (P > 0.05) \). Larval resistance can be separated into "leaf" and "stalk" resistance. Necasite and young larvae must be able to become established within the leaves, midribs, and leaf sheaths and obtain sufficient nutrients before entering stalks. In our tests, larvae showed preferences for foliar establishment in certain genotypes, and it appears larval preference may be locationally directed among different leaf sheaths within a stalk. The lack of foliar establishment and mortality of neonate larvae has been described as a major factor of resistance (Kyle and Henley 1970, David and Joseph 1984), with leaf sheath suppression, the ability of a plant to self-trash (shed lower leaves and leaf sheath), and leaf midrib harshness documented as specific resistant characters (Chung and Shih 1959, David and Kade 1967, Agewal 1969, Colom and Henley 1972, David and Joseph 1982). However, larval foliar establishment among cultivars as a resistance factor becomes important only if these differences persist.

ilar to those of E. lobi ifinis (Atkinson 1990). Generally, ovipositional resistance has not been correlated with lower stalker over populations in sugarcane (Tucker 1933, Kyle and Henley 1970, Fuchs and Harding 1978, David and Joseph 1984), but characters such as leaf pubescence have been shown recently to be associated with resistance against D. saccharalis (Sosa 1998, 1999).

Larvae: Laboratory Experiments. In tests using leaf sheath tissue, CP 70-321 had fewer larvae than NCo 310 for \( P > 0.05 \) only at 3 h after infestation (Fig. 2a). TPC 81-3058 had fewer larvae than NCo 310 only at 3 h after infestation (Fig. 2b). In comparisons with CP 70-321, fewer larvae were collected on CP 71-1038, whereas more larvae were collected on LCP 81-10 and TPC 81-3058 (Fig. 3). The other tested cultivars contained numbers of larvae similar to NCo 310 or CP 70-321 \((P > 0.05)\). In tests using leaf sheath tissue, only the 4th leaf sheath produced significant differences between NCo 310 and CP 70-321 (hour 4, \( 4.0 \approx 0.7, 3.1 \approx 1.1 \), respectively, \( t = 3.73, df = 0.7, P = 0.0068 \); hour 24, \( 4.0 \approx 0.9, 4.2 \approx 0.7 \), respectively, \( t = 3.17, df = 7.5, P = 0.014 \)). The 1st, 2nd, and 3rd
Fig. 3. Larval E. latifoli found on sugarcane leaf scar tissues (four CP 70-321 compared with other cultivars in laboratory trials tests. *, P < 0.05. **, P < 0.01, ***, P < 0.001 by FISCO T-TEST (SAS Institute 1987).

until stalks are invaded (Bernays et al. 1983); if over longer periods of development, the final level of infestation is independent of initial numbers, then differences among cultivars in establishment are not important (Chapman et al. 1983). Our study did not examine factors specifically involved with stalk resistance. Mid-sized and larger larvae must be able to enter, become established, tunnel within the stalk, and gain enough nutrition to complete development and emerge as a mature, fecund adult.

Field Susceptibility. Bored inserts, from the standard cultivar NCO 310 were compared with other clones in 41 field plantings. CP 70-321, TCF 86-4778, TCF 85-3160, and CP 90-1827 had significantly fewer bored intermediates in 62.5% (5 of 8 comparisons), 60.0% (6 of 10), 57.1% (4 of 7), and 53.9% (7 of 13) of the plantings, respectively (Table 5). CP 70-321 (28.9%), 8% (of 28), CP 72-1210 (25.0%), 5 of 20), CP 89-350 (25.0%, 1 of 4), TCF 85-3215 (14.3%, 1 of 7), and CP 87-6315 (6.3%, 1 of 15) also had a significantly lower number of bored intermediates, but in a few percentage of plantings, TCF 85-3348 (40.0%, 2 of 5) and LCP 81-10 (16.7%, 1 of 6) had a significantly higher number of bored intermediates than NCO 310.

Discussion

Comparisons in our studies among leaf sheath blossoms, adult and larval nonpreference studies, and field susceptibility results pose interesting questions (Table 5). The lack of antioxidants determined in laboratory tests of TCF 86-4778 and CP 70-321 indicates that larvae function well once they have entered leaf sheaths but have difficulty becoming established in leaf sheaths, entering stalks, or tunneling within stalks. Low larval numbers found on pieces of CP 70-321 leaf sheath provided evidence for low larval establishment in leaf sheaths. The opposite scenario was true for LCP 81-1, a genotype possessing high stalk injury. Diet mixtures with this genotype produced small larvae and pumice and long development times, but larval establishment, as indicated by numbers of larvae on leaf sheath pieces, was comparable with NCO 310. Perhaps stalk atraumatic and consumption by E. latifoli on LCP 81-10 is more efficient than on other genotypes. CP 70-321, a genotype possessing field resistance, showed evidence for leaf sheath

Table 5. Sugarcane genetic comparison with NCO 310, adult resistance, larval nonpreference, and larval nonpreference

<table>
<thead>
<tr>
<th>Field resistance, %</th>
<th>Leaf sheath</th>
<th>Larval nonpreference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW</td>
<td>PV</td>
<td>DW</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>62.5</td>
<td>+</td>
</tr>
<tr>
<td>TCP 86-4778</td>
<td>80.0</td>
<td>+</td>
</tr>
<tr>
<td>CP 75-321</td>
<td>57.1</td>
<td>+</td>
</tr>
<tr>
<td>CP 85-1827</td>
<td>53.9</td>
<td>+</td>
</tr>
<tr>
<td>CP 70-321</td>
<td>52.6</td>
<td>+</td>
</tr>
<tr>
<td>CP 86-4778</td>
<td>52.0</td>
<td>-</td>
</tr>
<tr>
<td>CP 85-3160</td>
<td>62.0</td>
<td>+</td>
</tr>
<tr>
<td>CP 88-3500</td>
<td>51.0</td>
<td>+</td>
</tr>
<tr>
<td>TCP 85-3215</td>
<td>14.3</td>
<td>-</td>
</tr>
<tr>
<td>CP 87-6315</td>
<td>6.3</td>
<td>-</td>
</tr>
<tr>
<td>LCP 81-10</td>
<td>16.7</td>
<td>-</td>
</tr>
<tr>
<td>TCP 86-4778</td>
<td>40.0</td>
<td>-</td>
</tr>
</tbody>
</table>

**P* Percentage of planting where bored intermediates were significantly different from NCO 310.

* Denotes fewer larvae found compared with NCO 310; N, not tested.
antibiotics and a trend for ovipositional nonpreference (Tables 3 and 4) but provided no evidence for larval nonpreference. Our results confirm that several mechanisms of strobilob resistance, including antibiotics and nonpreference, are present across sugarcane genotypes. Tolerance has been suggested as a resistance mechanism in the D. saccharalis crop system, a conclusion based on genotypes possessing high levels of injury such as bored internodes, but low levels of damage such as dead tops, adventitious shoots, secondary tillering, and cane weight loss (White and Henderson 1987, White 1993). However, studies to determine if tolerance is a resistance mechanism in the E. initials crop system have not been completed. Breeding of sugarcane for resistance to mollusks is difficult because of hereditary characteristics of the plant (Atrash and Fatima 1990; White et al. 1993) and limited knowledge of specific resistant characters. Sugar-cane plant breeding and genetic engineering research (Culao- Meagher and Irving 1993) continued to improve insect management would be enhanced by additional studies to determine resistance mechanisms and character identification precisely.

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