SCREENING FOR BORER RESISTANCE AMONG SUGARCANE CLONES IN PAPUA NEW GUINEA, 2010–2012

By

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Abstract

PAPUA NEW GUINEA (PNG) has several damaging moth borers that are not present in Australia, but which would almost certainly cause very serious losses in our sugarcane industry if they reached this country. To prepare for a possible incursion, Australian varieties and promising clones are being tested for their susceptibility to these borers in field trials at Ramu Agri-Industries, PNG. Two trials were planted in 2010 (32 clones) and 2011 (33 clones) and sampled for borers in the plant crop (both trials) and the first ratoon (2010 trial only). There were highly significant differences among clones for internode damage from *Sesamia grisescens* and *Chilo terrenellus* and stalk damage from *Scirpophaga excerptalis*. Generally, there was a greater difference among clones for damage from *S. grisescens* and *S. excerptalis* than from *C. terrenellus*. The twelve standard clones in these trials were also present in trials planted in 2002 and 2007, which were sampled for borers in the plant crop (both trials) and the first ratoon (2002 trial only). Comparing results of the six data sets, consistent differences among the standard clones were apparent for *S. grisescens* and *S. excerptalis* but were less clear for *C. terrenellus*. Estimates of damage from each of the three borers are presented for some Australian commercial varieties. Other commercial varieties will be included in trials to be planted in 2013.

Introduction

The Australian sugar industry is free of the serious moth borers that are the main sugarcane pests in most other countries. However, Papua New Guinea (PNG) just to our north has several damaging species: the stalk borers *Sesamia grisescen*s (large pink stalk borer; Noctuidae) and *Chilo terrenellus* (internode borer; Crambidae) and the top borer *Scirpophaga excerptalis* (top shoot borer; Pyralidae). *S. grisescens* and *C. terrenellus* are restricted to the island of New Guinea whereas *S. excerptalis* is widespread through Asia. Exotic moth borers are a biosecurity risk to the Australian sugar industry. In order to be prepared for a possible incursion, BSES Limited, in partnership with Ramu Agri-Industries and with partial funding from the Sugar Research and Development Corporation, commenced studying the resistance of Australian varieties to moth borers in PNG in 2010.

Some Australian commercial varieties and advanced clones were already being propagated in PNG while others were shipped to allow screening for borers and diseases (Ramu stunt and downy mildew). *S. grisescens* is the main target of the moth borer trials, as it is judged the most damaging pest at Ramu A-I (Kuniata, 2000), but the other borer species are also recorded during sampling. Results of variety trials testing for resistance to moth borers before 2010 were summarised by Korowi *et al.* (2011). Here we report on data collected since 2010, particularly focusing on consistency among trials and results for some Australian commercial varieties.

Materials and methods

Two trials named SRT (Sesamia Resistance Trial) 01-10 and SRT01-11 were planted on 13-15 December 2010 and 28 November 2011, respectively. SRT01-10 contained 32 clones and

SRT01-11 contained 33 clones, with 13 standard clones common to both. Twelve standard clones were chosen to represent a range of responses to *S. grisescens*, from susceptible to relatively resistant, with another clone, Q219$^{(\phi)}$, included to represent high susceptibility to *S. excerptalis*. The trials also included Australian commercial varieties and promising Australian clones.

Trials were laid out as randomised complete block designs with four replications. Plots measured four rows (1.8 m spacing) by 8 m. Varieties believed to be susceptible to *S. grisescens* (Cadmus or Q136) were planted in a spreader row between each column of plots and also around the outside of the trial to increase the local population of *S. grisescens*. Each plot was separated from the next plot within the column by a 1 m gap, and an empty row was left between each column and the spreader rows on either side.

SRT01-10 was sampled for borers in the plant crop from 20–23 June 2011, 27 weeks after planting, and in the first ratoon from 30 July–3 August 2012, 40 weeks after harvest on 22 October 2011. SRT01-11 was sampled in the plant crop from 5–7 June 2012, 27 weeks after planting. Samples were taken when damage from *S. grisescens* became apparent. Ten stalks were randomly selected from each of the outside rows of each plot and any dead hearts were classified as being the result of infestation by *S. grisescens* or *S. excerptalis*. Stalks were sliced open and total internodes and internodes damaged by each borer species were counted.

Plot totals (over 20 stalks) for numbers of internodes, damaged internodes (for *S. grisescens* and *C. terrenellus*) and infested stalks (for *S. excerptalis*) were analysed by generalised linear mixed models using GenStat 13.2. Numbers of damaged internodes were not analysed for *S. excerptalis* as larvae of this pest tunnel through only a few very young internodes; the primary damage is to the meristem which is almost invariably destroyed in infested stalks. Damage measurements as a proportion of total internodes or stalks were assumed to follow a binomial distribution with a logit link function.

The statistical probability of clonal effects was estimated by the Wald statistic with clone as the fixed term, replicate a random term and the dispersion parameter estimated. Clonal means were separated by Fisher's protected least-significant-difference test. Broad-sense heritabilities were calculated from the variance component estimates with both clone and replicate treated as random effects. Average damage to the standard clones from each borer species was compared among trials by simple correlation. Normalised values for the response of the standards in each trial were calculated from the mean ( ) and standard deviation (s) of transformed values (x) of the percentage damage from each borer after angular transformation (arsine √), using the formula $z = (x- \ )/s$ by the STANDARDIZE function in Excel 2010.

Results

Borer infestation levels

There were highly significant differences among clones ($P < 0.01$) for internode damage from *S. grisescens* and *C. terrenellus* and top damage from *S. excerptalis* in plant and ratoon crops of SRT01-10 and the plant crop of SRT01-11. Heritabilities in SRT01-10 P and 1R and SRT01-11 P were 0.51, 0.22 and 0.74 for internode damage from *S. grisescens*, 0.32, 0.20 and 0.49 for internode damage from *C. terrenellus*, and 0.93, 0.81 and 0.92 for top damage from *S. excerptalis*.

Comparing these data with those from previous trials (Korowi *et al.*, 2011), the average level of damage from *S. excerptalis* was substantially greater in the recent trials but damage from *S. grisescens* and *C. terrenellus* was not consistently different. In general, the clonal range for damage from *S. grisescens* and *S. excerptalis* was greater than for damage from *C. terrenellus*, especially in the trials planted in 2010 and 2011 (Table 1).

Correlations among trials

Results of borer sampling were compared among the plant crop of SRT01-11, the plant and first ratoon crops of SRT01-10, and the plant or first ratoon crops of three earlier trials (Korowi *et al.*, 2011; see Table 1), for the 12 standard clones that were common to all trials.

Table 1—Levels of damage (mean and clone range) in the six sets of data referred to in this paper; damage is mean of % bored internodes for *Sesamia grisescens* and *Chilo terrenellus* and % infested stalks for *Scirpophaga excerptalis*.

Data set	Sample date	*S. grisescens*	*C. terrenellus*	*S. excerptalis*
SRT01-11 P	June 2012	14.1 (2.9–39.6)	10.7 (4.6–18.0)	57.0 (17.5–92.5)
SRT01-10 1R	August 2012	6.8 (4.2–11.0)	9.8 (5.0–15.7)	14.5 (2.5–28.7)
SRT01-10 P	June 2011	8.8 (2.6–18.6)	8.5 (2.9–12.3)	33.1 (6.3–71.3)
SRT01-07 P	May 2008	9.0 (4.2–17.2)	12.0 (7.0–19.4)	19.3 (0.0–45.0)
SRT05-02 1R	Apr 2004	22.4 (12.3–29.7)	5.9 (2.4–10.2)	1.9 (0.0–6.7)
SRT05-02 P	Sept 2003	13.4 (2.7–24.9)	20.7 (9.8–33.9)	3.7 (0.0–16.7)

S. grisescens damage to the standard clones in SRT01-11, as measured by the proportion of bored internodes, was significantly correlated with the corresponding damage in the first ratoon of SRT01-10, the plant crop of SRT01-07 and the first ratoon of SRT05-02 (Table 2). Eight of the 15 correlation pairs were statistically significant ($P < 0.05$).

A plot of normalised response scores (after angular transformation) across the six data sets shows definite differences in responses among the standard clones, with PN92-439 and Q135 showing the extremes of resistance and susceptibility, respectively, but with considerable variation among trials (Figure 1). Presumably the more heavily infested trials (Table 1) are likely to give more reliable data.

Table 2—Correlations (*r*) between levels of *Sesamia grisescens* damage to 12 standard clones among trials or crop years; SRT05-02 and SRT01-07 were planted in 2002 and 2007, respectively.

Data set	SRT01-11 P	SRT01-10 1R	SRT01-10 P	SRT01-07 P	SRT05-02 1R
SRT01-10 1R	0.79 **				
SRT01-10 P	0.38	0.24			
SRT01-07 P	0.77 **	0.65 *	0.73 **		
SRT05-02 1R	0.64 *	0.32	0.41	0.60 *	
SRT05-02 P	0.35	0.13	0.72 **	0.72 **	0.43

*, $P < 0.05$; **, $P < 0.01$

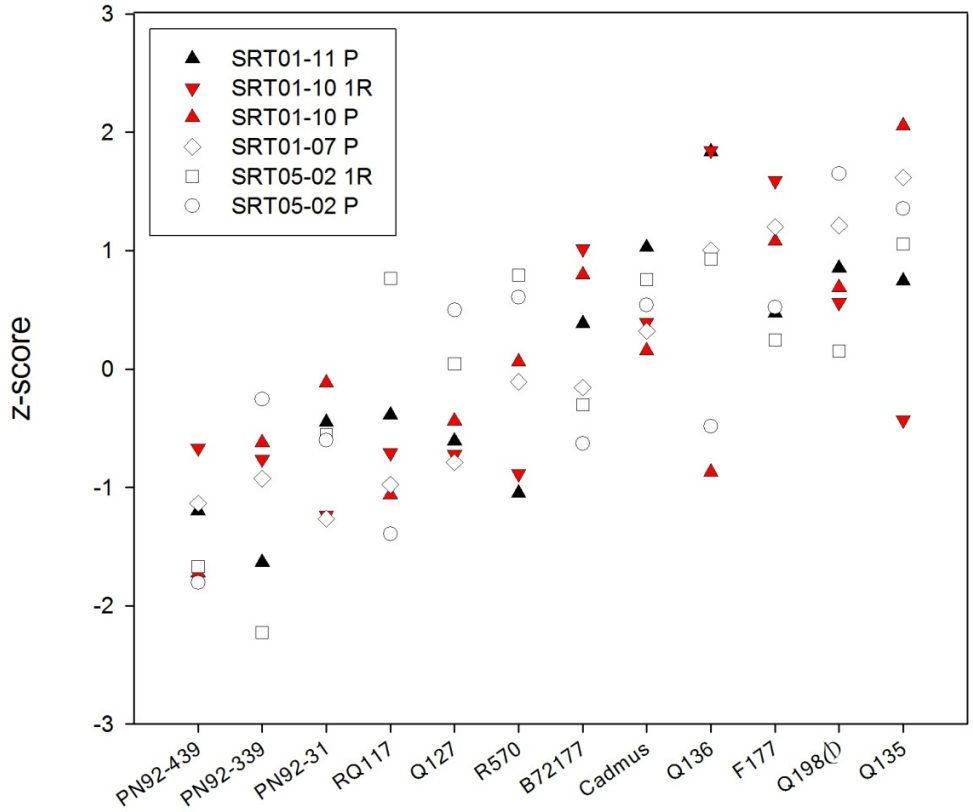

Fig. 1—Normalised levels of damage from *Sesamia grisescens* (proportion of bored internodes) to 12 standard clones in six trial data sets, with clones arranged in ascending order of mean z-scores.

C. terrenellus damage to the standard clones, as measured by the proportion of *C. terrenellus*-bored internodes, was correlated between only two trials, one of the current trials SRT01-11 and SRT01-07, both as plant crops (Table 3). Results were not correlated among the three recent sets of data, SRT01-10 (plant and ratoon crops) and SRT01-11, although there was a significant clonal effect on *C. terrenellus* damage in all three. For each standard clone, there was a large spread of standardised responses among the six data sets (Figure 2). The standard clones that were chosen for *S. grisescens* also seem to cover the range of *C. terrenellus* response (data not presented) so poor choice of standards seems not to be the reason for the lack of consistent differences among them with respect to *C. terrenellus* damage.

Table 3—Correlations (*r*) between levels of *Chilo terrenellus* damage to 12 standard clones among trials or crop years; SRT05-02 and SRT01-07 were planted in 2002 and 2007, respectively.

Data set	SRT01-11 P	SRT01-10 1R	SRT01-10 P	SRT01-07 P	SRT05-02 P
SRT01-10 1R	0.30				
SRT01-10 P	0.40	0.28			
SRT01-07 P	0.70 *	–0.22	0.27		
SRT05-02 1R	0.02	–0.36	–0.26	0.13	
SRT05-02 P	0.03	0.58	0.34	–0.25	–0.09

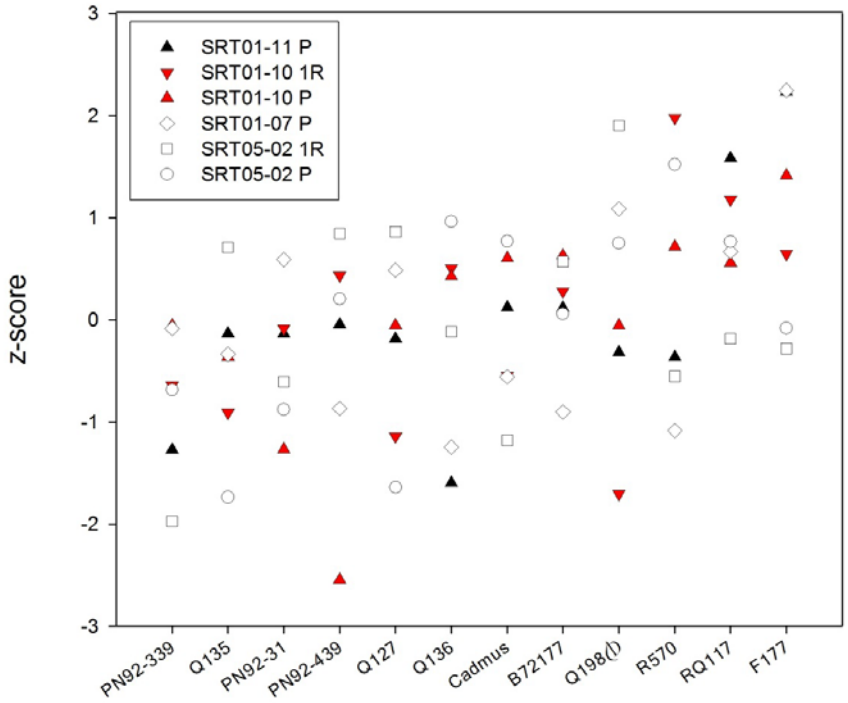

Fig. 2—Normalised levels of damage from *Chilo terrenellus* (proportion of bored internodes) to 12 standard clones in six trial data sets, with clones arranged in ascending order of mean z-scores.

S. excerptalis damage was measured satisfactorily in only one earlier trial, SRT01-07, as well as in SRT01-10 and SRT01-11; infestation was very light in both crop years of SRT05-02 (Table 1). Levels of *S. excerptalis* damage to the 12 *S. grisescens* standards were highly correlated between SRT01-11 and the plant crop of SRT01-10 but not SRT01-7 or the first ratoon crop of SRT01-10 (Table 4).

Variety Q219$^{(\Phi)}$ was planted as an additional standard clone in SRT01-11 specifically to calibrate susceptibility to *S. excerptalis*, as it was heavily attacked in the plant crop of SRT01-10.

It was also heavily attacked in SRT01-11, and the correlation in damage levels between SRT01-11 and the plant crop of SRT01-10 increased to 0.89 ($P < 0.001$) when analysed over 13 clones, the usual 12 *S. grisescens* standards plus Q219$^{(l)}$, while the correlation between SRT01-11 and the ratoon crop of SRT01-10 increased to 0.60 ($P = 0.032$). Clonal responses were fairly consistent in the four available data sets, and particularly in the three collected from trials SRT01-11 and SRT01-10 (Figure 3). Only 10 stalks were sampled from each plot in SRT01-07, whereas 20 stalks were sampled in the more recent trials to give a better estimate of the proportion of infested stalks.

Table 4—Correlations (*r*) between levels of *Scirpophaga excerptalis* damage to 12 standard clones among trials or crop years; SRT01-07 was planted in 2007.

Data set	SRT01-11 P	SRT01-10 1R	SRT01-10 P
SRT01-10 1R	0.27		
SRT01-10 P	0.83 **	0.43	
SRT01-07 P	0.38	0.55	0.47

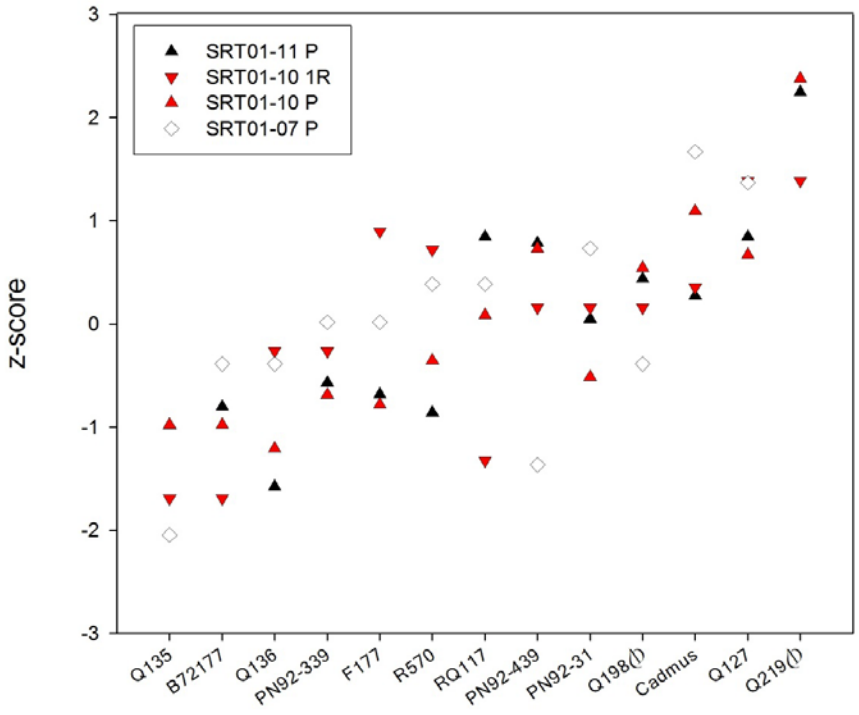

Fig. 3—Normalised levels of damage from *S. excerptalis* (proportion of damaged stalks) to 13 standard clones in four trial data sets, with clones arranged in ascending order of mean z-scores.

Borer susceptibility of Australian commercial varieties

Susceptibility data have so far been obtained for a limited number of 'recent' Australian commercial varieties (Q135 onwards), with existing trials also including many unreleased Australian clones as well as the standard clones.

In the plant crop of SRT01-10, the commercial varieties covered most of the range from low to high damage that was observed among all 32 clones, for each borer species (Table 5).

The order of susceptibility varied depending on the borer. For example, Q219$^{(l)}$ was only lightly damaged by *S. grisescens* but was heavily attacked by *S. excerptalis,* while the reverse was true for Q135.

Table 5—Damage to Australian commercial varieties from moth borers in trial SRT01-10 in the plant crop, 2011. Varieties are ranked in order of increasing damage from each pest.

Sesamia grisescens (2.6–18.6)[a]		*Chilo terrenellus* (2.9–12.3)[a]		*Scirpophaga excerptalis* (6.3–71.3)[a]	
Variety	%	Variety	%	Variety	%
Q183[Φ]	3.9	Q203[Φ]	4.6 a	Q136	6.3 a
Q219[Φ]	4.3	Q215[Φ]	5.9 ab	Q135	8.8 a
Q215[Φ]	4.8	Q209[Φ]	6.0 abc	Q230[Φ]	23.8 b
Q136	5.1	Q135	7.0 abcd	Q220[Φ]	25.0 b
Q220[Φ]	5.6	Q198[Φ]	7.7 abcd	Q224[Φ]	28.8 bc
Q200[Φ]	7.2	Q200[Φ]	7.7 abcd	Q183[Φ]	33.8 bcd
Q224[Φ]	7.4	Q213[Φ]	8.0 abcd	Q198[Φ]	33.8 bcd
Q190[Φ]	7.7	Q183[Φ]	8.5 bcde	Q231[Φ]	33.8 bcd
Q209[Φ]	7.9	Q136	8.8 bcde	Q213[Φ]	36.3 bcd
Q230[Φ]	9.1	Q182[Φ]	8.9 bcde	Q203[Φ]	37.5 bcd
Q203[Φ]	10.4	Q224[Φ]	9.2 bcde	Q200[Φ]	45.0 cd
Q231[Φ]	10.7	Q190[Φ]	10.0 cde	Q190[Φ]	47.5 d
Q198[Φ]	11.3	Q231[Φ]	10.5 de	Q182[Φ]	51.3 de
Q213[Φ]	14.8	Q230[Φ]	11.0 de	Q215[Φ]	51.3 de
Q182[Φ]	17.7	Q219[Φ]	11.0 de	Q209[Φ]	67.5 ef
Q135	18.6	Q220[Φ]	12.3 e	Q219[Φ]	71.3 f

[a] Range of mean damage for the 32 clones within the trial
Means within columns followed by the same letter are not significantly different (P = 0.05); no lettering is given for *S. grisescens* as variances varied and decisions regarding group membership were inconsistent

Damage from *S. grisescens* was lighter in the first ratoon crop than in the plant crop of SRT01-10, with a smaller range between the least and most damaged clone, and it may be for this reason that susceptibility trends were not as evident (Table 6).

Table 6—Damage to Australian commercial varieties from moth borers in trial SRT01-10 in the first ratoon crop, 2012. Varieties are ranked in order of increasing damage from each pest.

Sesamia grisescens (4.2–11.0)[a]		*Chilo terrenellus* (5.0–15.7)[a]		*Scirpophaga excerptalis* (2.5–28.8)[a]	
Variety	%	Variety	%	Variety	%
Q224[Φ]	4.2	Q182[Φ]	5.0	Q135	2.5 a
Q220[Φ]	4.8	Q198[Φ]	6.2	Q136	8.8 ab
Q135	5.5	Q190[Φ]	6.2	Q215[Φ]	8.8 ab
Q203[Φ]	6.9	Q135	7.6	Q198[Φ]	11.3 abc
Q198[Φ]	7.0	Q231[Φ]	7.7	Q213[Φ]	11.3 abc
Q200[Φ]	7.2	Q203[Φ]	7.9	Q224[Φ]	13.8 bcd
Q183[Φ]	7.4	Q224[Φ]	9.5	Q183[Φ]	16.3 bcd
Q231[Φ]	7.5	Q215[Φ]	9.6	Q231[Φ]	16.3 bcd
Q213[Φ]	8.0	Q209[Φ]	9.8	Q182[Φ]	18.8 bcd
Q190[Φ]	8.2	Q219[Φ]	10.4	Q219[A]	20.0 bcd
Q209[Φ]	8.4	Q136	10.4	Q220[Φ]	20.0 bcd
Q215[Φ]	8.5	Q200[Φ]	10.6	Q230[Φ]	21.3 bcd
Q219[Φ]	8.7	Q213[Φ]	10.7	Q203[Φ]	22.5 cd
Q182[Φ]	9.2	Q183[Φ]	11.8	Q190[Φ]	23.8 cd
Q136	9.4	Q220[Φ]	12.3	Q209[Φ]	27.5 d
Q230[Φ]	11.0	Q230[Φ]	15.7	Q200[Φ]	28.8 d

[a] Range of mean damage for the 32 clones within the trial
Means within columns followed by the same letter are not significantly different (P = 0.05); no lettering is given for *S. grisescens* and *C. terrenellus* as variances varied and decisions regarding group membership were inconsistent

Damage from *S. excerptalis* was also lighter in the first ratoon, but consistent trends were still apparent: Q135 and Q136 were lightly damaged while Q209$^{\phi}$ and Q219$^{\phi}$ were heavily attacked, similar to the plant crop.

Damage from *S. grisescens* and *S. excerptalis* was very heavy in the plant crop of SRT01-11, such that some test clones were almost destroyed (Figure 4).

Fig. 4—Plot of QN98-1947 with extreme damage from *Sesamia grisescens* in SRT01-11 when sampled in June 2012; bored internodes from *S. grisescens* averaged 39.6%, the highest of any clone in the trial.

In SRT01-11, Q219$^{\phi}$ suffered relatively little damage from *S. grisescens* but heavy damage from *S. excerptalis* (Table 7), as was also observed in the plant crop of SRT01-10. Q135 again showed moderate-high damage from *S. grisescens* and relatively light damage from *S. excerptalis* (compared with other varieties in the trial).

Table 7—Damage to Australian commercial varieties from moth borers in trial SRT01-11 in the plant crop, 2012. Varieties are ranked in order of increasing damage from each pest.

Sesamia grisescens (2.9–39.6)[a]		*Chilo terrenellus* (4.6–18.0)[a]		*Scirpophaga excerptalis* (17.5–92.5)[a]	
Variety	%	Variety	%	Variety	%
Q219$^{\phi}$	3.1 a	Q136	4.6 a	Q136	17.5 a
KQ228$^{\phi}$	3.5 ab	KQ228$^{\phi}$	7.9 ab	Q135	28.8 ab
Q127	8.3 bc	Q198$^{\phi}$	8.1 ab	Q188$^{\phi}$	38.8 bc
Q242$^{\phi}$	8.6 bcd	Q127	8.5 b	Q249$^{\phi}$	43.8 bcd
Q221$^{\phi}$	10.2 cd	Q135	8.7 b	Q242$^{\phi}$	47.5 cde
Q188$^{\phi}$	14.3 de	Q221$^{\phi}$	10.3 bc	Q234$^{\phi}$	52.5 cdef
Q135	17.2 ef	Q242$^{\phi}$	11.4 bc	Q198$^{\phi}$	60.0 defg
Q198$^{\phi}$	18.0 efg	Q188$^{\phi}$	12.0 bc	KQ228$^{\phi}$	65.0 efg
Q249$^{\phi}$	18.4 ef	Q219$^{\phi}$	12.5 bc	Q127	68.8 fgh
MQ239$^{\phi}$	19.1 efg	Q249$^{\phi}$	12.5 bc	Q221$^{\phi}$	76.3 gh
Q234$^{\phi}$	22.6 fg	MQ239$^{\phi}$	14.6 c	MQ239$^{\phi}$	83.8 hi
Q136	26.2 g	Q234$^{\phi}$	15.5 c	Q219$^{\phi}$	92.5 i

[a] Range of mean damage for the 33 clones within the trial
Means within columns followed by the same letter are not significantly different (P = 0.05)

Discussion

Kuniata (2000) used field data (pre-2000) to conclude that varieties Cadmus and Q135 were the most susceptible to *S. grisescens* out of 11 clones evaluated, both in terms of numbers of bored stalks and numbers of borer pupae. Our results support this conclusion, especially for Q135. Of the 12 standard clones, the three with the least damage from *S. grisescens* were all PN varieties selected at Ramu Agri-Industries.

Damage from *C. terrenellus* varied among clones in recent trials, but the clonal range of responses was not as great as measured for the other two borer species and heritabilities were lower than for *S. grisescens*.

The response of the standard clones was not consistent among trials. It is possible that there is interference between infestations of *C. terrenellus* and the other species, especially *S. grisescens*, as suggested by Korowi *et al.* (2011). Resistance has been documented for many other species of *Chilo* such as *C. auricilius* (Sharma *et al.*, 2007) and *C. sacchariphagus* (David and Joseph, 1984; Nibouche and Tibère, 2008), so some consistent variation in damage from *C. terrenellus* among varieties would have been expected in PNG.

There was a strong and consistent difference among clones for damage from *S. excerptalis*. Heritability values were much higher than for the other two borers, though direct comparison is not possible because of the different assessment method (damaged stalks rather than damaged internodes). Varietal resistance to *S. excerptalis* has been identified in studies elsewhere (e.g. Chaudhary and Yadav, 1995a).

The differences between the rankings of damage to the clones from each of the three borer species presumably reflect differences in behaviour of the insects and resulting plant resistance mechanisms. We have some evidence that clonal differences in damage from *S. grisescens* and *S. excerptalis* are influenced by numbers of eggs laid on each clone (unpublished data), which must be related to behaviour of the adult moths.

Behaviour of larvae after hatching also differs among the species. *S. grisescens* lays eggs behind the leaf sheaths whereas *C. terrenellus* and *S. excerptalis* both oviposit on the unfolded leaves. Young larvae of *S. grisescens* feed on the inner surfaces of leaf sheaths for several days and then bore into the stalk, where they feed gregariously in the upper internodes before migrating to nearby stalks (Young and Kuniata, 1992; Kuniata and Sweet, 1994; Kuniata, 1998).

Larvae of *C. terrenellus* tunnel inside semi-mature and mature stalks (Kuniata *et al.*, 2001). Newly hatched larvae of *S. excerptalis* enter the midrib of the top leaf on the stalk and then move from there to the meristem, and varietal resistance to this species is influenced by success of larval establishment in the midrib (Chaudhary and Yadav, 1995b, 1998a, b). It is not surprising, then, that there was no single pattern of resistance to the three borer species in our trials.

Given the correlations among trials for damage to the standard clones from *S. grisescens* and *S. excerptalis*, it should be possible to develop a rating system for these pests that will allow test varieties to be grouped into categories of resistance or susceptibility. This may be less successful for *C. terrenellus*.

Trial SRT01-11 will be sampled for borers in the first ratoon crop in 2013. Further variety trials will be planted in 2013, to include some of the Australian commercial varieties that have not been tested in trials thus far, as well as some of the most important commercial varieties that will be re-tested to check on repeatability of the results.

The current planting system using spreader rows and the sampling program are satisfactory for discriminating among clones for resistance to *S. grisescens*, the main target of the trials, and useful information is also being obtained for *S. excerptalis*. However, the very heavy damage from *S. excerptalis* in recent trials is a concern, as stalks with tops killed by this pest may no longer be attractive to *S. grisescens* (Lastus Kuniata, Ramu A-I, pers. comm.).

Insecticidal control of *S. excerptalis* may be necessary early in crop growth to maintain normal plant architecture. Additional recording of numbers of eggs laid by each borer may help to identify resistance mechanisms.

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