BSES Limited

FINAL REPORT - SRDC PROJECT BSS151

RESISTANCE MECHANISMS AND SELECTION FOR RESISTANCE IN SUGARCANE TO SUGARCANE WEEVIL BORER

by

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SD05009

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SUMMARY

From prior assessment of sugarcane weevil borer (SWB) infestation in parental clones at BSES Meringa and clones in advanced selection trials in the crop-improvement program based on BSES Meringa, as well as reference to existing literature, reaction to SWB infestation obviously is a multifaceted trait that may encompass many individual plant traits. This research was based on a hypothesis that attempted to cover as many of these traits and their possible interaction with the insect, e.g. the insect's selection of a clone based on canopy appearance, composition, chemistry, or height; selection of a clone based of the relationship between the senescing leaf sheaths and the stalk at the time of maximum infestation; basal-rind hardness of the stalk; composition of the rind and parenchyma in the basal stalk in terms of dry matter and insoluble carbohydrates, and attempting to predict SWB infestation by simply using near-infra-red spectroscopic spectral data of the rind.

Two four-replicate trials of 108 entries (10 duplicated cultivars, 47 parental clones, 41 advanced selection clones) planted in two sites in areas heavily infested with SWB formed the basis of this research. Plant and first-ratoon crops were assessed in each site. Leaves were sampled early- and mid-season for determination of dry matter. These leaves were milled and scanned to yield near-infra-red spectral data. Calibrations were developed for leaf nitrogen and silica. Stalk height and leaf colour, determined using a SPAD meter, were assessed in the plant crop. Leaf-stalk morphology was assessed early season in both crops. Rind hardness of the basal stalk internodes was determined with six-pin penetrometers early season. Infestation levels were determined by slicing 18 stalks per plot mid- to late-season. Shortly after, rind and parenchyma fraction of basal stalk portions were analyzed for dry matter, spectral data again acquired, insoluble carbohydrate measured in a sub-set of these samples and predictive calibration developed for insoluble carbohydrate on a dry matter basis. Insoluble carbohydrate, on a fresh weigh basis was then derived. All data were subjected to statistical analyses and correlation and regression analyses used to explore the relationships between three measures of resistance to SWB infestation and the morphological, compositional, and chemical data acquired.

There were statistically significant differences among clones in both trials for all traits measured directly or predicted. In the majority of analyses, differences among replicates also were significant, meaning that these traits were assessed against a background of macro-environmental variation within sites as well as the variation between sites. Mean percent bored stalks were 45.6 and 30.7 and 18.4 and 6.7% in the plant and first-ratoon crops at each of the sites, respectively. Clonal variation ranged from near zero to 90% bored stalks for the most severely infested clone. Estimates for broad-sense heritability were good to excellent, and there was a wealth of genetic variation to exploit via selection. Combined analyses for the three measures of reaction to SWB of crops over sites or over years within sites revealed significant site and year differences. Locations by clones and years by clones interactions were significant, verifying the importance of conduction assessment for SWB over environments and time. Correlation analyses revealed few usable relationships for crop improvement. The relationship between basal-rind hardness and resistance was significant but weak. There was little joy in any relationship involving any of the morphological measurements – leaf-stalk morphology and stalk height. There were variable and some significant relationships between leaf nitrogen and SWB infestation but these were weak. Combined with the measurement of

leaf colour, canopy lushness had little bearing on the insects' selection of clones for infestation. The relation between the SWB measures and leaf silica were weak to moderate but all highly significant. Multiple regression analyses using the SWB measures and leaf and stalk chemistry and compositional data accounted for only a small proportion of variation, but the dominance of early-season leaf silica in these regressions was a consistent feature. Prediction of reaction to SWB infestation based on spectra of basal rind was not useable because of the poor predictive value of the equation.

The study revealed a wealth of variation in all traits studied, including reaction to SWB. Disappointingly, none of the traits assessed were strongly correlated to SWB resistance, and no predictive measures were developed to assist in understanding the reaction of sugarcane to SWB. Why did this occur? All near-infra-red analyses failed to suggest any hint of a chemical signature in either the rind or parenchyma fractions processed. The rind fraction should have contained important chemistry with which the female interacts in the process of ovipositing, and the parenchyma chemistry with which the larvae and pupae interact during development. This failure perhaps resulted from used of dried and processed tissue, and any chemical signatures present may have been altered or destroyed. Would analysis of fresh tissue have yielded different results?

Despite the failure to elucidate key plant traits as facets of resistance to SWB, comfort can be drawn that SWB resistance is a highly heritable trait, tremendous genetic variation exists, and the trait is readily and economically screenable by slicing, despite the failure to determine any resistance mechanisms.

1.0 BACKGROUND

Before the widespread adoption of pre-harvest burning of cane in the 1940s, sugarcane weevil borer (SWB) (*Rhabdoscelus obscurus* (Boisduval) (Coleoptera: Curculionidae)) was the second-most damaging pest in Queensland after greyback canegrub. SWB is a serious pest in the high-rainfall belt between Cairns and Tully, where green-cane trash blanketing (GCTB) is practised, and localised infestations have been reported from the Herbert and Mackay districts under GCTB. SWB is a significant disincentive to increased adoption of GCTB in South Johnstone and Tully mill districts, and growers in the most severely affected area of Mourilyan reverted to burning trash after harvest in the 1994 season, to control SWB. GCTB is a sustainable practice that must be retained, and methods of reducing the impact of SWB in GCTB must be found.

Severe damage to cane by SWB was documented in parts of Mulgrave, Babinda, South Johnstone, Mourilyan, and Tully mill areas in 1992-94. Surveys by BSES and Cane Protection and Productivity Board (CPPB) staff throughout the affected areas in 1994 indicated that 20-70% of the stalks of the most popular cultivars were damaged by SWB. Average loss of sugar due to boring across all clones was 1.1 CCS units. Annual losses of $1 million worth of raw sugar occurred in each of the Mulgrave and Mourilyan mill districts, in both 1993 and 1994 seasons (Pope and Johnson 1996; Pope 1997). Total losses to SWB exceed $3 million per year across the wet tropics. In addition, dextran levels in juice at Mourilyan Mill were commonly about 200 mg/kg in 1993. Dextran occurs in stale cane as a result of SWB damage and removal of dextran incurs a further cost to the mills. Raw sugar shipped from the Mourilyan terminal has crystal size identified as difficult to process in Singapore refineries. Impurities caused by SWB damage may contribute to these crystallisation problems.

Methods of reducing damage by SWB while retaining GCTB were needed urgently to improve the economic and environmental sustainability of northern canegrowing regions. Cane cultivars that are resistant to SWB damage are available (Berding 1996), and canegrowers readily accept new cultivars if benefits are demonstrated. Reduction in SWB damage with adoption of resistant cane cultivars will improve productivity and profitability of both growers and millers.

This project primarily sought to determine resistance mechanisms and selection mechanisms for resistance in sugarcane to SWB. As such, it addressed the SRDC strategies of developing more productive cultivars by increasing clonal resistance to insect pests, and of developing resource management practices that ensure sustainable productivity through the expanded use of GCTB.

2.0 OBJECTIVES

The project originally aimed to identify high-yielding clones of sugarcane with resistance to SWB, for use in high-rainfall areas under green-cane trash blanketing. The original specific objectives were to:

- Develop a sampling strategy to monitor weevil borer infestations and assess damage;
- Assess weevil borer damage to a range of clones in replicated trials at heavily infested sites;
- Determine plant attributes that convey resistance to weevil borer using conventional analysis and NIR spectroscopy;
- Determine broad-sense heritability for weevil borer resistance in clones over locations and years;
- Apply knowledge of clonal resistance and mechanisms in the core breeding program.

These objectives were met in full as summarised below.

Original objective 1 – Develop a sampling strategy to monitor weevil borer infestations and assess damage

This strategy was developed prior to the commencement of this project. Preliminary work by Berding (1996) using parental surveys at BSES Meringa and subsequently survey work of advanced selection clone in trials conducted from BSES Meringa optimized guidelines for the partitioning of resources between number of replicates and number of stalks sliced per plot. This strategy used estimates of variance components to calculate the standard error of a treatment mean. This approach is depicted graphically in Fig. 1, with necessary explanation, if required, being drawn from Berding (1996). This strategy was implemented, within available resources, in this project. Trials were four-replicate, plot format was 1 row by 10 m, and 18 stalks were sliced per plot. Data recorded were the number of bored nodes evident in each sliced stalk.

Original objective 2 – Assess weevil borer damage to a range of clones in replicated trials at heavily infested sites

The trials, located at two sites in regions experiencing heavy SWB infestation, contained 10 cultivars duplicated in each replicate as standards, 47 parental clones, and 41 clones being assessed in advanced selection stages in the crop-improvement program based on BSES Meringa. Numbers of bored internodes per stalk were the recorded data. From these percent bored stalks, numbers of bored internodes per stalk, and numbers of bored internodes per bored stalk were derived. Data for these traits are presented for these clones in the plant and first-ratoon crop at each site, as well as combined analyses over sites for each crop. Results of these analyses, derived statistics, and means are presented for all six analyses.

Original objective 3 – Determine plant attributes that convey resistance to weevil borer using conventional analysis and NIR spectroscopy

The following traits were assessed: leaf-stalk morphology (plant and first-ratoon crops); leaf colour and stalk height (plant crop); leaf dry matter determined early- and mid-season (plant and first-ratoon crops); determination of leaf nitrogen and silica on a spectrally selected sub-set of samples drawn from the plant and first-ratoon crops and prediction of these components in the total spectral population; determination of rind hardness of the basal internode using 6-pin penetrometers; assessment of infestation by SWB and derivation of the three traits percent bored stalks, number of bored internode per stalk, and number of bored internodes per bored stalk. These measures were developed and discussed by Berding (1996).

Original objective 4 – Determine broad-sense heritability for weevil borer resistance in clones over locations and years

Broad-sense heritabilities were calculated for each single trial data set as well as from combined analyses of crops. Additionally, estimates of genetic coefficients of variation were calculated. There is a wealth of genetic variation available, and resistance to SWB is a highly heritable trait.

Original objective 5 - Apply knowledge of clonal resistance and mechanisms in the core breeding program

This was being applied to the crop-improvement program based on BSES Meringa well prior to commencement of this research. These data were consider at the annual selection meeting, as the data were drawn from slicings of Final Assessment Trials located in high SWB-infestation regions. The threat of a massive impact of SWB on the northern industry dissipated before conclusion of the research reported here. One can but conclude that the increased activity from SWB, and the negative impacts recorded on the northern industry, must have been precipitated by an environmental, ecological or crop-management perturbation that apparently diminished during the course of this research.

The project was subsequently amended to include a study of the factors affecting the incidence of and damage caused by SWB. The specific objectives of that part of the project were to:

- Analyse data collected by Mulgrave Mill to determine losses caused by SWB;
- Develop strategies for collection of data on damage in future years;
- Determine factors that affect the severity of SWB damage;
- Refine objectives of BSS151 as a result of analyses;
- Identify varieties with SWB resistance.

The objectives of this part of the project were achieved and reported in Stringer and Telford (1998) (Appendix 1). In summary the study showed:

- Sampling billets for SWB damage through the extraneous matter system of a sugar mill gives reliable data, as it supports field data collected by BSES;
- Mill data may allow simple field assessments to be related to an entire mill area and would benefit those mills who do not sample for SWB activity;
- Sampling should focus on counting the number of billets in each sampling and weighing the damaged billets to determine yield-loss estimates;
- Continuing the mill-based sampling would allow a good comparison of SWB damage to be obtained across years – this may be useful for long-term prediction of SWB outbreaks, but a large amount of data across years is needed to reliably predict outbreaks, as damage appears to be dependent on a number of factors, such as cultivar, location and soil type;
- Damage by SWB is greater in green cane than in burnt cane, reflecting historical data and that SWB was not a significant problem when pre-harvest burning of cane was standard industry practice;
- Identification of districts and their levels of damage may allow a management strategy for SWB to be implemented;
- Mulgrave Mill data show high susceptibility to SWB in cultivars such as Q113 and Q138, whilst Q117 has low susceptibility.

3.0 FIELD TRIAL METHODOLOGY AND RESULTS

3.1 Development of a sampling strategy

A strategy was developed as a preliminary study to the main project. Berding (1996) used parental surveys at BSES Meringa and, subsequently, survey work of advanced selection clone in trials conducted from BSES Meringa to optimize guidelines for the partitioning of resources between number of replicates and number of stalks sliced per plot. This strategy used estimates of variance components to calculate the standard error of a treatment mean. This approach is depicted graphically in Figure 1, with necessary explanation, if required, in Berding (1996) (Appendix 2).

This strategy was implemented, within available resources, in this project. Trials were four-replicate, plot format was 1 row by 10 m, and 18 stalks were sliced per plot. Data recorded were the number of bored nodes evident in each sliced stalk.

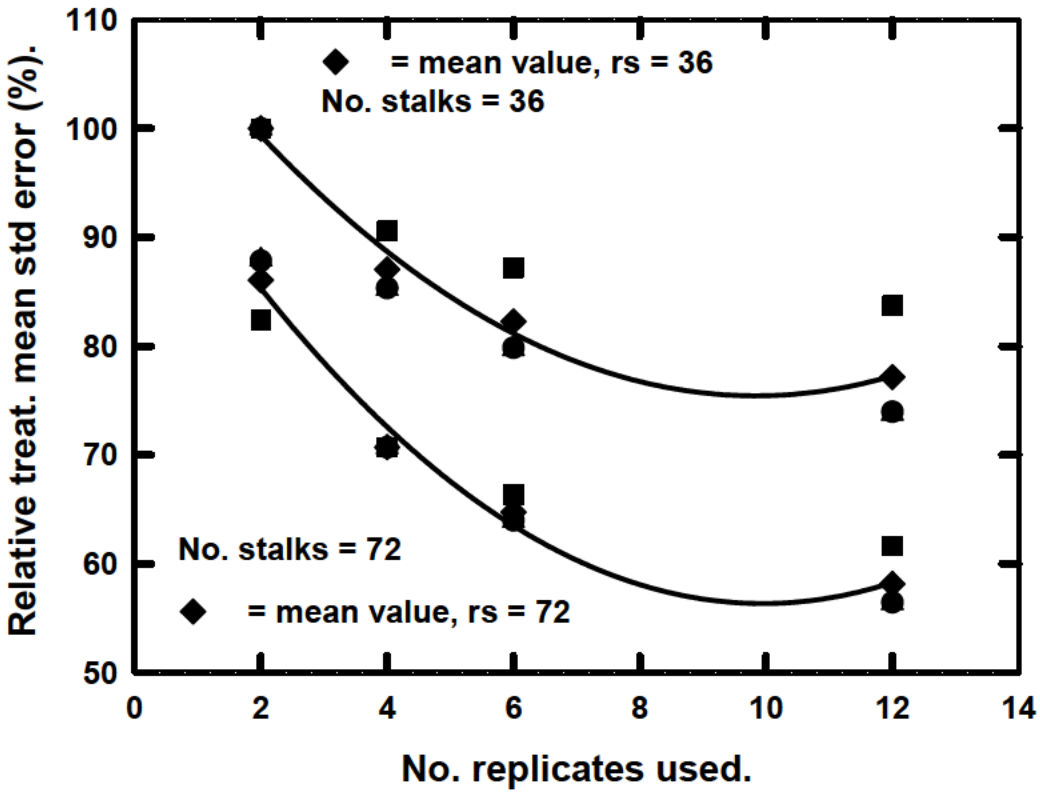

Figure 1 **Subsampling optimization for determination of sampling strategy to assess SWB infestation. Relative values for standard error of a treatment mean** $(s_{\bar{x}} = \sqrt{(\sigma_s^2 / rs) + (\sigma_e^2 / r)})$ **were calculated using estimates of** σ_s^2 **and** σ_e^2 **obtained from three trials and varying the number of sub-samples (s = stalks) for replicate numbers (r) = 2, 4, 6, and 12 for two resource expenditures of rs = 36 and 72 per clone. Values are expressed relative to** $s_{\bar{x}}$ **computed with s = 18 and r = 2. Data from Berding (1996)**

3.2 Trial methodology

3.2.1 Trial design

Two trials were established in 1996 in areas that had shown significant SWB activity in trapping survey work conducted earlier.

The first trial was planted in Block 6D on the farm of Graham Whitaker, Spanos Road, Silkwood, in the South Johnston mill area. The trial was located on a Bulgan Series soil, and was planted on 25 July. The trial was of a randomized complete block design of four replicates. Plot format was a single row, 10 m long. Each replicate consisted of 27 rows, at 1.5 m spacing, by four 10 m plots long. Rows ran N-S with the four replicates arranged

linearly on this axis. The trial was guarded on the S end (10 m) and on the E side (four rows) with Q152. The remained of the block to the north was planted with Q152 (E) and Q138 (W), while the remainder of the block to the W of the trial, for the full length of the block, was planted with Q135.

The second trial was planted in Block 22 on the farm of Alf Cali, New Harbour Line Road, Mourilyan, in the Mourilyan mill area. The trial was located on a Brosnan Series soil, and was planted on 7 August. The design and layout details were identical with the first trial, except the rows ran E-W. Independent randomizations were used. Again, the trial was guarded on the E end (10 m) and on the N side (two rows) with Q158. The remainder of the block was planted with Q158.

The 108 entries in the trials consisted of 10 current cultivars, with a broad range of reaction to SWB. These were planted in duplicate plots per replicate. Also included were 49 important parental clones, and 39 advanced selections (Table 1). Cultivars Q167$^{\phi}$, Q173$^{\phi}$ and Q175$^{\phi}$, as named clones, were classified in the latter class when the trials were conducted but subsequently were assigned cultivar status. Germination was excellent in both trials.

3.2.2 Measurements

3.2.2.1 Leaf chemistry

Nitrogen and silica content leaves were of interest, as these important leaf constituents possibly influenced selection of clones for infestation by the SWB. Three last exposed dewlap leaves were sampled at random from each plot in January and July 1997 and February and July 1998 (Table 2). The trials were sampled by replicate. The leaves, including the midrib, were immediately cut into pieces < 160 mm long, sealed in a pre-numbered, pre-weighed A4 Ziplock bag and then placed on ice in a cold box. On return to BSES Meringa, the bagged samples were weighed and each leaf sample then transferred into a pre-weighed Confoil # 7219 tray and dried at 70°C in a fan-forced oven until constant weight was achieved.

Leaf dry matter (g kg^{-1}) was computed as:

$$1000 \times [M_{(\text{dry leaf + tray})} - M_{(\text{tray})}]/[M_{(\text{fresh leaf + bag})} - M_{(\text{bag})}]$$

Table 1 **Clones and cultivars entered in two replicated clonal trials established for SWB research. Entries consisted of 10 cultivars, in duplicate plots, 47 important parental clones, and 41 clones from advanced selection stages from the crop-improvement program based on BSES Meringa**

Key no.	Clone	Key no.	Clone	Key no.	Clone
1	QN73-947	37	QN86-2195	73	Q107
2	QN82-1240	38	QN79-398	74	QN86-306
3	Q115	39	H56-752	75	Q113
4	QN81-314	40	QC81-351	76	QN85-2159
5	Q175$^{\phi}$	41	Q138	77	QN85-1400
6	Q167$^{\phi}$	42	QS63-782	78	QN86-1660
7	QN84-2965	43	Q124	79	QN83-1093
8	74C42	44	QN71-569	80	QN80-3499
9	Q115	45	QN77-606	81	Q173$^{\phi}$
10	TS64-1189	46	QN82-549	82	H74-0922
11	QN83-660	47	QC71-998	83	QN84-2875
12	QN77-380	48	QC73-16	84	QN83-925
13	QN84-2241	49	H56-752	85	Q158
14	QN79-752	50	QN86-460	86	QN79-1274
15	QN83-435	51	QN77-637	87	Q152
16	Q138	52	Q96	88	Q113
17	QN77-1233	53	QN86-2075	89	QN80-4412
18	QN79-1345	54	QC76-741	90	QN85-2757
19	QN85-3190	55	Q120	91	Q158
20	QC70-466	56	QN86-2043	92	Q150
21	QN77-1135	57	QN86-537	93	QN81-374
22	QN86-1572	58	QN86-1586	94	QN79-1108
23	QN86-1959	59	QN83-434	95	QN83-943
24	BN74-4422	60	Q124	96	QN84-2945
25	QN78-828	61	QN76-1772	97	QN83-1072
26	QN80-740	62	QN86-1530	98	QN84-2961
27	QN79-183	63	QN86-298	99	QN82-837
28	QN66-2008	64	QN79-179	100	F150
29	QN86-1576	65	QC75-139	101	QN84-2518
30	Q117	66	Q107	102	QN85-996
31	QS76-1038	67	QN78-430	103	SP70-1284
32	QN80-3600	68	QN85-70	104	QN78-870
33	QN86-2168	69	Q152	105	QN85-208
34	QN86-424	70	QN84-2172	106	QN80-158
35	NA56-79	71	Q117	107	QN79-238
36	QN86-471	72	Q120	108	QN84-2467

Each dried leaf sample was milled directly from the oven in a Pulverisette 15 Model 15.301/801 cutting mill (Fritsch GmbH, Idar-Oberstein, GDR) fitted with a 1-mm screen and stored in screw-top laboratory vials. Triplicate sub-samples were scanned in 'red' 25 mm quartz-windowed cells in a rotating cup module fitted to a B6500 scanning monochromator (NIRSystems, Silver Spring, MD). Samples were scanned in reflectance mode over the spectral range 400-2,398 nm. Thirty two scans were taken of each subsample and averaged to give a mean subsample spectrum. This was preceded by capture of 16 scans of the reference tile. The subsample spectra were collected to a set root-mean-square-error value, and, once this criterion was satisfied for three subsample spectra, these were averaged and a mean sample spectrum was stored. All instrument monitoring, data collection, and data processing were performed using WINISI V1.02+ (InfraSoft International, Port Matilda, PA).

The spectral population for each crop (plant and first ratoon) of the trials were CENTRED and a spectrally representative subset of about 200 selected, using the SELECT routine, for routine chemical analysis for nitrogen (micro-Kjeldahl - BSES, Indooroopilly) and silica (XDF - DNR, Indooroopilly). Calibrations were developed for each component using the full data set from each trial, over years, using standard calibration techniques, primarily cross-validation calibration, and modified partial-least-squares regression. The best calibration for each component, selected by simple use of the rank summed over standard error of calibration (SEC), multiple coefficient of determination (R^2), standard error of cross validation (SECV), and number of terms in the equation, then was used to predict on the total spectral population. Analyses of variance were performed on the predicted data sets using MSTAT-C. (MSU, MI).

3.2.2.2 Stalk traits

Leaf-stalk morphology. This trait was assessed to test the hypothesis that the relationship between the leaf sheathes of senesced leaves and the stalk during the period of maximum SWB activity early in the monsoon period may have influenced the level of infestation a clone displayed. i.e. SWB would find clones with tightly held sheathes (rated 0) versus those with loosely held trash (rated 5) more difficult to access and infest. Clones were rated for this trait in January in 1997 and February 1998 (Table 2). A group of three assessors each assigned a rating to each clonal plot, on a 1-5 scale, and these ratings were averaged, and modified by consensus, if necessary, to yield a plot rating.

Leaf colour. Canopy colour was hypothesised as a possible criterion influencing selection of clones by the SWB. Leaf colour was measured using a SPAD-502 chlorophyll meter (Minolta Camera Co., Japan). The SPAD scale had a range from 0 to 50, an accuracy of ±1.0 SPAD scale units, and a repeatability of ±0.3 SPAD units. This instrument had been assessed by the NSW Agriculture group at Yanco as a rapid means of measuring canopy colour of rice, but was found inferior to the determination of canopy leaf nitrogen. The rapidity of measurement using this instrument influenced assessment of this measure. Five measurements were captured per plot from mid-point lamina positions of last exposed dewlap leaves chosen at random throughout the plot. These data were collected only in the plant crop (Table 2).

Table 2 Timetable of activities undertaken in replicated trials on two farms (Cali and Whitaker) in 1997 (plant crop) and 1998 (first-ratoon crop)

Year	Date	Trial	Activity
1997	28 January	Cali	Permanent pegging
	28 January	Whitaker	
	31 January	Cali	First leaf sampling for NIS and rating leaf-stalk morphology
	28-29 January	Whitaker	
	3-4 February	Cali	Determining leaf colour and measuring stalk height
	6-7 February	Whitaker	
	26-27 February, 3 March	Cali	Determination of basal-rind hardness (penetrometer)
	4, 5, 11 March	Whitaker	
	7, 9, 14-15 July	Cali	Collection of stalk samples
	21-24 July	Whitaker	
	7-11, 14 -16 July	Cali	Processing of stalk samples
	21-25 July	Whitaker	
	28 July	Cali	Second leaf sampling for NIS
	29 July	Whitaker	
	30-31 July, 1 August	Cali	Weevil borer infestation assessment
	4-6 August	Whitaker	
	5 September	Whitaker	Weevil borer damage assessment
1998	3 February	Cali	Permanent pegging
	4 February	Whitaker	
	5-7 February	Cali	First leaf sampling for NIS and rating leaf-stalk morphology
	11-12 February	Whitaker	
	9-12 March	Cali	Determination of basal-rind hardness (penetrometer)
	12-17 March	Whitaker	
	31 March – 2 April	Whitaker	Vascular bundle counts
	--	Cali	Collection of stalk samples
	26 to 28 October	Whitaker	
	--	Cali	Processing of stalk samples
	26, 29-30 October	Whitaker	
	6-8 July	Cali	Second leaf sampling for NIS
	13-14 July	Whitaker	
	5-7 October	Cali	Weevil borer infestation assessment
	7-9 October	Whitaker	

Stalk height. Stalk height was hypothesised as a possible selection criterion for SWB, clones, with sufficient height being spectrally distinguishable from surrounding cultivars. The height from ground level to the last exposed dewlap leaf of five randomly chosen stalks per plot was measured in the plant crop in 1997 (Table 2). These data were subjected to routine analyses of variance with MSTAT-C.

Basal-rind hardness. The trait was of interest because of data presented by Buzacott (1940) on the relationship between stalk hardness and clonal resistance. This was determined in the plant crop in February-March, 1997, and in the first-ratoon crop in March 1998 (Table 2), using two six-pin penetrometers designed and made by Lionel Otto

Instruments Pty Ltd (Salisbury, QLD). The two instruments used were an updated version of the instrument described by Skinner (1974). Although they were of identical specification, data from six stalks were acquired per instrument per plot. Data were acquired from randomly selected stalks in each plot, the internode nearest the ground being measured at the midpoint between nodes and on a line 90° away from bud line. These data were subjected to routine analyses of variance using MSTAT-C.

Stalk composition. The aim of this aspect of the project was to examine whether any chemical signatures correlated with resistance were detectable in stalk tissue using near-infra-red spectroscopy (NIS), in a manner used by Rutherford in exploring chemical facets of resistance to eldana borer (*Eldana saccharina* Walker (Lepidoptera: Pyralidae)) (Rutherford *et al.* 1993; Rutherford 1996; Rutherford and van Staden 1996). Clear differences in terms of chemistry among clones and susceptibility to SWB were demonstrated by Chang and Jensen (1972) using juice as a component of an artificial diet.

Six random stalks were removed from each plot at each site in the plant crop in July 1997 and from the first-ratoon crop at the Whitaker site in October 1998 (Table 2). The first-ratoon crop of the trial at the Cali site was harvested before sampling could be conducted, and so was not sampled. The stalk samples were returned to BSES Meringa. Here, a sett of about 350 mm was removed from the base of each stalk. Each sett was placed in a spindle of a device that allowed rotation of nearly the total length of the sett past a rotating, shouldered, tungsten-toothed saw blade. This device removed the outer 2.5 mm of stalk material. This material, labelled rind, was collected from the six setts from each plot, weighed, and dried to constant weight at 70°C in a fan-forced oven. The naked cores of the stalk, consisting of the nodes and storage parenchyma, had the unstripped sett ends and stripped nodes excised and all portions of parenchyma weighed and dried to constant weight at 70°C in a fan-forced oven. Percent dry matter in the rind and parenchyma was calculated from the fresh and dry weight data captured. All these procedures were completed using methods to minimize moisture losses from the samples during processing.

Preparatory to capture of near-infra-red spectral data, the rind samples were processed through a Pulverisette 15 15.301/801 cutting mill, fitted with a 1-mm screen. The parenchyma samples were processed through a Newport Scientific model 6200 mill (Newport Scientific, Warriewood, NSW) fitted with a 0.5-mm screen, a stainless steel impeller, and a full diamond strap. Samples were prepared directly from the drying oven and were stored in airtight containers to await near-infra-red analysis.

Duplicate sub-samples of both materials were scanned in NR7080 coarse granular sample cells (NIRSystems, MD) in a transport module fitted to a B6500 scanning monochromator. Samples were scanned in reflectance mode over the spectral range 400-2,498 nm. Thirty two spectral scans were captured for each subsample, these being averaged to give a mean subsample spectrum. Sixteen scans of the reference tile were captured immediately before and after capture of the subsample spectra. Spectra were collected to a set root-mean-square-error value, and once this criterion was satisfied for two mean subsample spectra, a mean spectrum was stored. All instrument monitoring, data collection, and data processing were performed using WINISI V1.02+.

Again, two sub-sets of about 200 samples were spectrally selected from the population of rind and parenchyma samples ($n \approx 1{,}296$, for each fraction) using the CENTRE and SELECT routines from WINISI. Insoluble carbohydrate (IC) was determined on these samples using the technique detailed in Appendix 3. The precision of these analyses was checked by subjecting the duplicate data for each fraction to a subsampling analysis using MSTAT-C.

Calibrations were developed for IC in each component, rind and parenchyma, using the mean values from the duplicate analyses, using standard calibration techniques, primarily cross-validation, and modified partial-least-squares regression. The best calibration for each component, selected by simple use of the rank summed over SEC, R^2, SECV, and number of terms in the equation, then was used to predict on the total spectral population.

Insoluble carbohydrate content of the rind and parenchyma sample from each plot, on a fresh weight basis, was calculated as:

Insoluble carbohydrate (g kg^{-1}) = Dry matter content (g kg^{-1}) x insoluble carbohydrate content of dry matter (g kg^{-1})/1000.

Analyses of variance of insoluble carbohydrate data for rind and parenchyma samples were performed using MSTAT-C.

Vascular-bundle density. The 10 most susceptible and 10 most resistant clones, based on the plant-crop assessment at the Whitaker site, were sampled at the end of March 1998 (Table 2) and assessed for vascular-bundle density in the rind, this being defined as the outer 2 mm region of the stalk. Three random stalks were removed from plots of the chosen clones in the two southern-most replicates. At BSES Meringa, each stalk was cut at the mid-point of the basal internode and a thin cross-section removed using a sharp, thin-bladed knife. Each cross-section was treated to highlight the vascular bundles using acidified phloroglucin, a stain for lignin (Sass 1958, p. 97). Each section was arranged on the stage of a Leica MZ6 dissecting microscope (Leica Microsystems, Wetzlar, GDR) fitted with a Leica C-mount adapter on which a Pulnix TM-6CN CCD camera (PULNiX America Corp., Mountain View, CA) was mounted. Images were captured as a *.wmf file using a combination of V^{++} Precision Digital Imaging System software (Digital Optics Ltd, Auckland, NZ) and DT3120 software (Total Turnkey Solutions, Sydney, Australia). Each captured image was printed on an A4 page for the vascular page count. A 1-mm marked ruler was laid tangentially to the stalk cross-section on the microscope stage, and this was included in the captured image. This allowed an arc of 15 mm around the external edge of the stalk by 2 mm deep to be marked on the cross-sectional image. The number of vascular bundles falling within this marked arc was counted. These data were subjected to routine analyses of variance using MSTAT-C as well as being graphically presented using SigmaPlot V9 (Systat Software Inc., Point Richmond, CA).

3.2.2.3 Stalk infestation by SWB

Infestations in plots in the trials were determined in July and August in the plant crops and October in the first-ratoon crops (Table 2) using the assessment technique of Berding (1996) (Appendix 2). Data collected were for 18 stalks per plot, and were recorded as the

number of bored internodes per stalk. Measures computed from this were percent bored stalks (%BS), number of bored internodes per stalk (#BI/S), and number of bored internodes per bored stalk (#BI/BS) (Berding 1996). These data were subjected to routine analyses of variance using MSTAT-C.

These data were used to develop predictive equations against NIS spectral data for the rind tissue collected from the two trial sites. The latter were available for the two plant crops and one first-ratoon crop (Whitaker). All data from these for the three infestation measures and the rind spectra were used. Cross-validation techniques and modified partial-least-squares regression were used to examine the value of the predictive equations, but these were not applied to any independent spectral data.

3.2.2.4 Impact of SWB on stalk quality components

This was determined by sampling the first three replicates of the plant-crop trial at the Whitaker site in September 1997 (Table 2). Fifty stalks, selected at random, were removed from each of the plots for the 10 cultivars planted in duplicates plots per replicate. The stalks were returned to BSES Meringa, where the stalks from each plot were systematically sliced longitudinally and classified as unbored or bored. When a minimum of six stalks was placed in either class, a six-stalk sample for each class was immediately disintegrated in a cane disintegrator (Dedini S/A Indústrias de Base, Piracicaba, SP), and mixed for 90 s. A subsample of about 1000 g was placed in the pressure cage of a hydraulic press (Pinette Emidecau Model OB-104) to yield express juice for solubles analyses – Brix and polariscope reading. Fibre, or insoluble carbohydrate, on a fresh-weight basis, was determined using the rapid-bag-fibre technique developed at BSES Meringa.

3.2.3 Statistical analyses

In addition to the analyses already discussed, data for the various phenotypic and chemical measures described above were related to the measures of resistance to SWB using basic statistical techniques such as correlation and regression analyses. These were performed using MSTAT-C.

3.3 Trial results

3.3.1 Leaf dry matter

Analyses of variance of leaf dry matter for the four samples taken in the plant crop revealed significant or highly significant differences among replicates, and highly significant differences among clones, on all occasions (Table 3). Coefficients of variation for all analyses were low (2.87-4.15%), with the early season sampling in each year having a lower value than the mid-season analysis. General means for leaf matter ranged from 270 to 306 g kg^{-1}, and again, not surprisingly, values during the grand growth period (January) being lower than later in the season (Table 3). The range in value at each of the four samplings was considerable, each being many-fold greater (8.6-12.5) than the least-

significant-difference value for each sampling (Table 3). There was considerable genetic variation for this trait, regardless of the sample time or trial location. The range seen in the July sampling exceeded that seen in the January sampling at both locations (48.4 versus 80.0 g kg^{-1}, Cali; 50.3 versus 110.0 g kg^{-1}, Whitaker). All these comments are also applicable to the analyses of data from the first-ratoon crop (Table 4).

Table 3 Summary statistics from analyses of variance for leaf dry matter (g/kg) of samples taken early- (January) and mid- (July) season in 1997 in the plant crop from replicated trials on two farms in northern Queensland

Statistic	Cali		Whitaker	
	January	July	January	July
$MS_{(Replicates)}$	2,300.4**	1,211.4**	6,988.9**	472.4*
$MS_{(Clones)}$	459.5**	716.9**	469.0**	926.0**
$MS_{(Error)}$	63.7	161.0	59.9	154.0
C.V. %	2.94	4.15	2.87	4.05
$L.s.d._{(0.05)}$	5.6	9.0	5.5	8.8
General mean	271.9	305.9	269.6	306.3
Minimum	249.4	276.5	239.2	253.1
Maximum	297.8	356.5	289.5	363.9

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 4 Summary statistics from analyses of variance for leaf dry matter (g/kg) of samples taken early- (February) and mid- (July) season in 1998 in the first-ratoon crop from replicated trials on two farms in northern Queensland

Statistic	Cali		Whitaker	
	February	July	February	July
$MS_{(Replicates)}$	2,798.00**	1,253.5**	6,492.2**	510.1**
$MS_{(Clones)}$	547.0**	777.6**	459.9**	850.2**
$MS_{(Error)}$	108.3	109.5	67.8	131.6
C.V. %	3.70	3.47	2.71	3.60
$L.s.d._{(0.05)}$	7.4	7.4	5.8	8.2
General mean	281.4	301.7	303.3	318.9
Minimum	254.0	267.4	275.5	287.3
Maximum	320.2	351.0	331.0	355.3

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.

Replicate means for the Cali site for the July sampling, which was completed in a single day, revealed a reduction in leaf moisture as the day progressed (Table 5). Replicate means range from 302.7, for the first sampled, to 310.1 g kg^{-1}, for the last sampled. The difference from replicate to replicate in the sampling sequence exceeded the least-significant difference. Conditions on this day were clear and sunny. Such a neat and

logical pattern was not evident for other samplings completed in a single day (Cali, January 1997; Whitaker, July 1997), and comment on the sampling conducted over 2 days is rather irrelevant. However, the low coefficients of variation for analyses of these data in general, and the generally significant differences between replicates in the sampling sequence show the perhaps surprising sensitivity and low error of this measure. In large part, this reflects, perhaps, the care taken in conducting this measure.

Table 5 **Replicate means and least significant differences (L.s.d.) from analyses of variance of leaf dry matter (g kg^{-1}) sampled early- (January/February) and mid- (July) season, 1997, in the plant crop, and 1998, first-ratoon crop, on two farms located in northern Queensland. Replicate means are listed in order from the access end of the trials, which was the order of sampling. Sampling duration for each event also is presented**

Trial	Replicate number	1997		1998	
		January	July	February	July
Cali	3	272.9	302.7	287.6	298.3
	4	277.0	303.8	282.4	300.2
	2	265.8	307.1	275.4	302.3
	1	271.9	310.1	280.1	306.2
	$L.s.d._{(0.05)}$	1.1	1.7	1.4	1.4
	No. sample days	1	1	2	2
Whitaker	1	276.9	308.6	299.6	318.4
	2	276.0	306.5	294.1	321.8
	4	260.9	306.5	309.9	316.6
	3	264.6	303.5	309.5	318.8
	$L.s.d._{(0.05)}$	1.0	1.7	1.1	1.6
	No. sample days	2	1	2	2

$L.s.d_{(0\ 05)}$ = least significant difference.

3.3.2 Leaf nitrogen and silica

Consideration of the simply summed ranks across the major calibration parameters reveals that leaf nitrogen data of 16 nm data gap subjected to first derivate treatment and 16 nm data smoothing, i.e. a 1,8,8 treatment (Table 6), yielded the most desirable calibration for prediction of leaf nitrogen. The same spectral data yielded the most desirable calibration for leaf silica when analyzed as 8 nm gap data and subjected to a second derivative and 8 nm data smoothing treatments (Table 6). The R^2 values for both these calibrations were 0.90.

Table 6 **Summary statistics[1] from development of near-infra-red spectroscopic calibrations for total nitrogen and silica of last exposed dewlap leaves, using a spectrally selected subset of samples (*n* = 400), collected in January and July 1997, in the plant crop, and February and July 1998, in the first-ratoon crop from replicated trials on two farms in northern Queensland**

Constituent	Maths[2]	SEC	Rank	R^2	Rank	SECV	Rank	No. terms	Rank	Total rank
Nitrogen (g kg^{-1})	0, 4, 4	1.22	3.5	0.89	3	1.32	2	13	5.5	14
	1, 4, 4	1.21	2	0.89	3	1.34	3.5	9	3	11.5
	2, 4, 4	1.28	5	0.88	5.5	1.40	4	6	1	15.5
	0, 8, 8	1.22	3.5	0.89	3	1.34	3.5	13	5.5	15.5
	1, 8, 8	1.17	1	0.90	1	1.31	1	11	4	7
	2, 8, 8	1.30	6	0.88	5.5	1.43	5	7	2	18.5
Silica (g kg^{-1})	0, 4, 4	1.21	6	0.67	6	1.32	6	15	1	19
	1, 4, 4	0.89	3	0.84	3	1.00	3	16	4	13
	2, 4, 4	0.70	1	0.90	1	0.90	1	16	4	7
	0, 8, 8	1.18	5	0.69	5	1.30	5	16	4	19
	1, 8, 8	0.93	4	0.82	4	1.04	4	16	4	16
	2, 8, 8	0.86	2	0.87	2	0.98	2	16	4	10

[1]SEC = standard error of calibration; R^2 = multiple coefficient of determination; SECV = standard error of cross validation; # terms = number of terms in the equation developed using modified partial least squares regression.

[2]Three digits of the maths treatment indicate the data basis (0 = raw log (1/R) data, 1 = first derivative data, 2 = second derivative data), data gap, in data points (= nm/2), and data smoothing, in data points.

Table 7 **Summary statistics from analyses of variance of nitrogen and silica content of last exposed dewlap leaves sampled on eight occasions (two sites, two crops, two samples) predicted from near-infra-red spectra using calibrations developed on a spectrally selected sub-set of this total population (*n* = 3,456) submitted for routine laboratory analyses**

Component	Statistic[1]	Cali				Whitaker			
		1997		1998		1997		1998	
		January	July	February	July	January	July	February	July
Nitrogen ($g\ kg^{-1}$)	$MS_{(Replicates)}$	37.05**	19.96**	30.98**	5.53*	51.56**	18.18**	68.46**	12.34**
	$MS_{(Clones)}$	7.39**	5.32**	5.64**	8.55**	6.77**	11.52**	5.91**	9.31**
	$MS_{(Error)}$	1.54	1.63	0.81	1.53	0.54	1.25	0.84	1.52
	C.V. %	8.06	12.19	6.43	13.27	4.81	8.83	7.24	14.21
	General mean	15.4	10.5	13.9	9.3	15.2	12.7	12.7	8.7
	$L.s.d._{(0.05)}$	1.7	1.8	1.2	1.7	1.0	1.6	1.3	1.7
	Minimum	12.9	7.1	11.5	3.7	12.2	6.3	10.5	4.0
	Maximum	18.3	13.6	17.0	13.0	19.1	18.0	16.3	11.7
Silica ($g\ kg^{-1}$)	$MS_{(Replicates)}$	23.78**	3.29	33.73**	13.12**	20.33**	17.92**	5.32**	33.00**
	$MS_{(Clones)}$	3.94**	7.3**	3.85**	6.45**	1.81**	3.66**	1.29**	3.35**
	$MS_{(Error)}$	2.13	3.63	2.35	3.12	0.65	1.10	0.67	0.87
	C.V. %	32.37	28.49	21.18	28.54	26.50	19.80	26.42	21.82
	$L.s.d._{(0.05)}$	2.0	2.6	2.1	2.5	1.1	1.5	1.1	1.3
	General mean	4.5	6.7	7.2	6.2	3.0	5.3	3.1	4.3
	Minimum	2.4	2.8	4.7	3.9	1.4	2.6	1.7	1.8
	Maximum	7.9	11.6	10.5	11.7	5.2	8.7	4.6	6.8

C.V. % = coefficient of variation; $L.s.d_{(0.05)}$ = least significant difference.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Analyses of the predicted leaf nitrogen and silica data obtained by applying these calibrations to the total population of spectra revealed that there were highly significant differences among replicates and clones in all except one analysis for leaf nitrogen (Replicates, for Cali, July 1998; significant) and one analysis for leaf silica ((Replicates, Cali, July 1997; non-significant). Coefficients of variation for analyses of leaf nitrogen, ranging from 8.8 to 14.2, were considerable smaller than those for leaf silica, ranging from 19.8 to 32.4. Intuitively, this is logical, as NIS lends itself to analysis of constituents of an organic, rather than an inorganic nature, unless the latter have a strong association with an organic component in the matrix being analyzed. The general mean for leaf nitrogen for the early sampling (January or February) was always higher than that for the later sampling (July) for each crop and each site (Table 7). Again, this is expected. None of the general means approach the desired threshold of 18 g kg^{-1} of leaf nitrogen for commercial crops (AP Hurney, pers. com., June 2005). Part of this shortfall may be explained by processing of the entire leaf sample, and not just the leaf lamina obtained by stripping out the midrib. However, both trials were managed as commercial crops, as the trials were not excluded from the blocks containing them in terms of management. In only three of the eight samplings reported does the maximum value exceed this threshold.

The picture for leaf silica differed from nitrogen in that for three of the four crop samplings (Cali 1997; Whitaker 1997, 1998) the general mean for the July sampling was markedly higher than the January/February mean (Table 7). For the remaining sampling (Cali 1998) the general mean for the February sample was higher than that for the July sample (7.2 versus 6.2 g kg^{-1}; Table 7.). The accepted threshold for leaf silica for commercial management is 7 g kg^{-1} (AP Hurney, pers. com., June, 2005), and so in only one of the eight samplings reported (Cali, February 1998) does the general mean exceed this value. None of the general means reported for the four samplings at the Whitaker site approach this threshold. The mean over the four samplings, 3.9 g kg^{-1}, is well below the mean for the four samplings at the Cali site, 6.2 g kg^{-1}.

Variation among replicates for both leaf nutrients was substantially greater than that among clones for all except two of the 16 analyses reported. The mean levels for both nutrients at a majority of samplings fell below the commercially accepted thresholds for well nutritioned commercial crops, despite both sites being grown under commercial nutrition regimes. Despite this qualification, ample genetic variation was evident for both leaf nitrogen and silica at all samplings. This variation was determined over substantial macro-environmental variation in both crops at both sites.

3.3.3 Leaf-stalk morphology

Analyses of variance of this subjectively assessed trait for each of the four site/crop combinations revealed that there were highly significant differences among replicates and among clones (Table 8). Values for the coefficient of variation in each analysis were higher than seen for most traits assessed in this project, ranging from 13.5-16.4%. The observed ranges in all situations exceeded the respective least-significant-difference values by several to many multiples. The minimum values at each site were comparable, but the maxima values in both crops at Whitaker exceeded that observed at the Cali site, perhaps as a consequence of the greater and more rapid growth seen there. There were

clones at the Whitaker that were close to freely trashing of senesced leaves early in the grand growth period (February-March).

Table 8 Summary statistics from analyses of variance for leaf-stalk morphology[1] assessed early (January) in the plant crop (1997) and early (February) in the first-ratoon crop (1998) in replicated trials on two farms in northern Queensland

Statistic	Cali		Whitaker	
	1997	1998	1997	1998
$MS_{(Replicates)}$	0.54**	2.0**	0.97**	2.6**
$MS_{(Clones)}$	1.24**	1.5**	1.53**	1.5**
$MS_{(Error)}$	0.12	0.15	0.14	0.16
C.V. %	16.41	17.06	13.46	16.21
$L.s.d._{(0.05)}$	0.25	0.54	0.26	0.55
General mean	2.1	2.3	2.7	2.4
Minimum	1.1	0.8	1.1	1.0
Maximum	3.7	3.5	4.9	4.1

[1]Rated as 0 = tightly clinging basal leaf sheathes, and 5 = loosely-clinging or freely-shed basal leaf sheathes.
C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.

3.3.4 Leaf colour and stalk height

Replicates and clones were highly significant main effects for both these traits measured in only the plant crop at each site (Table 9). The subsampling strategy used for these traits proved deficient, with the error ratio test ($5\sigma_e^2 / \sigma_s^2$) falling well below the desired threshold value of 3.0, i.e. the variation among the five units (leaves or stalks) measured simply swamped the plot-to-plot variation, excluding the subsampling component. Obviously, measurement of mean leaf colour, using the SPAD meter, or mean stalk height must be based on greater than five units per plot. Values for the coefficient of variation, ranging from 9.4-11.8 (Table 9), were acceptable. Again, there was ample variation, as indicated by range /least significant difference value, for both traits in both site/crop combinations measured.

Table 9 Summary statistics from analyses of variance for leaf colour and stalk height of clones measured early (January-February, 1997) in the plant crop of replicated trials on two farms in northern Queensland.

Statistic	Cali		Whitaker	
	Leaf colour[1]	Stalk height[2] (cm)	Leaf colour	Stalk height (cm)
$MS_{(Replicates)}$	103.1**	6,592.2**	201.3**	4,655.7**
$MS_{(Clones)}$	165.8**	4,090.3**	142.4**	4,602.7**
$MS_{(Error)}$	19.9**	257.0**	14.2**	236.0**
$MS_{(Sub\text{-}sampling)}$[3]	8.7	83.9	7.5	71.3
C.V. %	10.79	11.88	9.36	8.75
$L.s.d._{(0.05)}$	1.4	5.0	1.2	4.9
General mean	41.4	135.0	40.2	175.6
Minimum	31.6	101.0	29.9	139.5
Maximum	48.5	168.7	46.9	214.9

[1]Measured using a Minolta SPAD-502 chlorophyll meter, with a range of 0 - 50 SPAD units.
[2]Measured from the ground to the last exposed dewlap.
[3]Variation arising from measurement of five leaves or stalk per plot leaf colour and stalk height, respectively.
C.V. % = coefficient of variation; $L.s.d._{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.

3.3.5 Basal-rind hardness

Variation among replicates and clones in both crops at both locations was highly significant for the penetrometer data (Table 10). The variation among the six stalks sampled per plot by each of the two penetrometers swamped the variation between the two penetrometers used, as indicated by the error ratio test of $s\sigma_i^2 / \sigma_s^2$, where $s\sigma_i^2$ = instrument variation. None of the four values for this measure exceeded the accepted threshold of 3.0, clearly suggesting that more than 6 stalks per instrument per plot was required to improve sampling precision. The mean square for plot error was highly significant for all analyses except the 1998 assessment at the Whitaker site (Table 10). Perhaps not surprisingly, given the use of what proved to be an inadequate subsampling strategy, coefficient of variation values were high relative to those for traits already discussed, ranging from 22.4 to 41.5% (Table 10). Again, there was broad variation for this trait at each crop and site, with the range of maximum minus minimum values at each site, relative to the respective least significant difference value being from 6.0 to 18.0 (Table 10). Broad-sense heritability (g^2) values were generally moderated (0.49-0.65; Table 10), yet the genetic coefficient of variation (G.C.V. %) values generally indicated ample genetic variation existed for this trait (13.6-20.3%) regardless of the assessment crop and site.

Table 10 Summary and genetic statistics from analyses of variance for basal-rind hardness, as measured by penetrometer, early in the plant crop (February-March 1997) and early in the first-ratoon crop (March 1998) of replicated trials on two farms in northern Queensland

Statistic	Cali		Whitaker	
	1997	1998	1997	1998
$MS_{(Replicates)}$	690.4**	723.5**	260.4**	2,452.9**
$MS_{(Clones)}$	872.9**	683.2**	1,210.9**	794.1**
$MS_{(Error)}$	69.7**	45.9**	53.2**	36.8
$MS_{(Sub\text{-}sampling\ 1)}$[1]	46.7**	31.3**	40.8**	45.0**
$MS_{(Sub\text{-}sampling\ 2)}$[2]	17.2	18.7	20.9	19.1
C.V. %	41.50	25.18	28.15	22.40
$L.s.d._{(0.05)}$	3.34	1.38	2.92	1.32
General mean	20.1	26.9	25.9	28.8
Minimum	12.6	19.0	16.7	19.6
Maximum	34.0	39.0	48.5	43.4
g^2	0.49	0.54	0.65	0.60
G.C.V. %	20.33	13.55	18.95	13.77

[1]Variation arising from use of two penetrometers per plot.
[2]Variation arising from measurement of six stalks per penetrometer per plot.
C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.
$g^2 = ((MS_{(Clones)} - MS_{(Error)})/48)/(((MS_{(Clones)} - MS_{(Error)})/48) + MS_{(Error)}/4)$.
$G.C.V.\ \% = 100(\sqrt{((MS_{(Clones)} - MS_{(Error)})/48)}/G.M.)$

3.3.6 Rind and parenchyma dry matter

Analyses of these data for the three site/crop combinations available revealed highly significant differences among replicates and clones for all except the replicates term in the first-ratoon crop at the Whitaker site (Table 11), which was significant. Values for the coefficient of variation were excellent, ranging from 2.8-5.6%. The ratio of mean dry matter in rind to that in parenchyma was rather consistent in the three site/crops combinations, ranging from 1.63-1.69. The dry matter in the excised parenchyma (240.4-259.6 g kg^{-1}) would be predominantly soluble carbohydrates, while that in the rind (392.4-438.6 g kg^{-1}) would consist predominantly of insoluble carbohydrate. Comparison with mean values presented for insoluble carbohydrate (Table 14) confirms this. For parenchyma, on average, 54.03 of 249.4 g kg^{-1}, or 21.7%, was insoluble carbohydrate while for rind 278.53 of 414.30 g kg^{-1}, or 67.2% was insoluble carbohydrate. Again, relative to the least significant values, there was ample variation displayed in the ranges witnessed for each trait.

Table 11 Summary statistics from analyses of variance of parenchyma and rind dry matter from basal mature stalks sampled in 1997, from the plant crop of two replicated trials and in 1998, from the first-ratoon crop of one of these trials, on two farms in northern Queensland

Component	Statistic	Cali	Whitaker	
		1997	1997	1998
Parenchyma (g kg^{-1})	$MS_{(Replicates)}$	942.5**	181.6**	598.0*
	$MS_{(Clones)}$	500.4**	652.3**	838.6**
	$MS_{(Error)}$	102.0	43.8	213.6
	C.V. %	4.07	2.75	5.63
	$L.s.d_{(0.05)}$	14.05	9.21	20.3
	General mean	248.2	240.4	259.6
	Minimum	210.0	185.9	210.6
	Maximum	270.8	267.1	295.7
Rind (g kg^{-1})	$MS_{(Replicates)}$	3,428.8**	2,165.5**	9,395.0**
	$MS_{(Clones)}$	2,138.1**	2,578.2**	3,584.8**
	$MS_{(Error)}$	447.9	248.2	395.8
	C.V. %	5.14	4.02	4.54
	$L.s.d_{(0.05)}$	29.44	21.90	27.69
	General mean	411.9	392.4	438.6
	Minimum	361.0	327.3	376.6
	Maximum	479.1	453.6	544.8

C.V. % = coefficient of variation; $L.s.d_{(0.05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and $P \leq 0.01$ respectively.

3.3.7 Rind and parenchyma insoluble carbohydrates

Analysis of variance of data for insoluble carbohydrates in the rind and parenchyma fractions of the basal regions of mature stalks revealed that the method used for these determinations yielded very acceptable precision. The error ratio test ($2\sigma_e^2 / \sigma_s^2$) realized values of 82.7 and 24.9 for the parenchyma and rind fractions, respectively, well in excess of the threshold limit of 3.0 (Table 12). The level of insoluble carbohydrate in the parenchyma, on a dry matter basis, was one-third that found in the rind for the samples spectrally selected from the total population of available samples (222.6 versus 666.9 g kg^{-1}; Table 12). There was considerably more variation present in the parenchyma than in the rind faction, with the maximum values being 265 and 165%, respectively, of the respective minimum values.

Selection of the calibration equations developed with these data and the relevant NIS spectra using the simple summed ranking method of the primary calibration statistics yielded the best equation for parenchyma based on first derivative pre-treatment of data of 16 nm data points and with 16 nm data smoothing. The best equation for the rind faction used raw data and 8 nm data spacing and smoothing (Table 13). The selected equation for the parenchyma faction was considerably superior to that developed for the rind faction,

with R^2 values of 0.95 and 0.67, respectively (Table 13). A reason for this difference is difficult to offer given the higher levels of the insoluble carbohydrate in the rind fraction.

Table 12 **Summary statistics from analyses of variance of total insoluble carbohydrates (g kg^{-1}) determined for duplicates of independent, spectrally-selected parenchyma and rind samples from the basal region of mature stalks from clonal plots (n ≈ 1,296 for each fraction) sampled in 1997, plant crop of two replicated trials and 1998, first-ratoon crop of one of these trials on two farms in northern Queensland**

Statistic[1]	Parenchyma	Rind
$MS_{(Samples)}$	3,159.2**	6,171.5**
$MS_{(Error)}$	37.7	238.6
ERT	82.7	24.9
C.V. %	2.76	2.32
General mean	222.6	666.9
S.D.	39.7	55.6
Minimum	139.0	525.4
Maximum	368.0	866.6

[1]For $MS_{(samples)}$, n = 198 and 197, respectively, for parenchyma and rind; ERT = error ratio test = (F - 1) = $[(MS_{(Samples)} - MS_{(Error)}]/ MS_{(Error)} = 2\sigma_c^2 / \sigma_s^2$; S.D. = standard deviation of clonal means
C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
** = $P \leq 0.01$.

Table 13 **Summary statistics[1] from development of calibrations for insoluble carbohydrates of parenchyma and rind samples from basal mature stalks using a spectrally selected sub-set of samples (*n* = 198 and 197, respectively) sampled in 1997, plant crop of two replicated trials and 1998, first-ratoon crop of one of these trials on two farms in northern Queensland**

Constituent	Maths[2]	SEC	Rank	R^2	Rank	SECV	Rank	No. terms	Rank	Total rank
Parenchyma ($g\ kg^{-1}$)	0, 4, 4	10.93	5	0.92	5.5	11.96	5	8	2	17.5
	1, 4, 4	8.77	2	0.95	2.5	10.46	1	10	6	11.5
	2, 4, 4	9.01	4	0.95	2.5	11.10	4	9	4.5	15.0
	0, 8, 8	10.95	6	0.92	5.5	12.00	6	8	2	19.5
	1, 8, 8	8.76	1	0.95	2.5	10.53	2	9	4.5	10.0
	2, 8, 8	8.78	3	0.95	2.5	10.78	3	8	2	10.5
Rind ($g\ kg^{-1}$)	0, 4, 4	29.54	1	0.67	1.5	32.60	1	6	5.5	9
	1, 4, 4	32.06	4	0.64	5	33.73	3	4	2.5	14.5
	2, 4, 4	32.48	6	0.64	5	34.63	6	4	2.5	19.5
	0, 8, 8	29.55	2	0.67	1.5	32.63	2	6	5.5	11.0
	1, 8, 8	31.04	3	0.65	3	33.70	5	4	2.5	13.5
	2, 8, 8	32.16	5	0.64	5	33.91	4	4	2.5	16.5

[1]SEC = standard error of calibration; R^2 = multiple coefficient of determination; SECV = standard error of cross validation; # terms = number of terms in the equation developed using modified partial least squares regression.

[2]Three digits of the maths treatment indicate the data basis (0 = raw log (1/R) data, 1 = first derivative data, 2 = second derivative data), data gap, in data points (= nm/2), and data smoothing, in data points.

Analyses of variance of data for insoluble carbohydrate of rind and parenchyma, on a fresh-weight basis (Table 14), derived using NIS-predicted, dry-weight basis data for the same fractions, revealed significant or highly significant differences among replicates and among clones in all three trials site/crop combinations analyzed. Coefficients of variation were low for all analyses, with there being minimal differences between those for the two fractions. The mean value for insoluble carbohydrate level in parenchyma was about 60% of than in the rind (249.4 versus 414.3 g kg^{-1}). The range exhibited in both fractions exceed the necessary least significant difference value in all site/crop sets, ranging from 4.0 (rind, Cali 1997) to 8.8 (parenchyma, Whitaker 1998). Again, there was ample genetic variation displayed for insoluble carbohydrate level in rind and parenchyma fractions.

Table 14 Summary statistics from analyses of variance of insoluble carbohydrates, on a fresh weight basis, of parenchyma and rind from basal mature stalks sampled in 1997 from the plant crop of two replicated trials and in 1998 from the first-ratoon crop of one of these trials on two farms in northern Queensland

Component	Statistic[1]	Cali	Whitaker	
		1997	1997	1998
Parenchyma (g kg^{-1})	$MS_{(Replicates)}$	429.7**	220.1**	327.3**
	$MS_{(Clones)}$	295.5**	243.3**	211.7**
	$MS_{(Error)}$	35.9	17.3	18.8
	C.V. %	10.75	7.94	8.02
	$L.s.d_{(0.05)}$	8.31	5.76	6.01
	General mean	55.7	52.3	54.1
	Minimum	40.2	36.7	39.7
	Maximum	93.2	92.6	92.1
Rind (g kg^{-1})	$MS_{(Replicates)}$	2,883.6**	2,436.3**	6,962.0**
	$MS_{(Clones)}$	2,404.9**	2,296.9**	3,347.5**
	$MS_{(Error)}$	311.9	239.9	315.1
	C.V. %	6.39	5.67	6.20
	$L.s.d_{(0.05)}$	24.48	21.47	24.60
	General mean	276.4	273.1	286.1
	Minimum	230.5	225.9	222.1
	Maximum	359.0	361.6	400.4

[1]C.V. % = coefficient of variation; $L.s.d_{(0.05)}$ = least significant difference;
** = $P \leq 0.01$.

3.3.8 SWB resistance assessment

There was highly significant variation among clones for reaction to SWB as measured by %BS, #BI/S, and #BI/BS (Tables 15 and 16) in all four crops sampled in this research. Overall reaction to SWB is given by %BS, while #BI/S indicated the severity of stalk damage and #BI/BS yield a measure of the intensity of damage once the stalk has succumbed to infestation by the SWB (Berding 1996). There were no significant differences among replicates in the plant crop at Cali (1997) for any of these measures,

but highly significant differences among replicates existed at the Whitaker site in the same year for all three traits. In the ratoon crop at Cali, only %BS yield significant differences among replicates (Table 16), but at the Whitaker site the %BS and #BI/S yielded highly significant differences among replicates. Infestation (%BS) was higher at the Whitaker (45.6 and 30.7) than Cali (18.4 and 6.7%; Tables 15 and 16). Coefficients of variation for this suite of traits were considerably lower at Whitaker than at Cali, but this was a consequence of higher errors at Whitaker despite the higher means for all traits (Tables 15 and 16). These generally higher C.V. % values are beyond those generally experienced for yield and quality component traits, but are not abnormal in my experience of measures of entomological and disease resistance. There were substantial ranges for all three traits in all four site/crop sets. Estimates of broad-sense heritability (g^2) for all three traits were good to excellent (Tables 15 and 16). There was a wealth of genetic variation, as measured by the genetic coefficient of variation (G.C.V. %), for all three traits, in all site/crop sets, to exploit via selection (Tables 15 and 16).

Combined analyses of the same crop (plant crop or first-ratoon crop) at both sites (Cali and Whitaker) or the two crops (plant and first-ratoon crops) at each site (Cali or Whitaker) for all three SWB traits (%BS, #BI/S, and #BI/BS) revealed that variation between sites in each year and between years at each site were highly significant (Table 17). In general, the comments that can be made on the statistics presented from these analyses are similar to those made for the individual analyses (Tables 15 and 16). Importantly, these analyses over time and space confirm in general the moderate to excellent broad-sense heritability (g^2) for each of the three traits, as well as the ample genetic variation (G.C.V. %) available for each of the traits (Table 17). Importantly, all four analyses demonstrated highly significant locations by clones or years by clones interactions (Table 17). This reinforces the principle that screening for a trait such as SWB resistance must encompass environmental and temporal variation.

Clonal means for the three measures of SWB resistance (%BS, #BI/S, and #BI/BS) from the individual and combined analyses over sites within years (1997 and 1998) show the individual variation present (Tables 18 and 19). Cultivar H74-0922 was the most resistant for %BS in the combined analyses in both years. This place was shared with clone QN80-3600 in the individual analyses. Values were zero or close to this. At the other extreme, one entry of the cultivar Q120 had the most susceptible reaction (%BS, 75.7%; Table 18) in the combined plant-crop analysis. This cultivar also was the most susceptible at the Cali site (63.9 %BS), but was beaten by QN84-2172 at the Whitaker site (90.3 %BS). The clone QN86-2195 was the most susceptible in the combined analysis of the first-ratoon crop (41.0 %BS; Table 19), but QN77-1135 was the most susceptible at the Cali site (32.0 %BS) and Q173$^{(}$ the most susceptible at the Whitaker site (63.9 %BS).

Table 15 Summary and genetic statistics from analysis of variance for three measures[1] of resistance to SWB infestation in July-August 1997 in the plant crop of two trials in northern Queensland

Statistic	Cali			Whitaker		
	%BS	10(#BI/S)	10(#BI/BS)	%BS	10(#BI/S)	10(#BI/BS)
$MS_{(Replicates)}$	62.7	44.2	74.9	958.0**	588.6**	575.3**
$MS_{(Clones)}$	676.8**	104.1**	320.5**	1,917.5**	496.4**	324.7**
$MS_{(Error)}$	149.0	22.2	124.0	196.0	43.5	58.6
C.V. %	66.51	84.76	48.18	30.73	40.57	24.00
$L.s.d._{(0.05)}$	17.13	6.62	15.62	19.64	9.25	10.74
General mean	18.4	5.6	23.1	45.6	16.3	31.9
Minimum	1.4	0.0	0.0	1.4	0.3	5.0
Maximum	63.9	26.5	47.6	90.3	48.8	57.8
g^2	0.78	0.79	0.61	0.90	0.91	0.82
G.C.V. %	62.58	81.28	30.32	45.53	65.46	25.57

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.

$g^2 = ((MS_{(Clones)} - MS_{(Error)})/r)/(((MS_{(Clones)} - MS_{(Error)})/r) + MS_{(Error)}/r)$.

G.C.V. % = $100(\sqrt{((MS_{(Clones)} - MS_{(Error)})/r)}/G.M.)$.

$^{**} = P \leq 0.01$.

Table 16 **Summary and genetic statistics from analysis of variance for three measures[1] of resistance to SWB infestation in October 1998 in the first-ratoon crop from replicated trails on two farms in northern Queensland**

Statistic	Cali			Whitaker		
	%BS	10(#BI/S)	10(#BI/BS)	%BS	10(#BI/S)	10(#BI/BS)
$MS_{(Replicates)}$	153.7*	10.8	294.4	645.0**	150.0**	64.9
$MS_{(Clones)}$	142.7**	16.4**	414.1**	857.7**	227.5**	370.4**
$MS_{(Error)}$	48.1	4.9	198.5	161.6	31.72	90.2
C.V. %	103.68	118.96	91.28	41.41	55.17	32.50
$L.s.d._{(0.05)}$	9.62	3.07	19.53	17.62	7.81	13.17
General mean	6.69	1.86	15.44	30.70	10.2	29.2
Minimum	0.0	0.0	0.0	4.2	0.4	5.0
Maximum	31.9	11.5	42.5	63.9	44.0	58.3
g^2	0.663	0.700	0.521	0.811	0.861	0.756
G.C.V. %	72.65	90.90	47.56	35.95	68.52	28.64

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.

$g^2 = ((MS(Clones) - MS_{(Error)})/r)/(((MS(Clones) - MS_{(Error)})/r) + MS_{(Error)}/r)$.

G.C.V. % = $100(\sqrt{((MS(Clones) - MS_{(Error)})/r)}/G.M.)$.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 17 Summary and genetic statistics from combined analyses of variance over sites within years and over years within sites for three measures of resistance to SWB infestation[1] in July-August 1997 and October 1998, in plant and first-ratoon crops, respectively, of replicated trials on two farms in northern Queensland

Resistance measure	Statistic	Cali 1997 and Whitaker 1997	Cali 1998 and Whitaker 1998	Cali 1997 and Cali 1998	Whitaker 1997 and Whitaker 1998
%BS	$MS_{(Locations)}$	159,897.2**	124,471.0**	29,385.1**	47,773.2**
	$MS_{(Error-1)}$	510.4**	399.4**	108.2**	801.3**
	$MS_{(Clones)}$	2159.1**	657.1**	600.5**	2,121.9**
	$MS_{(Loc\ x\ Clones)}$	435.2**	343.3**	219.2**	653.3**
	$MS_{(Error-2)}$	172.6	105.0	98.0	178.6
	C.V. %	41.11	54.8	79.05	35.05
	$L.s.d._{(0\ 05)}$	12.9	10.0	9.7	13.1
	General mean	31.9	18.7	12.5	38.1
	Minimum	1.4	2.1	0.0	2.8
	Maximum	75.7	41.0	41.7	73.6
	g^2	0.798	0.478	0.635	0.692
	G.C.V. %	45.93	33.5	55.14	35.54
10(#BI/S)	$MS_{(Locations)}$	24,690.4**	15,050.5**	2,961.0**	7,904.4**
	$MS_{(Error-1)}$	316.4**	80.4**	27.4**	369.3**
	$MS_{(Clones)}$	486.6**	148.6**	86.4**	550.1**
	$MS_{(Loc\ x\ Clones)}$	113.8**	95.2**	34.0**	173.8**
	$MS_{(Error-2)}$	32.9	18.3	13.5	37.6
	C.V. %	52.58	70.9	98.95	46.33
	$L.s.d._{(0\ 05)}$	5.6	4.2	4.0	6.0
	General mean	10.9	6.0	3.7	13.2
	Minimum	0.208	0.21	0.1	0.3
	Maximum	37.639	18.82	16.5	39.9
	g^2	0.766	0.359	0.810	0.684
	G.C.V. %	62.57	42.81	79.68	51.84
10(#BI/BS)	$MS_{(Locations)}$	16,664.0**	41,070.0**	12,518.2**	1,545.8**
	$MS_{(Error-1)}$	325.1**	179.6	188.9	320.0**
	$MS_{(Clones)}$	542.1**	559.7**	529.4**	547.4**
	$MS_{(Loc\ x\ Clones)}$	103.1	224.8**	204.5*	147.7**
	$MS_{(Error-2)}$	91.2	144.3	160.6	74.3
	C.V. %	34.72	53.8	65.63	28.20
	$L.s.d._{(0\ 05)}$	9.4	11.8	12.4	8.4
	General mean	27.5	22.3	19.3	30.56
	Minimum	3.8	2.5	0.0	5.0
	Maximum	52.7	43.2	41.5	58.4
	g^2	0.829	0.598	0.613	0.783
	G.C.V. %	27.24	28.97	33.00	14.01

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.

$g^2 = ((MS_{(Clones)} - MS_{(Error)})/r)/(((MS_{(Clones)} - MS_{(Error)})/r) + MS_{(Error)}/r)$.

$G.C.V.\ \% = 100(\sqrt{((MS_{(Clones)} - MS_{(Error)})/r)}/G.M.)$.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 18 **Combined and individual means for three measures of resistance to SWB infestation[1], together with ranking[2] of clones for percent bored stalks, obtained from slicing of clones and cultivars in July-August 1997 in the plant crop of replicated trials on two farms in northern Queensland**

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
BN74-4422	P	52.78	95	21.60	37.22	34.72	95	15.00	34.05	70.83	91	28.19	40.39
F150	P	18.75	24	5.97	24.69	11.11	36	2.78	18.12	26.39	22	9.17	31.25
H56-752	C	24.31	41	7.36	27.49	9.72	30	2.36	26.25	38.89	44	12.36	28.72
H56-752	C	30.56	53	9.58	26.38	12.50	45	3.89	22.92	48.61	56	15.28	29.85
H74-0922	P	1.39	1	0.21	3.75	1.39	2	0.14	2.50	1.39	1	0.28	5.00
NA56-79	P	33.33	61	9.10	27.15	16.67	65	3.89	24.17	50.00	63	14.31	30.13
Q96	P	34.03	66	10.00	25.98	18.06	70	3.75	19.46	50.00	64	16.25	32.50
Q107	C	61.81	101	23.89	37.23	38.89	97	14.44	35.35	84.72	104	33.33	39.12
Q107	C	63.89	104	24.38	36.83	50.00	105	16.11	31.77	77.78	96	32.64	41.90
Q113	C	51.39	92	17.15	30.54	22.22	79	5.83	26.25	80.56	99	28.47	34.84
Q113	C	55.56	98	21.11	30.42	27.78	87	8.19	19.75	83.33	101	34.03	41.09
Q115	C	52.78	94	19.86	35.58	27.78	86	9.31	32.31	77.78	94	30.42	38.86
Q115	C	50.00	89	18.82	36.41	20.83	74	7.36	34.46	79.17	97	30.28	38.35
Q117	C	32.64	59	9.72	27.18	16.67	64	4.58	24.17	48.61	58	14.86	30.18
Q117	C	41.67	81	12.29	29.43	31.94	92	9.31	30.59	51.39	68	15.28	28.28
Q120	C	75.69	108	33.61	43.07	63.89	108	22.78	35.89	87.50	107	44.44	50.25
Q120	C	63.89	103	27.99	40.91	44.44	104	15.14	33.61	83.33	103	40.83	48.20
Q124	C	20.14	28	6.11	30.20	19.44	71	5.14	24.25	20.83	16	7.08	36.15
Q124	C	29.86	52	11.74	27.63	6.94	16	2.08	15.00	52.78	70	21.39	40.25
Q138	C	21.53	31	6.94	25.80	13.89	49	3.47	18.12	29.17	29	10.42	33.48
Q138	C	22.22	34	7.71	28.90	13.89	50	5.00	25.58	30.56	32	10.42	32.22
Q150	P	38.19	79	16.46	39.80	25.00	83	8.89	34.72	51.39	67	24.03	44.89
Q152	C	18.75	23	5.21	20.50	9.72	27	2.64	17.50	27.78	26	7.78	23.50
Q152	C	26.39	47	7.92	24.75	11.11	38	3.47	20.21	41.67	51	12.36	29.29
Q158	C	13.89	12	4.44	22.60	4.17	8	0.56	10.00	23.61	17	8.33	35.21
Q158	C	20.83	30	5.56	26.15	6.94	15	1.94	30.00	34.72	38	9.17	22.31
Q167[(b)]	A	27.78	49	7.50	27.16	12.50	44	3.19	26.67	43.06	52	11.81	27.66
Q173[(b)]	A	47.22	87	20.00	38.08	23.61	81	7.22	30.73	70.83	90	32.78	45.44

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
Q175[(b)]	A	9.72	7	2.57	25.25	5.56	12	1.39	25.00	13.89	7	3.75	25.50
QC70-466	P	34.72	69	11.46	26.81	11.11	39	1.94	17.50	58.33	79	20.97	36.11
QC71-998	P	22.92	37	5.21	22.11	18.06	68	4.31	22.08	27.78	27	6.11	22.14
QC73-16	P	27.78	51	7.01	25.30	9.72	33	2.50	25.83	45.83	54	11.53	24.77
QC73-947	P	38.19	76	11.81	28.11	22.22	77	6.94	26.43	54.17	73	16.67	29.78
QC74-42	P	27.78	50	7.5	25.59	29.17	88	7.78	23.44	26.39	24	7.22	27.75
QC75-139	P	25.00	46	6.67	25.82	9.72	32	3.19	26.25	40.28	49	10.14	25.38
QC76-741	P	31.94	58	7.92	24.78	25.00	82	6.11	24.41	38.89	47	9.72	25.16
QC81-351	P	25.00	45	9.03	32.58	12.5	43	3.33	27.50	37.50	43	14.72	37.66
QN66-2008	P	27.08	48	9.03	24.05	15.28	56	3.47	14.58	38.89	46	14.58	33.52
QN71-569	P	19.44	25	4.51	20.60	13.89	47	2.50	14.17	25.00	20	6.53	27.02
QN76-1772	P	15.28	15	3.19	18.67	9.72	25	1.81	14.38	20.83	14	4.58	22.96
QN77-380	P	42.36	83	11.94	25.65	29.17	89	6.25	19.72	55.56	76	17.64	31.59
QN77-606	P	68.75	106	28.75	40.18	51.39	106	17.64	34.42	86.11	106	39.86	45.95
QN77-637	P	56.94	99	21.04	36.56	40.28	98	13.89	34.48	73.61	93	28.19	38.63
QN77-1135	P	25.00	44	6.67	16.30	9.72	31	2.22	5.71	40.28	48	11.11	26.88
QN77-1233	P	43.06	85	20.21	43.69	26.39	85	10.97	39.83	59.72	84	29.44	47.55
QN78-430	P	31.25	56	8.33	23.68	13.89	51	2.64	18.83	48.61	57	14.03	28.52
QN78-828	P	18.75	21	4.65	23.40	9.72	26	2.5	25.00	27.78	25	6.81	21.81
QN78-870	P	34.72	70	9.31	29.11	20.83	73	5.83	31.88	48.61	60	12.78	26.35
QN79-179	P	30.56	54	9.03	24.55	15.28	57	4.31	20.50	45.83	55	13.75	28.60
QN79-183	P	34.03	64	9.93	26.27	19.44	72	5.14	22.29	48.61	59	14.72	30.25
QN79-238	P	10.42	10	2.78	18.00	13.89	46	3.75	17.25	6.94	2	1.81	18.75
QN79-398	P	4.86	2	1.18	12.29	1.39	3	0.28	5.00	8.33	3	2.08	19.58
QN79-752	P	8.33	6	1.81	13.44	1.39	5	0.42	7.50	15.28	9	3.19	19.38
QN79-1108	P	15.28	16	4.17	20.42	4.17	9	0.69	12.5	26.39	21	7.64	28.33
QN79-1274	P	41.67	82	13.33	31.64	31.94	93	9.72	30.45	51.39	69	16.94	32.82
QN79-1345	P	6.94	4	1.25	14.38	5.56	11	0.69	12.5	8.33	4	1.81	16.25
QN80-158	P	10.42	9	2.15	16.38	4.17	7	0.83	11.25	16.67	10	3.47	21.50
QN80-740	P	34.03	63	8.12	22.1	15.28	60	3.75	20.88	52.78	72	12.50	23.33
QN80-3499	P	22.92	38	5.76	20.96	8.33	22	1.39	15.00	37.50	42	10.14	26.92
QN80-3600	P	15.97	17	4.10	12.20	0.00	1	0.00	0.00	31.94	33	8.19	24.40
QN80-4412	P	14.58	14	3.40	17.42	11.11	35	1.94	8.00	18.06	12	4.86	26.85

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
QN81-314	P	20.14	27	5.21	27.12	13.89	48	3.06	25.00	26.39	23	7.36	29.25
QN81-374	P	42.36	84	14.86	31.28	13.89	54	3.61	25.83	70.83	89	26.11	36.72
QN82-549	P	39.58	80	10.00	25.57	25.00	84	6.81	27.17	54.17	75	13.19	23.98
QN82-837	P	50.00	90	21.39	33.68	16.67	67	5.14	22.54	83.33	100	37.64	44.82
QN82-1240	P	63.89	102	21.81	31.27	44.44	103	12.50	25.57	83.33	102	31.11	36.97
QN83-434	A	21.53	33	5.56	17.29	8.33	20	1.25	6.88	34.72	39	9.86	27.71
QN83-435	A	36.81	74	12.78	28.36	15.28	61	5.00	22.00	58.33	81	20.56	34.72
QN83-660	A	36.11	73	10.83	26.89	13.89	52	3.19	22.29	58.33	80	18.47	31.50
QN83-925	A	23.61	40	8.47	33.70	18.06	69	6.53	33.12	29.17	30	10.42	34.27
QN83-943	A	36.81	75	10.83	23.59	13.89	53	2.92	16.25	59.72	83	18.75	30.93
QN83-1072	A	24.31	42	6.25	26.45	16.67	63	4.31	27.00	31.94	35	8.19	25.90
QN83-1093	A	16.67	20	5.07	32.12	12.50	42	3.47	28.75	20.83	15	6.67	35.50
QN84-2172	A	66.67	105	31.74	43.61	43.06	101	15.69	34.96	90.28	108	47.78	52.27
QN84-2241	A	35.42	71	11.04	28.24	11.11	40	2.92	25.62	59.72	82	19.17	30.86
QN84-2467	A	45.14	86	16.81	35.09	34.72	94	10.83	30.49	55.56	77	22.78	39.70
QN84-2518	A	31.25	57	11.39	33.73	22.22	75	6.53	28.75	40.28	50	16.25	38.71
QN84-2875	A	54.17	96	24.79	41.18	29.17	90	9.72	32.44	79.17	98	39.86	49.92
QN84-2945	A	22.22	35	7.01	26.89	8.33	21	2.64	20.83	36.11	40	11.39	32.95
QN84-2961	A	34.03	68	11.6	33.95	16.67	66	5.14	33.12	51.39	66	18.06	34.78
QN84-2965	A	38.19	77	17.01	39.43	22.22	78	6.81	28.93	54.17	74	27.22	49.93
QN85-70	A	51.39	91	18.61	33.96	30.56	91	9.17	29.00	72.22	92	28.06	38.91
QN85-208	A	35.42	72	10.14	26.35	22.22	76	5.42	22.19	48.61	61	14.86	30.52
QN85-996	A	19.44	26	4.17	20.81	9.72	28	1.67	19.17	29.17	28	6.67	22.46
QN85-1400	A	34.03	67	10.9	25.79	9.72	34	2.22	16.67	58.33	78	19.58	34.92
QN85-2159	A	15.97	19	4.38	25.45	8.33	19	2.36	27.50	23.61	19	6.39	23.40
QN85-2757	A	5.56	3	1.25	8.33	1.39	4	0.28	5.00	9.72	6	2.22	11.67
QN85-3190	A	7.64	5	2.08	27.08	6.94	14	1.39	16.67	8.33	5	2.78	37.50
QN86-298	A	15.97	18	4.58	27.67	8.33	18	2.08	26.25	23.61	18	7.08	29.08
QN86-306	A	20.14	29	6.53	26.42	9.72	29	3.19	23.75	30.56	31	9.86	29.08
QN86-424	A	52.08	93	24.24	45.19	43.06	100	18.06	40.58	61.11	87	30.42	49.81
QN86-460	A	21.53	32	7.43	23.68	5.56	13	1.94	13.33	37.50	41	12.92	34.02
QN86-471	A	49.31	88	15.28	29.38	37.50	96	10.97	27.20	61.11	86	19.58	31.56
QN86-537	A	68.75	107	37.64	52.68	52.78	107	26.53	47.57	84.72	105	48.75	57.79

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
QN86-1530	A	18.75	22	3.61	17.01	4.17	10	0.83	15.00	33.33	36	6.39	19.01
QN86-1572	A	59.72	100	27.01	42.59	41.67	99	15.14	36.61	77.78	95	38.89	48.57
QN86-1576	A	34.03	65	12.29	34.55	23.61	80	7.64	30.29	44.44	53	16.94	38.81
QN86-1586	A	32.64	60	10.83	29.75	15.28	58	3.19	22.75	50.00	62	18.47	36.75
QN86-1660	A	9.72	8	2.08	12.54	1.39	6	0.14	2.50	18.06	11	4.03	22.58
QN86-1959	A	38.19	78	10.9	24.81	15.28	62	3.19	18.75	61.11	85	18.61	30.87
QN86-2043	A	22.44	36	4.95	22.06	11.56	41	1.71	19.86	33.33	37	8.19	24.27
QN86-2075	A	54.86	97	20.07	34.19	44.44	102	17.22	34.50	65.28	88	22.92	33.87
QN86-2168	A	23.61	39	6.32	22.48	15.28	55	4.17	20.48	31.94	34	8.47	24.48
QN86-2195	A	14.58	13	3.26	19.90	9.72	24	1.81	15.42	19.44	13	4.72	24.38
QS63-782	P	33.33	62	9.65	27.24	15.28	59	4.72	25.83	51.39	65	14.58	28.65
QS76-1038	P	11.11	11	3.19	19.96	8.33	17	2.78	17.50	13.89	8	3.61	22.42
SP70-1284	P	30.56	55	9.38	28.05	8.33	23	3.61	27.5	52.78	71	15.14	28.61
TS64-1189	P	25.00	43	6.94	23.07	11.11	37	2.78	17.92	38.89	45	11.11	28.21

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk)

[2]Ranking for percent bored stalks ranges from 1 for lowest value to 108 for highest value.

[3]A = advance clone (n = 41); C = standard cultivar (n = 10 x 2); P = parental clone (n = 47).

Table 19 **Combined and individual means for three measures of resistance to SWB infestation[1], together with ranking[2] of clones for percent bored stalks, obtained from slicing of clones and cultivars in October 1998 in the first-ratoon crop of replicated trials on two farms in northern Queensland**

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
BN74-4422	P	13.89	36	3.75	20.92	5.56	59	1.25	15.00	22.23	34	6.25	26.83
F150	P	23.62	78	9.03	32.42	8.34	78	3.47	26.67	38.90	81	14.58	38.17
H56-752	C	17.36	55	4.93	20.02	4.17	52	0.69	12.50	30.55	59	9.16	27.53
H56-752	C	20.15	70	6.25	19.62	5.55	56	1.39	6.25	34.75	74	11.11	33.00
H74-0922	P	2.09	1	0.21	2.50	0.00	1	0.00	0.00	4.17	1	0.42	5.00
NA56-79	P	14.59	45	4.72	20.46	2.78	33	0.69	12.50	26.40	50	8.75	28.43
Q96	P	6.96	9	1.81	16.25	1.39	11	0.69	12.50	12.53	9	2.92	20.00
Q107	C	27.08	87	8.40	23.51	20.83	104	4.58	15.80	33.33	70	12.22	31.21
Q107	C	27.77	88	7.71	19.79	13.89	98	4.03	12.50	41.65	85	11.39	27.09
Q113	C	24.30	81	7.99	18.67	2.78	28	0.42	3.75	45.83	89	15.55	33.59
Q113	C	18.06	61	5.83	23.34	4.17	43	0.97	12.50	31.95	62	10.70	34.19
Q115	C	32.65	99	11.18	24.52	6.95	67	1.95	14.38	58.35	102	20.42	34.67
Q115	C	18.05	59	6.11	23.26	2.78	34	0.69	12.50	33.33	68	11.53	34.03
Q117	C	26.39	85	7.08	24.20	9.72	86	2.78	21.67	43.05	87	11.39	26.73
Q117	C	22.92	77	7.22	26.46	9.72	83	2.64	20.00	36.12	77	11.8	32.93
Q120	C	31.95	98	13.40	35.60	15.28	101	5.83	31.25	48.62	93	20.97	39.94
Q120	C	29.86	92	10.83	29.20	6.95	71	1.80	22.50	52.77	97	19.86	35.91
Q124	C	31.26	95	18.27	36.02	4.17	45	1.25	13.75	58.35	101	35.28	58.29
Q124	C	26.38	83	11.25	41.28	8.34	80	3.61	40.00	44.42	88	18.89	42.56
Q138	C	31.25	94	8.82	19.36	5.56	64	1.25	10.83	56.95	100	16.39	27.9
Q138	C	23.62	79	6.60	25.81	13.89	97	3.19	21.25	33.35	72	10	30.38
Q150	P	27.77	89	12.01	32.31	4.17	53	1.11	20.00	51.38	95	22.91	44.63
Q152	C	15.96	50	4.51	18.02	5.55	55	1.67	7.50	26.38	47	7.36	28.54
Q152	C	19.44	65	6.04	36.75	11.11	88	3.61	42.50	27.77	55	8.47	31
Q158	C	19.44	64	4.58	24.94	5.56	63	1.95	28.75	33.33	69	7.22	21.12
Q158	C	20.13	67	4.58	17.95	4.17	44	1.11	13.75	36.10	76	8.05	22.14
Q167[ф]	A	15.98	52	4.10	22.62	18.06	102	4.44	18.57	13.9	12	3.75	26.66
Q173[ф]	A	38.20	106	24.31	51.69	12.50	96	4.58	32.08	63.90	108	44.03	71.29

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
Q175[4]	A	5.56	5	1.81	17.50	1.39	9	0.42	7.50	9.72	6	3.19	27.5
QC70-466	P	15.97	51	4.45	16.27	1.39	22	0.14	2.50	30.55	58	8.75	30.04
QC71-998	P	22.22	75	6.25	22.81	6.95	69	1.39	16.67	37.50	80	11.11	28.95
QC73-16	P	11.81	26	3.13	15.08	1.39	17	0.14	2.50	22.23	33	6.11	27.67
QC73-947	P	11.11	22	2.71	17.81	4.17	37	0.97	12.50	18.05	20	4.45	23.12
QC74-42	P	22.23	76	6.74	29.45	12.50	95	3.33	24.58	31.95	66	10.14	34.32
QC75-139	P	13.90	38	4.86	24.81	4.17	40	1.67	17.50	23.62	42	8.05	32.12
QC76-741	P	15.28	47	3.33	19.67	5.56	60	1.11	16.25	25.00	44	5.55	23.09
QC81-351	P	9.71	15	3.68	25.31	2.78	29	0.97	17.50	16.65	15	6.39	33.12
QN66-2008	P	16.67	54	4.51	19.39	5.56	61	0.83	8.33	27.77	54	8.2	30.46
QN71-569	P	9.73	17	2.15	12.04	4.17	36	0.56	6.25	15.30	14	3.75	17.83
QN76-1772	P	6.96	10	1.32	11.35	1.39	12	0.14	2.50	12.53	10	2.5	20.21
QN77-380	P	16.66	53	4.58	13.94	0.00	6	0.00	0.00	33.33	67	9.17	27.88
QN77-606	P	26.39	84	9.24	30.82	6.95	70	1.95	27.50	45.83	90	16.53	34.15
QN77-637	P	30.56	93	16.39	42.30	9.72	87	3.61	28.33	51.40	96	29.17	56.26
QN77-1135	P	34.03	101	11.32	31.96	31.95	108	11.53	34.41	36.12	78	11.11	29.52
QN77-1233	P	38.20	107	12.85	35.09	23.61	105	9.30	39.21	52.80	99	16.39	30.97
QN78-430	P	14.58	41	4.24	17.14	2.78	32	0.42	7.50	26.38	46	8.05	26.77
QN78-828	P	5.55	4	0.69	5.00	2.78	25	0.28	2.50	8.32	4	1.11	7.5
QN78-870	P	11.12	25	2.22	16.19	4.17	48	0.83	15.00	18.07	22	3.61	17.38
QN79-179	P	18.06	60	5.21	16.42	1.39	23	0.28	5.00	34.73	73	10.14	27.83
QN79-183	P	19.44	63	5.97	29.43	12.50	93	3.61	28.75	26.38	48	8.33	30.11
QN79-238	P	13.20	31	3.54	13.96	2.78	30	0.42	7.50	23.62	40	6.67	20.43
QN79-398	P	35.42	102	9.79	22.79	6.95	72	1.25	17.50	63.90	107	18.34	28.07
QN79-752	P	22.22	74	8.89	22.66	1.39	24	0.28	5.00	43.05	86	17.5	40.31
QN79-1108	P	7.64	11	2.15	16.25	1.39	13	0.28	5.00	13.90	11	4.03	27.5
QN79-1274	P	10.43	20	2.43	16.12	2.78	27	0.69	6.25	18.07	21	4.17	25.98
QN79-1345	P	2.78	2	0.56	7.50	1.39	7	0.28	5.00	4.17	2	0.83	10
QN80-158	P	15.96	49	3.82	17.34	4.17	41	0.69	8.75	27.75	51	6.94	25.94
QN80-740	P	11.11	21	2.99	14.79	1.39	16	0.14	2.50	20.82	29	5.83	27.09
QN80-3499	P	11.11	23	2.99	13.75	0.00	5	0.00	0.00	22.23	32	5.97	27.5
QN80-3600	P	12.51	29	2.99	14.54	4.17	38	0.97	5.83	20.85	31	5	23.25
QN80-4412	P	17.36	56	4.37	21.40	15.28	100	2.78	12.12	19.45	27	5.97	30.67

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
QN81-314	P	13.88	34	3.33	20.80	4.17	50	0.83	15.00	23.60	37	5.83	26.61
QN81-374	P	33.35	100	10.76	21.39	4.17	46	0.83	10.00	62.52	106	20.7	32.78
QN82-549	P	27.78	90	7.01	21.61	8.34	81	2.08	18.33	47.23	91	11.94	24.88
QN82-837	P	25.69	82	6.18	23.5	11.11	90	2.08	21.88	40.27	83	10.28	25.12
QN82-1240	P	27.79	91	10.28	35.76	8.34	82	3.06	35.00	47.25	92	17.5	36.53
QN83-434	A	11.81	27	3.82	24.38	4.17	49	0.97	17.50	19.45	24	6.67	31.25
QN83-435	A	9.03	14	1.60	9.83	1.39	15	0.14	2.50	16.68	17	3.06	17.17
QN83-660	A	27.07	86	9.58	31.92	12.50	94	3.89	26.04	41.65	84	15.28	37.8
QN83-925	A	10.42	18	2.99	24.17	5.56	57	1.53	20.00	15.28	13	4.45	28.33
QN83-943	A	19.45	66	4.17	21.60	8.34	75	1.95	23.75	30.57	60	6.39	19.44
QN83-1072	A	9.03	12	3.68	18.33	0.00	2	0.00	0.00	18.05	19	7.36	36.67
QN83-1093	A	12.50	28	3.19	19.42	5.55	54	1.25	11.25	19.45	25	5.14	27.58
QN84-2172	A	20.14	69	5.00	25.10	11.11	89	3.19	29.58	29.18	57	6.8	20.62
QN84-2241	A	21.54	73	5.76	22.49	8.34	77	1.80	17.50	34.75	75	9.72	27.47
QN84-2467	A	20.84	72	6.60	20.31	8.33	73	1.80	10.62	33.35	71	11.39	30.00
QN84-2518	A	14.58	43	4.30	20.08	1.39	20	0.69	12.50	27.77	53	7.91	27.66
QN84-2875	A	37.51	105	17.85	43.18	13.89	99	5.14	36.88	61.12	104	30.55	49.48
QN84-2945	A	31.93	96	10.07	31.58	26.39	107	7.78	29.83	37.48	79	12.36	33.33
QN84-2961	A	6.26	7	0.97	12.81	4.17	47	0.69	12.50	8.35	5	1.25	13.12
QN84-2965	A	13.21	33	4.31	22.83	4.17	39	1.53	22.50	22.25	36	7.08	23.17
QN85-70	A	20.84	71	6.25	24.98	9.72	85	2.78	21.67	31.95	65	9.72	28.28
QN85-208	A	24.29	80	7.36	24.45	8.34	79	1.39	16.25	40.25	82	13.34	32.64
QN85-996	A	13.88	35	4.10	23.80	4.17	51	1.39	25.00	23.60	38	6.80	22.61
QN85-1400	A	6.95	8	2.22	15.00	2.78	26	0.69	6.25	11.12	8	3.75	23.75
QN85-2159	A	5.57	6	1.81	13.33	1.39	10	0.28	5.00	9.75	7	3.33	21.67
QN85-2757	A	15.27	46	4.45	25.25	6.95	68	2.08	20.83	23.60	39	6.80	29.67
QN85-3190	A	2.78	3	0.62	9.38	1.39	8	0.56	10.00	4.17	3	0.69	8.75
QN86-298	A	31.94	97	12.98	34.18	11.11	91	4.44	27.00	52.77	98	21.53	41.35
QN86-306	A	35.43	103	14.79	31.48	11.12	92	2.50	19.00	59.75	103	27.08	43.97
QN86-424	A	14.59	44	3.68	18.23	6.95	66	1.25	9.38	22.23	35	6.11	27.08
QN86-460	A	9.03	13	2.22	14.96	1.39	14	0.28	5.00	16.68	16	4.17	24.92
QN86-471	A	11.12	24	2.78	22.29	5.56	58	1.39	18.75	16.68	18	4.16	25.84
QN86-537	A	13.89	37	4.44	20.66	1.39	18	0.42	7.50	26.40	49	8.47	33.82

Clone/cultivar	Class[3]	Cali & Whitaker				Cali				Whitaker			
		%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)	%BS	Rank	10(#BI/S)	10(#BI/BS)
QN86-1530	A	37.49	104	11.32	30.47	25.00	106	8.20	31.96	49.98	94	14.45	28.97
QN86-1572	A	14.10	40	3.06	15.45	3.2	35	0.71	10.56	25.00	43	5.42	20.34
QN86-1576	A	20.14	68	5.49	23.62	8.34	76	2.08	18.75	31.95	64	8.89	28.50
QN86-1586	A	13.90	39	3.06	18.84	8.34	74	2.08	18.75	19.48	28	4.03	18.93
QN86-1660	A	13.20	32	3.54	18.00	2.78	31	0.56	10.00	23.62	41	6.53	26.00
QN86-1959	A	17.38	57	3.82	20.96	9.72	84	2.78	20.00	25.02	45	4.86	21.93
QN86-2043	A	13.20	30	4.65	29.00	6.95	65	1.80	18.75	19.45	26	7.50	39.25
QN86-2075	A	14.58	42	5.83	22.23	1.39	19	0.42	7.50	27.77	52	11.25	36.96
QN86-2168	A	17.86	58	4.94	20.58	4.17	42	0.97	11.25	31.55	61	8.91	29.91
QN86-2195	A	40.97	108	18.82	43.15	19.45	103	6.53	35.33	62.50	105	31.11	50.96
QS63-782	P	10.43	19	3.61	15.84	0.00	4	0.00	0.00	20.85	30	7.22	31.67
QS76-1038	P	9.72	16	3.33	14.50	0.00	3	0.00	0.00	19.45	23	6.67	29.00
SP70-1284	P	15.28	48	2.64	9.60	1.39	21	0.14	2.50	29.18	56	5.14	16.70
TS64-1189	P	18.75	62	4.93	22.02	,5.56	62	1.25	17.50	31.95	63	8.61	26.55

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk)

[2]Ranking for percent bored stalks ranges from 1 for lowest value to 108 for highest value.

[3]A = advance clone (n = 41); C = standard cultivar (n = 10 x 2); P = parental clone (n = 47).

3.3.9 Inter-relationship among SWB resistance measures and physical traits

The relationships between the three measures of SWB resistance (%BS, 10*(#BI/S), and 10*(#BI/BS)) and the physical measurements taken (basal-rind hardness, leaf colour, leaf dry matter, parenchyma and rind dry matter, stalk-leaf morphology, and stalk height) in the plant crop are presented using clonal means over years within sites (Cali, Table 20; Whitaker, Table 21), clonal means over years for both sites (Table 22), and clonal means over years and sites (Table 23).

There were numerous significant correlations in all four analyses (Tables 20-23). However, the majority of correlations of potential breeding significance ($r > 0.6$) were spurious or were not associated with a SWB resistance measure. The highly significant correlations, ranging from 0.42-0.83, between basal-rind hardness (BRH) and rind dry matter (RDM) are logical. The correlations overs sites, however (Table 22), are zero, despite the moderate and highly significant values observed in the individual plant crops at either site (Tables 20 and 21). Those between basal-rind hardness (BRH) and stalk height (range 0.54-0.71) are explainable by consideration of physiology. Longer and more mature, or perhaps older stalks would be physiologically more developed in terms of lignification of the rind cells, and therefore would return high penetrometer values. This is verified when the association between rind dry matter and stalk height is examined; this is highly significant and of moderate value in three of the four cases ($r = 0.43$-0.46).

The correlation matrices presented for the ratoon crops are truncated as leaf colour and stalk height were not measured in either ratoon crop. As well, the premature harvest of the ratoon crop at the Cali site prevented any analyses, including dry matter determinations, of the basal stalk fractions. While there are a number of significant correlations in the matrices presented (Tables 24-27), many of these can be discounted on their basis as spurious correlations, and the few of the remaining ones can be considered of breeding significance. Those between basal-rind hardness and the measures of SWB infestation are significant, with one exception, are negative, but generally are weak to moderate in magnitude and below values observed in the plant crop data (Tables 20-23). All correlations with rind dry matter at the Whitaker site were highly significant. As in the plant-crop data, there was a moderate-to-good correlation between basal-rind hardness and rind dry matter. Again, this relationship is logical, but the relationship with the three measures of SWB resistance is weaker, and negative, reflecting the pattern seen in the plant crop (Tables 20-23).

Table 20 **Correlation matrix for three measures of resistance to SWB infestation[1] and nine plant traits[2] for clonal means from the 1997 plant crop from replicated trials at the Cali site in northern Queensland. (*n* = 108)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	Leaf colour	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	PDM (g kg^{-1})	RDM (g kg^{-1})	S-L M	St-ht (cm)
%BS	0.966**	0.743**	-0.425**	0.044	-0.236*	-0.170	-0.227*	-0.128	-0.491**	0.061	-0.220*
10(#BI/S)		0.772**	-0.404**	0.001	-0.235*	-0.183	-0.234*	-0.180	-0.506**	0.031	-0.209*
10(#BI/BS)			-0.369**	0.017	-0.147	-0.104	-0.140	-0.065	-0.427**	-0.031	-0.130
BRH (kg)				-0.082	0.240*	0.150	0.216*	0.189*	0.760**	0.419**	0.596**
Leaf colour					-0.396**	-0.070	-0.244*	-0.013	-0.152	0.193*	0.013
LDM-1 (g kg^{-1})						0.547**	0.849**	0.180	0.275**	0.197*	0.106
LDM-2 (g kg^{-1})							0.906**	0.256**	0.291**	0.042	-0.044
CLDM (g kg^{-1})								0.253**	0.322**	0.126	0.026
PDM (g kg^{-1})									0.523**	-0.052	0.142
RDM (g kg^{-1})										0.174	0.428**
S-L M											0.491**

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); PDM = parenchyma dry matter; RDM = rind dry matter; S-L M = stalk leaf morphology; St-ht = stalk height (cm).

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 21 **Correlation matrix for three measures of resistance to SWB infestation[1] and nine plant traits[2] for clonal means from the 1997 plant crop from a replicated trials at the Whitaker site in northern Queensland (*n* = 108)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	Leaf colour	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	PDM (g kg^{-1})	RDM (g kg^{-1})	S-L M	St-ht (cm)
%BS	0.944**	0.756**	-0.493**	0.013	-0.119	0.093	0.005	-0.131	-0.395**	-0.198*	-0.298**
10(#BI/S)		0.874**	-0.462**	-0.010	-0.132	0.067	-0.019	-0.147	-0.376**	-0.147	-0.242*
10(#BI/BS)			-0.433**	-0.070	-0.070	0.039	-0.008	-0.119	-0.318**	-0.159	-0.193*
BRH (kg)				-0.131	0.094	-0.024	0.031	0.294**	0.807**	0.319**	0.541**
Leaf colour					-0.354**	-0.106	-0.252**	-0.070	-0.147	0.068	-0.025
LDM-1 (g kg^{-1})						0.349**	0.749**	0.133	0.134	0.123	0.076
LDM-2 (g kg^{-1})							0.882**	0.244*	0.111	-0.026	-0.071
CLDM (g kg^{-1})								0.240*	0.146	0.044	-0.012
PDM (g kg^{-1})									0.585**	-0.100	0.232*
RDM (g kg^{-1})										0.127	0.443**
S-L M											0.351**

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); PDM = parenchyma dry matter; RDM = rind dry matter; S-L M = stalk leaf morphology; St-ht = stalk height (cm).

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 22 **Correlation matrix for three measures of resistance to SWB infestation[1] and nine plant traits[2] for clonal means, from the 1997 plant crop from replicated trials at two farms in northern Queensland (*n* = 216)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	Leaf colour	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	PDM (g kg^{-1})	RDM (g kg^{-1})	S-L M	St-ht (cm)
%BS	0.957**	0.787**	0.007	-0.107	-0.188**	0.009	-0.089	-0.285**	-0.537**	0.196**	0.367**
10(#BI/S)		0.835**	-0.030	-0.115	-0.186**	0.003	-0.092	-0.285**	-0.508**	0.168*	0.317**
10(#BI/BS)			-0.073	-0.114	-0.143*	-0.019	-0.085	-0.217**	-0.472**	0.119	0.272**
BRH (kg)				-0.199**	0.080	0.049	0.073	0.036	0.420**	0.513**	0.710**
Leaf colour					-0.343**	-0.089	-0.233**	0.025	-0.057	0.019	-0.172*
LDM-1 (g kg^{-1})						0.437**	0.798**	0.179**	0.225**	0.093	-0.032
LDM-2 (g kg^{-1})							0.890**	0.233**	0.172*	0.009	-0.024
CLDM (g kg^{-1})								0.247**	0.229**	0.053	-0.032
PDM (g kg^{-1})									0.608**	-0.207**	-0.146*
RDM (g kg^{-1})										-0.046	-0.067
S-L M											0.581**

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); PDM = parenchyma dry matter; RDM = rind dry matter; S-L M = stalk leaf morphology; St-ht = stalk height (cm).

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 23 Correlation matrix for three measures of resistance to SWB infestation[1] and nine plant traits[2] for clonal means, over sites, from the 1997 plant crop from replicated trials on two farms in northern Queensland (*n* = 108)

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	Leaf colour	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	PDM (g kg^{-1})	RDM (g kg^{-1})	S-L M	St-ht (cm)
%BS	0.961**	0.823**	-0.518**	0.028	-0.203*	-0.040	-0.127	-0.135	-0.503**	-0.108	-0.326**
10(#BI/S)		0.873**	-0.483**	-0.016	-0.202*	-0.068	-0.145	-0.167	-0.484**	-0.094	-0.275**
10(#BI/BS)			-0.446**	-0.052	-0.113	-0.075	-0.105	-0.1000	-0.420**	-0.111	-0.195*
BRH (kg)				-0.122	0.186**	0.064	0.134	0.233*	0.826**	0.371**	0.574**
Leaf colour					-0.390**	-0.110	-0.266**	-0.027	-0.158	0.119	-0.019
LDM-1 (g kg^{-1})						0.511**	0.831**	0.179	0.245*	0.197*	0.111
LDM-2 (g kg^{-1})							0.903**	0.258**	0.214*	-0.001	-0.085
CLDM (g kg^{-1})								0.256**	0.261**	0.098	0.001
PDM (g kg^{-1})									0.526**	-0.091	0.206*
RDM (g kg^{-1})										0.172	0.464**
S-L M											0.432**

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); PDM = parenchyma dry matter; RDM = rind dry matter; S-L M = stalk leaf morphology; St-ht = stalk height (cm).

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 24 **Correlation matrix for three measures of resistance to SWB infestation[1] and five plant traits[2] for clonal means from the 1998 first-ratoon crop from replicated trial at the Cali site in northern Queensland. (*n* = 108)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	S-L M
%BS	0.960**	0.730**	-0.244*	-0.105	-0.041	-0.084	0.214*
10(#BI/S)		0.784**	-0.268**	-0.118	-0.091	-0.123	0.170
10(#BI/BS)			-0.346**	-0.114	-0.035	-0.084	-0.088
BRH (kg)				0.023	0.135	0.100	0.172
LDM-1 (g kg^{-1})					0.406**	0.806**	0.058
LDM-2 (g kg^{-1})						0.868**	0.080
CLDM (g kg^{-1})							0.083

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); S-L M = stalk leaf morphology.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 25 Correlation matrix for three measures of resistance to SWB infestation[1] and seven plant traits[2] for clonal means from the 1998 first-ratoon crop from a replicated trial at the Whitaker site in northern Queensland (*n* = 108)

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	PDM (g kg^{-1})	RDM (g kg^{-1})	S-L M
%BS	0.897**	0.699**	-0.509**	-0.238*	-0.019	-0.132	-0.035	-0.374**	-0.142
10(#BI/S)		0.877**	-0.486**	-0.297**	-0.027	-0.167	-0.029	-0.378**	-0.174
10(#BI/BS)			-0.494**	-0.199*	0.001	-0.099	-0.090	-0.427**	-0.233*
BRH (kg)				0.227*	0.159	0.221*	0.241*	0.699**	0.203*
LDM-1 (g kg^{-1})					0.427**	0.789**	0.295**	0.286**	0.160
LDM-2 (g kg^{-1})						0.892**	0.256*	0.287**	0.077
CLDM (g kg^{-1})							0.321*	0.338**	0.132
PDM (g kg^{-1})								0.596**	0.054
RDM (g kg^{-1})									0.152

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); PDM = parenchyma dry matter; RDM = rind dry matter; S-L M = stalk leaf morphology.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 26 **Correlation matrix for three measures of resistance to SWB infestation[1] and five plant traits[2] for clonal means, from the 1998 first-ratoon crop from replicated trials at two farms in northern Queensland (*n* = 216)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	S-L M
%BS	0.929**	0.780**	-0.099	0.427**	0.366**	0.440**	0.052
10(#BI/S)		0.823**	-0.162*	-0.301**	0.289**	0.328**	-0.007
10(#BI/BS)			-0.201**	-0.312**	0.284**	0.331**	0.004
BRH (kg)				0.249**	0.244**	0.274**	0.206**
LDM-1 (g kg^{-1})					0.616**	0.893**	0.147*
LDM-2 (g kg^{-1})						0.905**	0.120
CLDM (g kg^{-1})							0.148

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); S-L M = stalk leaf morphology.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 27 **Correlation matrix for three measures of resistance to SWB infestation[1] and five plant traits[2] for clonal means, over sites, from the 1998 first-ratoon crop from replicated trials on two farms in northern Queensland (*n* = 108)**

Trait	10(#BI/S)	10(#BI/BS)	BRH (kg)	LDM-1 (g kg^{-1})	LDM-2 (g kg^{-1})	CLDM (g kg^{-1})	S-L M
%BS	0.908**	0.783**	-0.524**	-0.234*	-0.052	-0.155	-0.022
10(#BI/S)		0.867**	-0.515**	-0.291**	-0.082	-0.204*	-0.083
10(#BI/BS)			-0.497**	-0.173	-0.024	-0.105	-0.064
BRH (kg)				0.133	0.161	0.174	0.177
LDM-1 (g kg^{-1})					0.471**	0.822**	0.120
LDM-2 (g kg^{-1})						0.890**	-0.083
CLDM (g kg^{-1})							0.116

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[2]BRH = basal-rind hardness; 1LDM = first leaf dry matter (January); 2LDM = first leaf dry matter (July); CLDM = combined leaf dry matter (1LDM + 2LDM); S-L M = stalk leaf morphology.

*, ** = $P \leq 0.05$ and 0.01, respectively.

3.3.10 Inter-relationship among SWB resistance measures and chemical traits

Correlation analysis of the three measures of SWB resistance and leaf nitrogen measured early- and mid-season over the total population showed there was no relationship between leaf nitrogen and infestation in February (Table 28). The mid-season measures were significantly, or highly significant, but values were weak. This leads to the conclusion that, in conjunction with leaf colour data presented (Tables 20-23), canopy lushness or nitrogen status plays little part in clonal selection on the part of the SWB. In contrast, correlations between measures of SWB resistance and leaf silica are weak to moderate and all highly significant (Table 28). This is in keeping with emerging evidence that correct silica nutrition is beneficial in maintaining resistance to infestation by a range of stem and leaf insects. In this case, SWB attacks the sugarcane culm rather than the leaf, but presumably a strong correlation exists between leaf and stem silica levels to substantiate the biological basis of the observed correlations.

Table 28 Correlation matrix for three measures of resistance to SWB infestation[1] and two leaf chemistry traits for clonal means from 1997 plant and 1998 first-ratoon crop from replicated trials on two farms in northern Queensland

Trait	Nitrogen		Silica	
	February	July	February	July
%BS	0.052	0.268 **	-0.556 **	-0.340 **
10(#BI/S)	0.015	0.211 **	-0.450 **	-0.283 **
10(#BI/BS)	-0.023	0.113 *	-0.474 **	-0.307 **

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).
*, ** = $P \leq 0.05$ and 0.01, respectively.

Table 29 Correlation matrix for three measures of resistance to SWB[1] and two stalk chemistry traits[2] for clonal means from the Cali 1997 plant crop and the Whitaker 1997 plant, and 1998 first-ratoon crops

Trait	PINSCH	RINSCH
%BS	-0.367**	-0.423**
10(#BI/S)	-0.381**	-0.439**
10(#BI/BS)	-0.434**	-0.470**

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10 (number of bored internodes per bored stalk).
[2]PINSCH = Parenchyma insoluble carbohydrates (F.W. basis); RINSCH = Rind insoluble carbohydrates (F.W. basis).
** = $P \leq 0.01$.

Correlation analysis using the three site/crop sets available revealed moderate, negative association between the three measure of SWB resistance and insoluble carbohydrate levels, on a fresh weight basis, in the parenchyma and rind fractions (Table 29). All these

correlations were highly significantly different from zero. Again, none of these could be considered useful in terms of crop improvement.

Multiple regression analyses attempting to predict the three measures of resistance to SWB using leaf and stalk chemistry traits resulted in about 30% of the variation being explained (Tables 30). The significant independent variables were leaf nitrogen determined in February and July, leaf silica determined in July, and rind insoluble carbohydrate, for %BS and 10(#BI/S), and all these except July-determined leaf nitrogen for 10(#BI/BS) (Table 30). In terms of the relative important of these independent variables in their contribution to the regression, the leaf-nitrogen determinations were most potent, but in all three regressions these were only marginally to moderately greater than leaf silica and rind insoluble carbohydrate, where these were involved.

Table 30 Multiple regression statistics[1] for three measures of resistance to SWB[2] and significant leaf and stalk chemistry traits[3] using clonal means from the Cali 1997 plant crop and the Whitaker 1997, 1998 plant and first-ratoon crops (n = 324)

Dependant variable	Significant independent variables	R^2	b'	Prob.
%BS	$LN_{(Feb)}$	0.325	6.33	0.00
	$LN_{(Jul)}$		6.02	0.00
	$LSi_{(Jul)}$		4.90	0.00
	RINSCH		4.78	0.00
10(#BI/S)	$LN_{(Feb)}$	0.295	6.47	0.00
	$LN_{(Jul)}$		6.16	0.00
	$LSi_{(Jul)}$		5.01	0.00
	RINSCH		4.88	0.00
10(#BI/BS)	$LN_{(Feb)}$	0.340	5.00	0.01
	$LSi_{(Jul)}$		4.84	0.00
	RINSCH		4.70	0.00

[1] R^2 = multiple coefficient of determination; b' = standardized partial regression coefficient; Prob. = probability.

[2] %BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10 (number of bored internode per bored stalk).

[3] $LN_{(Feb)}$ = leaf nitrogen (g kg^{-1}) sampled in February; $LN_{(Jul)}$ = leaf nitrogen (g kg^{-1}) sampled in July; $LSi_{(Jul)}$ = leaf silica (g kg^{-1}) sampled in July; RINSCH = rind insoluble carbohydrates.

Examination of the full data set for leaf chemistry alone available for the four site/crop sets yielded multiple regressions marginally below those drawing on the available stalk and leaf chemistry for the three site/crop sets (R^2 = 0.221-0.333 versus R^2 = 0.295 versus 0.340; Tables 30 and 31). In terms of contribution to %BS, 10(#BI/S) and 10(#BI/BS), February-determined leaf nitrogen was not statistically significantly in any, July-determined leaf silica only for %BS, and July-determined leaf nitrogen was not significant for 10(#BI/BS) (Table 31). For %BS, February-determined silica was 2.4 times as important as July-determined leaf nitrogen and 2.1 times as potent as July-determined leaf

silica, and of opposite sign to both (Table 31). February-determined leaf silica was 2.1 times as important as July-determined leaf nitrogen for 10(#BI/S), and again of opposite sign. Although the predictive value of all three regressions using leaf chemistry data is marginal, the dominance of February-determined leaf silica in all these was a consistent element.

Table 31 Multiple regression statistics[1] for three measures of resistance to SWB[2] and significant leaf chemistry traits[3] for clonal means from the Cali and Whitaker 1997, 1998 plant and first-ratoon crops (n = 432)

Dependant variable	Significant independent variables	R^2	b'	Prob.
%BS	$LN_{(Feb)}$	0.333	-4.71	0.37
	$LN_{(Jul)}$		1.84	0.00
	$LSi_{(Feb)}$		-4.50	0.00
	$LSi_{(Jul)}$		1.05	0.04
10(#BI/S)	$LN_{(Feb)}$	0.221	-7.80	0.17
	$LN_{(Jul)}$		1.71	0.00
	$LSi_{(Feb)}$		-3.57	0.00
	$LSi_{(Jul)}$		-8.88	0.10
10(#BI/BS)	$LN_{(Feb)}$	0.229	-2.55	0.65
	$LN_{(Jul)}$		1.72	0.77
	$LSi_{(Feb)}$		-4.32	0.00
	$LSi_{(Jul)}$		-6.93	0.20

[1]R^2 = multiple coefficient of determination; b' = standardized partial regression coefficient; Prob. = probability.

[2]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

[3]$LN_{(Feb)}$ = leaf nitrogen (g kg^{-1}) sampled in February; $LN_{(Jul)}$ = leaf nitrogen (g kg^{-1}) sampled in July; $LSi_{(Feb)}$ = leaf silica (g kg^{-1}) sampled in February; $LSi_{(Jul)}$ = leaf silica (g kg^{-1}) sampled in July.

3.3.11 Prediction of field resistance to SWB from near-infra-red spectra of stalk fractions

Development of predictive equations using NIS spectra and data for the three measures of resistance to SWB proved relatively unsuccessful (Table 32). The R^2 values for the best equation for each trait using parenchyma spectral data were 0.338 (%BS, 2,4,4), 0.272 (10(#BI/BS), 1,4,4), and 0.181 (10(#BI/BS), 1,8,8), and would be useless in practice. Similarly, for the rind fraction the best R^2 values were 0.427, 0.370, and 0.272 for %BS, 10(#BI/S), and 10(#BI/BS), respectively. All resulted from use of 1,8,8 spectral data (Table 32). These statistics clearly indicate the uselessness of this simplistic approach in attempting to develop predictive equations from spectral data, of parenchyma or rind fractions, using SWB slicing data. This failure is further highlighted graphically by plotting the predicted versus observed %BS data (Figure 2). A cutoff of 10% NIS-predicted %BS would result in clones with up to 50% BS being selected; selection of clones using an NIS-predicted cutoff of 20% would yield clones of up to 65% BS; and a

cutoff of 30% NIS-predicted %BS would result in clones of up to 90% BS being selected (Figure 2). Clearly, this approach has not yielded a viable selection screen.

Table 32 Summary statistics[1] from near-infra-red spectroscopic (NIS) cross-validation calibration and prediction results using field ratings for three measures of resistance to SWB infestation[2] and NIS spectra from 400-2500 nm for parenchyma and rind stalk fractions

Component	Character	Maths[3]	No. terms	SEC	R^2	SECV	General mean
Parenchyma	%BS	1,4,4	8	18.0	0.332	18.4	30.5
		1,8,8	8	18.1	0.326	18.6	30.6
		2,4,4	6	17.7	0.338	18.2	30.3
		2,8,8	7	17.8	0.327	18.2	30.2
	10(#BI/S)	1,4,4	8	6.3	0.272	6.8	8.7
		1,8,8	8	6.3	0.269	6.9	8.7
		2,4,4	6	6.9	0.236	7.8	9.8
		2,8,8	7	6.4	0.273	6.9	8.7
	10(#BI/BS)	1,4,4	3	10.4	0.163	10.6	27.9
		1,8,8	4	10.3	0.181	10.5	27.8
		2,4,4	3	10.5	0.169	10.8	27.7
		2,8,8	3	10.3	0.169	10.6	27.8
Rind	%BS	1,4,4	8	17.0	0.415	17.3	30.7
		1,8,8	9	16.8	0.427	17.2	30.7
		2,4,4	6	17.1	0.400	17.6	30.5
		2,8,8	6	17.0	0.396	17.6	30.3
	10(#BI/S)	1,4,4	8	6.1	0.351	6.6	8.8
		1,8,8	9	6.1	0.370	6.6	8.9
		2,4,4	5	6.3	0.327	6.8	8.9
		2,8,8	6	6.3	0.328	6.7	8.9
	10(#BI/BS)	1,4,4	4	10.3	0.243	10.5	27.8
		1,8,8	6	10.0	0.273	10.3	27.8
		2,4,4	2	10.3	0.212	10.6	27.8
		2,8,8	2	10.2	0.228	10.5	27.7

[1]SEC = standard error of calibration; R^2 = multiple coefficient of determination; SECV = standard error of cross validation; # terms = number of terms in the equation developed using modified partial least squares regression.

[2]%BS = percent bored stalks; 10(#BI/S) = 10 x number of bored internodes per stalk;10(#BI/BS) = 10 x number of bored internodes per bored stalk.

[3]Three digits of the maths treatment indicate the data basis (0 = raw log (1/R) data, 1 = first derivative data, 2 = second derivative data), data gap, in data points (= nm/2), and data smoothing, in data points.

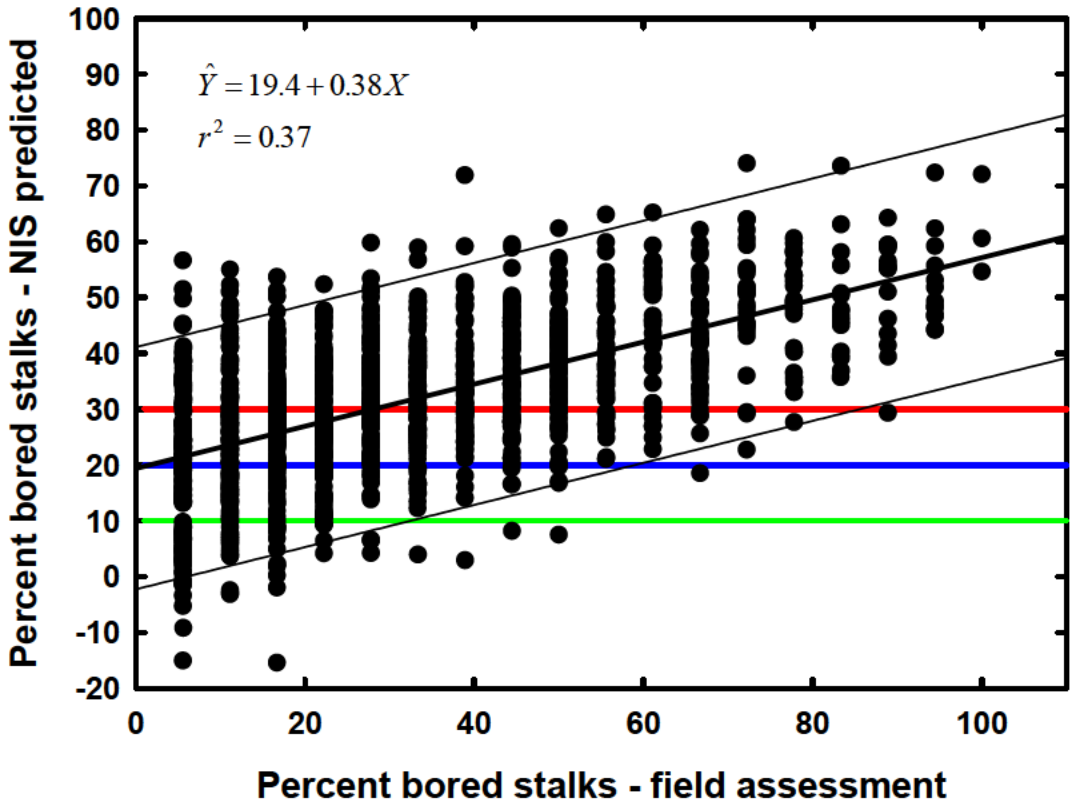

Figure 2 **Relationship between percent stalks bored by SWB, predicted from near-infra-red spectra of dried and milled rind tissue (outer 2.5 mm), and observed percent bored stalks for 108 clones sampled from four replicates of the plant crop at two locations in northern Queensland and a ratoon crop at one of these locations**

3.3.12 Impact of SWB infestation on quality components

The 10 cultivars included as duplicate standards in the trials exhibited a broad range of reaction to SWB for the three measures of resistance (Table 33). For %BS and 10(#BI/S), Q120 was the most susceptible clone at both sites and Q158 the most resistant. For 10(#BI/BS), Q120 again was the most highly rated while Q152 was the lowest rated at both sites.

Analysis of data for bored versus unbored stalks revealed there were highly significant differences among clones for all six quality components assessed except purity percent (Table 34). The contrast between means for bored versus unbored samples was highly significant for all six components except fibre percent. There were no significant cultivar by condition interactions. Values for coefficients of variation for all analyses were low (2.11-4.85%), and all traits displayed a broad range of variation (Table 34).

Table 33 Clonal means for three measures of resistance to SWB infestation[1] for the plant crop, 1997 of 10 cultivars contained in duplicate plots per replicate in four-replicate trials on two farms in northern Queensland

Character	Clone	Data source		
		Cali	Whitaker	Combined
%BS	H56-752	11.11	43.75	27.43
	Q107	44.44	81.25	62.85
	Q113	25.00	81.94	53.47
	Q115	24.31	78.47	51.39
	Q117	24.31	50.00	37.15
	Q120	54.17	85.42	69.79
	Q124	13.19	36.81	25.00
	Q138	13.89	29.86	21.88
	Q152	10.42	34.72	22.57
	Q158	5.56	29.17	17.36
	General mean	22.64	55.14	38.89
10(#BI/S)	H56-752	3.13	13.82	8.47
	Q107	15.28	32.99	24.13
	Q113	7.01	31.25	19.13
	Q115	8.33	30.35	19.34
	Q117	6.94	15.07	11.01
	Q120	18.96	42.64	30.80
	Q124	3.61	14.24	8.92
	Q138	4.24	10.42	7.33
	Q152	3.06	10.07	6.56
	Q158	1.25	8.75	5.00
	General mean	7.18	20.96	14.07
10(#BI/BS)	H56-752	24.58	29.30	26.94
	Q107	33.56	40.51	37.03
	Q113	23.00	37.96	30.48
	Q115	33.38	38.61	36.00
	Q117	27.38	29.23	28.30
	Q120	34.75	49.22	41.99
	Q124	19.63	38.20	28.91
	Q138	21.85	32.85	28.35
	Q152	18.85	26.40	22.63
	Q158	20.00	28.76	24.38
	General mean	25.70	35.10	30.40

[1]%BS = percent bored stalks; 10(#BI/S) = 10(number of bored internodes per stalk); 10(#BI/BS) = 10(number of bored internodes per bored stalk).

Table 34 **Summary statistics from analyses of variance of six quality components determined on stalks unbored and bored by SWB taken from duplicate plots of 10 cultivars from three replicates of the plant crop of a trial (Whitaker) located in northern Queensland**

Statistic	d.f.[1]	Brix	CCS	Fibre percent	Pol. percent cane	Pol. reading	Purity percent
$MS_{(Replicates)}$	2	0.00	0.12	0.15	0.05	0.96	1.25
$MS_{(Clones)}$	9	4.44**	3.59**	15.56**	4.95**	97.17**	6.79
$MS_{(Error)}$	18	0.47	0.49	0.50	0.55	10.60	3.32
$MS_{(Sampling)}$	30	0.61*	0.82	0.63*	0.85*	16.29*	4.26
$MS_{(Condition)}$	1	48.67**	45.39**	0.35	60.67**	1,186.42**	42.41**
$MS_{(Clone\ x\ Cond.)}$	9	0.44	0.95	0.38	0.92	17.51	5.98
$MS_{(Error)}$	50	0.30	0.49	0.33	0.49	9.19	3.90
C.V. %		2.80	4.85	4.33	3.80	3.97	2.11
General mean		19.6	14.4	13.2	18.4	76.4	93.8
Minimum		17.0	11.4	10.8	15.5	63.6	79.0
Maximum		22.1	16.6	15.8	21.1	88.3	98.3

[1]Because of missing plots three d.f. were subtracted from the final error term in the analysis for percent fibre, and four d.f. in analyses for Brix, pol percent cane, pol. reading, and purity percent.

C.V. % = coefficient of variation; CCS = commercial can sugar.

*, ** = $P \leq 0.05$ and 0.01, respectively.

Infestation by SWB resulted in a loss of 1.4° Brix, 1.2 units of CCS, no effect on fibre percent, 1.4% of pol. in cane, 6.3 °Z of pol. reading, and 2.2% purity (Table 35). The differences can be scaled against the necessary least-significant differences (Table 35). These were derived from the analyses depicted in Table 34. Excluding fibre percent, all differentials were substantially greater than the relevant least significant differences. This loss assessment was simplistic as any sign of SWB activity in a sliced stalk resulted in the stalk being classified as bored. With more resources, perhaps an account of severity of infestation could have been made so component could have been determined in stalks of differing infestation levels, e.g., 1-3 BI, 4-6 BI. These losses are presented on a bored versus unbored basis. Application of these losses to an actual situation would require computation of weighted means applying these losses to the proportion of bored and un-bored stalks in the sample being assessed.

Table 35 Means of six quality components determined on stalks unbored and bored by SWB taken from duplicate plots of 10 cultivars from three replicates of the plant crop, 1997 at the Whitaker site in northern Queensland

Stalk condition	Brix	CCS	Fibre percent	Pol. percent cane	Pol. reading	Purity percent
Unbored (U)	20.3	15.0	13.2	19.1	79.5	94.4
Bored (B)	19.0	13.8	13.3	17.7	73.2	93.2
Difference(U - B)	1.3	1.2	-0.1	1.4	6.3	2.2
$L.s.d_{(0.05)}$	0.20	0.26	--	0.26	1.12	0.73

3.3.13 Relation between rind vascular-bundle density and reaction to SWB

A typical image used to determine these data is shown in Figure 3. The arc marking the counted area is not depicted in this image, but the 1 mm scale included in the captured image clearly shows the concept used in the counting. An arc 15 mm around the circumference of the stalk and extending 2 mm deep into the stalk was defined as the rind and the vascular bundle number in this counted.

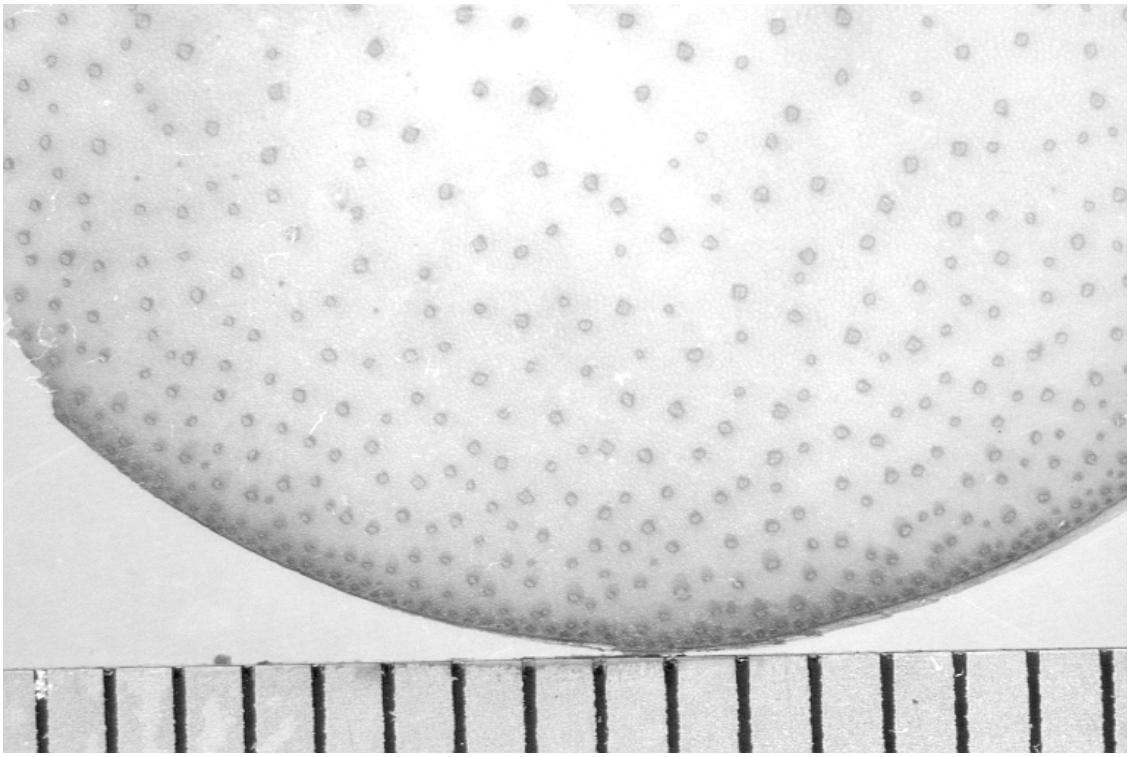

Figure 3 **Image of a basal mid-internode cross-section of QN82-1240, a clone with 83% bored stalks in the plant crop, captured using a CCD camera on a dissecting microscope, showing vascular bundles highlighted using phloroglucin and the millimetre scale ruler from which a 15 mm arc by 2 mm deep area was marked post-capture when the image was printed to A4 paper for counting the vascular bundles**

Analyses of these data (Table 36) showed no significant differences among replicates for vascular bundle number. There were highly significant differences among clones. When this sum of squares was partitioned to between and within groups, the two groups (resistant versus susceptible) differed highly significantly, there was no difference among the resistant clones, and the difference among susceptible clones was only significant. Again, the subsampling strategy used proved flawed with the error ratio test, with a value of 1.9, falling short of the threshold value of 3.0. Use of more than three culm sections, or more replicates (three of four were used) would be required to correct this deficiency.

Table 36 **Summary statistics from analyses of variance of vascular bundle number in a 15 mm arc of the outer 2 mm of mid-internode, basal stem rind for the 10 most susceptible and 10 most resistant clones to SWB infestation based on the assessment from the plant crop of the trial at Whitaker's farm, using samples taken from the first-ratoon crop at the same site. Samples were drawn from two replicates, chosen at random, from the four available. Counts were performed for rind samples from three random stalks per plot**

Statistic	d.f.	Value
$MS_{(Replicates)}$	1	232.4
$MS_{(Clones)}$	19	4,456.2**
Groups	1	29,108.9**
Resistant	9	594.3
Susceptible	9	5,578.9*
$MS_{(Error)}$	19	968.1**
Groups	1	195.1
Resistant	9	349.7
Susceptible	9	1,672.4**
$MS_{(Sampling)}$	80	329.5
C.V. %		23.25
General mean		133.825
Minimum		93.3
Maximum		204.7

C.V. % = coefficient of variation; $L.s.d_{(0\ 05)}$ = least significant difference.
*, ** = $P \leq 0.05$ and 0.01, respectively.

While regressions are presented in Figures 4-6, these are indicative only. The main purpose of the graphs is to depict the means for the three traits depicted, number of vascular bundles, %BS, and basal-rind hardness. There was a large difference between the 10 most susceptible and 10 most resistant clones to SWB infestation in terms of %BS. The means for the two groups were 83.4 versus 10.3% BS (Figure 4). There was little variation among the resistant clones for vascular bundle number but considerable variation among the susceptible group. Perhaps surprisingly, the mean vascular-bundle number for the resistant clones (118.3) was well below that for the susceptible group (149.4; Figure 4).

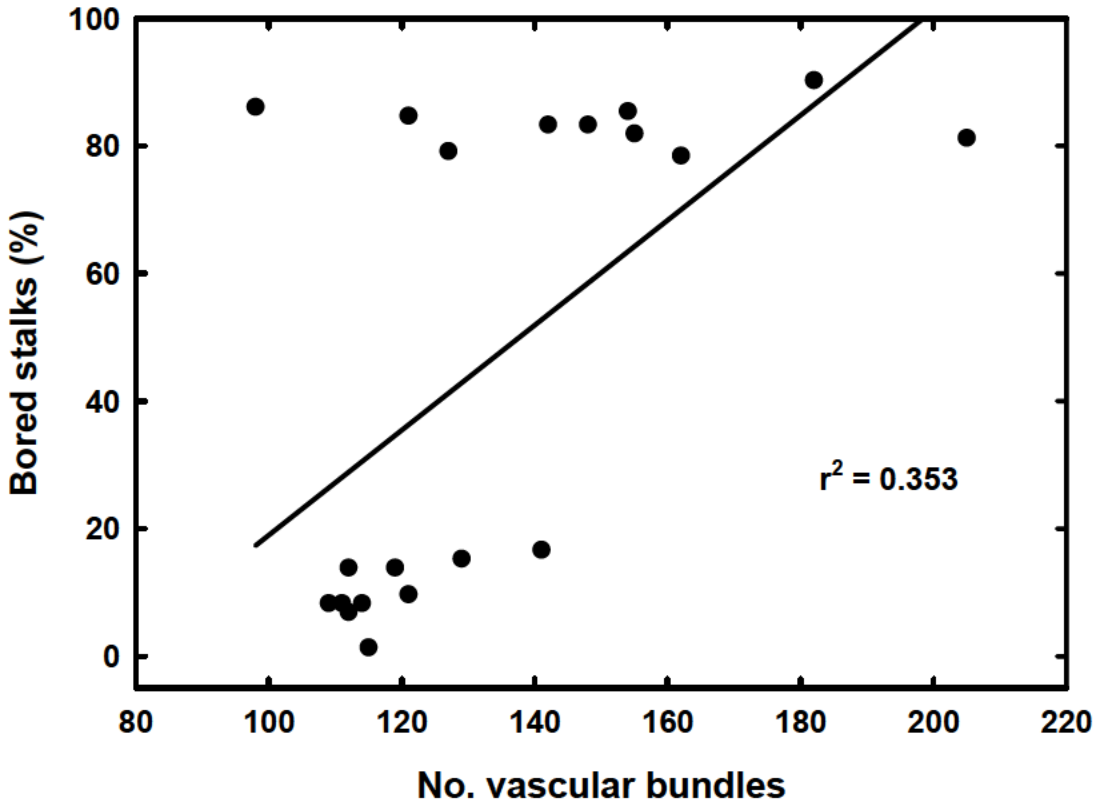

Figure 4 **Relationship between percent of stalks bored by SWB and number of vascular bundles in a 15 mm arc of the outer 2 mm of mid-internode, basal stem rind, for the 10 most susceptible and 10 most resistant clones to SWB infestation based on the assessment from the plant crop of the trial at Whitaker's farm, using samples taken from the first-ratoon crop at the same site**

There was a loose relationship between basal-rind hardness and vascular-bundle number using the 20 clones chosen, with an R^2 value = 0.123 (Figure 5). There was one clone, an outlier with an exceptionally hard rind (48.5 kg) that had a relatively low vascular-bundle number (115) (Figure 5), yet had a low %BS value (1.4%). In a case like this, either thickening of the vascular bundles, or some other aspect of rind anatomy must account for the high rind hardness and high resistance to SWB.

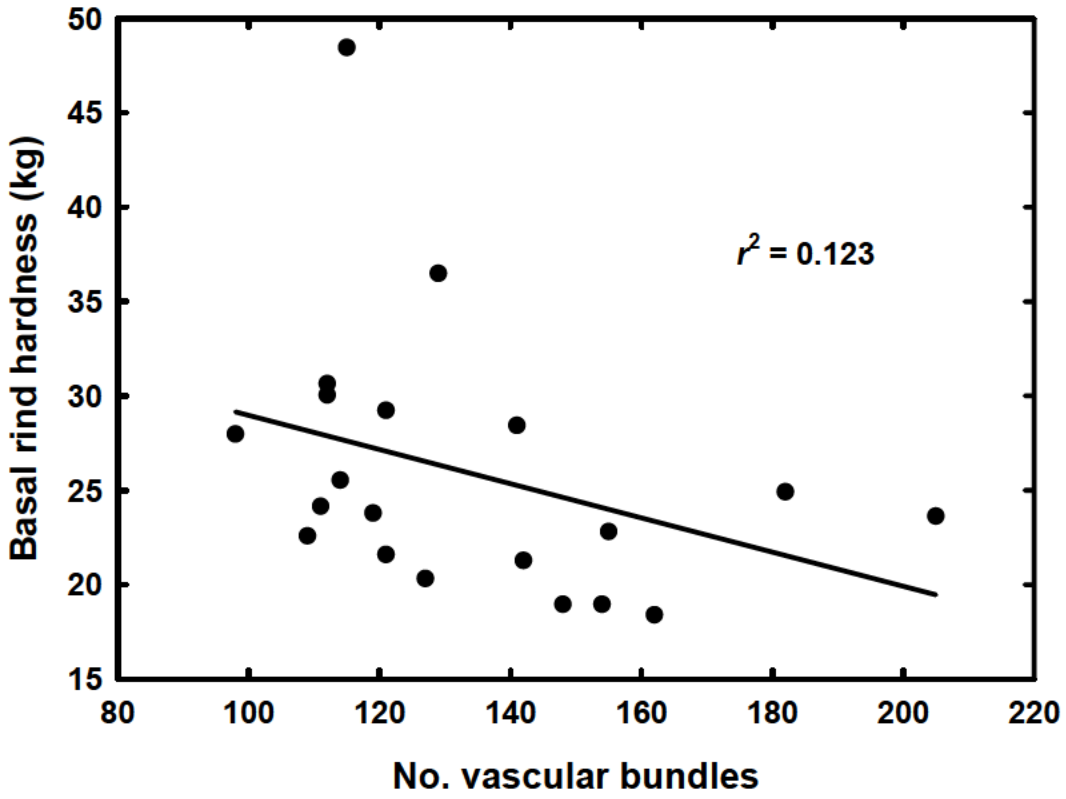

Figure 5 **Relationship between basal-rind hardness, as determined by penetrometer, and number of vascular bundles in a 15 mm arc of the outer 2 mm of mid-internode, basal stem rind, for the 10 most susceptible and 10 most resistant clones to SWB infestation based on the assessment from the plant crop of the trial at Whitaker's farm, using samples taken from the first-ratoon crop at the same site**

There was little variation among the most susceptible clones (mean %BS = 83.4) for basal-rind hardness (Figure 6). This was not the case for the resistant group (mean %BS = 10.3), but the mean difference between the two groups was small, approximately 21.9 (susceptible) versus 29.6 kg (Figure 4). The outlier clone discussed above is again evident (Figure 6).

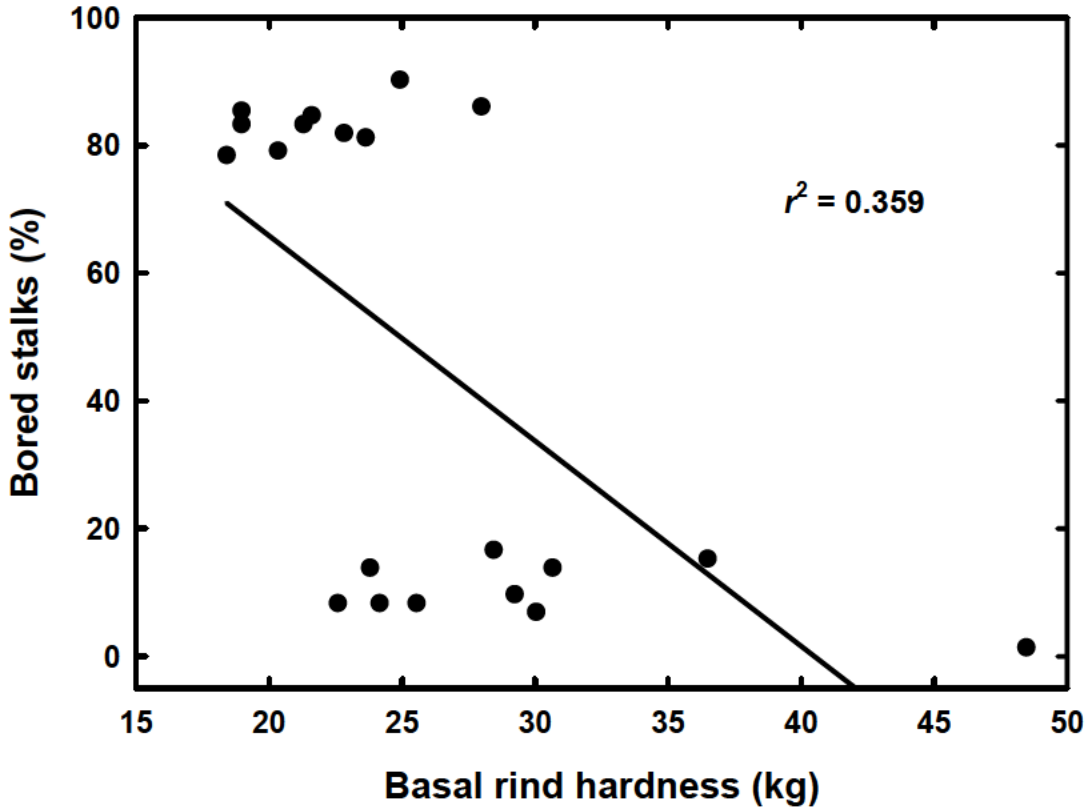

Figure 6 **Relationship between percent of stalks bored by SWB and basal-rind hardness, as determined by penetrometer, for the 10 most susceptible and 10 most resistant clones to SWB infestation based on the assessment from the plant crop of the trial at Whitaker's farm, using samples taken from the first-ratoon crop at the same site**

3.4 Conclusions

There were statistically significant differences among clones in both trials for all traits measured directly or predicted. In the majority of analyses, differences among replicates also were significant, meaning that these traits were assessed against a background of macro-environmental variation within sites as well as the variation between sites. Mean percent bored stalks were 45.6 and 30.7 and 18.4 and 6.7% in the plant and first-ratoon crops at each of the sites, respectively. Clonal variation ranged from near zero to 90% bored stalks for the most severely infested clone. Estimates for broad-sense heritability were good to excellent, and there was a wealth of genetic variation to exploit via selection. Combined analyses for the three measures of reaction to SWB of crops over sites or over years within sites revealed significant site and year differences. Locations by clones and years by clones interactions were significant, verifying the importance of conduction assessment for SWB over environments and time. Correlation analyses revealed few usable relationships for crop improvement. The relationship between basal-rind hardness and resistance was significant but weak. There was little joy in any relationship involving any of the morphological measurements – leaf-stalk morphology

and stalk height. There were variable and some significant relationships between leaf nitrogen and SWB infestation but these were weak. Combined with the measurement of leaf colour, canopy lushness had little bearing on the insects' selection of clones for infestation. The relation between the SWB measures and leaf silica were weak to moderate but all highly significant. Multiple regression analyses using the SWB measures and leaf and stalk chemistry and compositional data accounted for only a small proportion of variation, but the dominance of early-season leaf silica in these regressions was a consistent feature. Prediction of reaction to SWB infestation based on spectra of basal rind was not useable because of the poor predictive value of the equation.

The study revealed a wealth of variation in all traits studied, including reaction to SWB. Disappointingly, none of the traits assessed were strongly correlated to SWB resistance, and no predictive measures were developed to assist in understanding the reaction of sugarcane to SWB. Why did this occur? All near-infra-red analyses failed to suggest any hint of a chemical signature in either the rind or parenchyma fractions processed. The rind fraction should have contained important chemistry with which the female interacts in the process of ovipositing, and the parenchyma chemistry with which the larvae and pupae interact during development. This failure perhaps resulted from used of dried and processed tissue, and any chemical signatures present may have been altered or destroyed. Would analysis of fresh tissue have yielded different results?

Despite the failure to elucidate key plant traits as facets of resistance to SWB, comfort can be drawn that SWB resistance is a highly heritable trait, tremendous genetic variation exists, and the trait is readily and economically screenable by slicing, despite the failure to determine any resistance mechanisms.

4.0 OUTPUTS

The main part of the project demonstrated that resistance to SWB is a moderate to highly heritable trait, and that substantial genetic variation exists for this trait. Data showing this came from:

1. Determination of resistance of 88 cultivars and clones to infestation by SWB. Data were recorded as number of bored internodes per stalk. For analysis these were converted into percent bored stalks, number of bored internodes per stalk, and number of bored internodes per bored stalks.
2. Combined analyses of these traits within crops over sites and over crops within sites confirmed significant sites by clones and years by clones interaction, reinforcing the strategy that any screening for SWB resistance must be done over environments and over time.
3. Significant variation among clones for all traits explored, and almost a similar level of significance for variation among replicates for the majority of analyses conducted. Assessments were, therefore, conducted over a background of macro-environmental variation within sites in addition to the major differences between sites, adding further robustness to the data collected and analyses performed.

The project attempted to determine resistance mechanisms that could lead to a reliable, easy-to-use screening technique. Data obtained were:

1. Leaf dry matter was determined early and mid-season for all entries in the two four-replicate trials for the plant and first-ratoon crops.
2. Leaf nitrogen and silica levels were determined by collecting near-infra-red spectra on all leaf samples, having a spectrally selected subset of samples from the plant and the first-ratoon crop analysed for nitrogen and silica using routine, conventional analyses, and then developing predictive calibration equations for these components. These calibrations were applied to the total spectral populations and these predicted data subjected to statistical analyses and interpretations.
3. Leaf colour was determined in the plant crop using a Minolta SPAD leaf-colour meter.
4. Stalk height was determined in the plant crop.
5. The hardness of the rind of the basal internode was determined early-season in the plant and first ratoon crops using six-pin penetrometers.
6. Basal portions of stalks, collected from two trial in the plant crop and one trial in the ratoon crop, were processed to yield rind and parenchyma samples. Dry matter was determined for each fraction. Each sample was milled and near-infra-red spectra collected from all stalk samples. A spectrally selected subset of samples from the total population available was analysed for insoluble carbohydrate. A calibration was developed for insoluble carbohydrate, and these predictive calibrations applied to the total population. These data were subjected to statistical analysis. Insoluble carbohydrate on a fresh weight basis also was computed and subject to similar analyses.

However, no resistance mechanisms were identified:

1. There were no correlations between the traits determined and the measures of SWB resistance of significant magnitude ($r > 0.6$) for use in crop improvement.
2. Regression of compositional and chemical data and measures of SWB resistance accounted for only a small proportion of variation. While some measures of leaf nitrogen, leaf silica, and basal stalk composition (insoluble carbohydrate) suggested an element of consistency, in addition to obvious statistical significance, none revealed a predictive ability or explanation of these traits in determining or assisting plant resistance to SWB.
3. The failure to reveal any chemical signature in tissues analysed that warrant further analysis to pinpoint an explanation of the basis of plant resistance to SWB was disappointing. A chemical basis is an obvious facet of resistance, based on observation and from the literature, and the question why the analyses and approaches used failed is difficult to answer. Could the drying and processing of the various tissues analyzed have destroyed the chemical signatures sought?
4. The impact of SWB infestation on commonly determined quality components was quantified using duplicate plots of the 10 cultivars from the most heavily infested site in the plant crop. This was done using differential analysis of bored versus unbored stalks.
5. The relationship between number of vascular bundles in the rind and rind hardness and percent bored stalks was explored using the 10 most susceptible and 10 most resistant clones, based on the heaviest infected plant crop site, with material drawn from the early first-ratoon crop. Again, there was no clear indication predictive outcome from this exploration.

The additional part of the project showed that:

1. Sampling billets for SWB damage through the extraneous matter system of a sugar mill gives reliable data, as it supports field data collected by BSES.
2. Mill data may allow simple field assessments to be related to an entire mill area and would benefit those mills who do not sample for SWB activity.
3. Sampling should focus on counting the number of billets in each sampling and weighing the damaged billets to determine yield-loss estimates.
4. Continuing the mill-based sampling would allow a good comparison of SWB damage to be obtained across years – this may be useful for long-term prediction of SWB outbreaks, but a large amount of data across years is needed to reliably predict outbreaks, as damage appears to be dependent on a number of factors, such as cultivar, location and soil type.
5. Damage by SWB is greater in green cane than in burnt cane, reflecting historical data and that SWB was not a significant problem when pre-harvest burning of cane was standard industry practice.
6. Identification of districts and their levels of damage may allow a management strategy for SWB to be implemented.
7. Mulgrave Mill data show high susceptibility to SWB in cultivars such as Q113 and Q138, whilst Q117 has low susceptibility.

5.0 OUTCOMES

Despite a failure in the main part of the project to elucidate key plant traits as facets of resistance to SWB, SWB resistance was shown to be a highly heritable trait, with tremendous genetic variation. The trait is readily and economically screenable by slicing, despite the failure to determine any resistance mechanisms. Combined analyses of resistance traits within crops over sites and over crops within sites confirmed significant sites by clones and years by clones interaction, reinforcing the strategy that any screening for SWB resistance must be done over environments and over time.

6.0 RECOMMENDATIONS FOR FURTHER RESEARCH

The importance of SWB in the northern crop production environment has diminished dramatically since this research was concluded. A dedicated ‘breeding solution’ would appear not to be warranted.

7.0 PUBLICATIONS

Elements of this research were presented at the 8th Conference of the Australian Near-infra-red Spectroscopy Group, held in Horsham, Victoria, 1998.

Results of the development of a sampling strategy were presented by Berding (1996) (Appendix 2).

Results of the field trials will be presented for consideration in a referred journal paper.

The results of the additional study were presented as:
Stringer JK & Telford DE. 1998. SRDC project report BS151S Factors affecting the incidence of and damage caused by weevil borer. *BSES Publication SRDC Project Report* PR98004.

An outline of the project was presented as:
Webster DE. 1997. Sugarcane weevil borers – breeding for resistance. *BSES Bulletin* 58: 19 (Appendix 4).

8.0 ACKNOWLEDGEMENTS

Data for this project would not have been collected, often under trying tropical conditions, without the dedication and commitment of a number of research assistants in the crop-improvement program based on BSES Meringa – David le Brocq, Joanne Caltabiano and Melissa Denney. Debra Telford, Extension Officer, is thanked for her assistance in initiating the project and her inputs to the project. Special thanks are due to Dr Graeme Batten and Anthony Blakeney, both then with NSW Agriculture, Yanco, for loan of the Minolta SPAD leaf colour meter and the Newport Scientific sample grinder used to prepare dried parenchyma for near-infra-red analysis. Rhylee Pendrigh is thanked for her assistance analyzing data and compiling results for presentation in this report.

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APPENDIX 1 – Stringer and Telford (1998) report

BUREAU OF SUGAR EXPERIMENT STATIONS
QUEENSLAND, AUSTRALIA

SRDC PROJECT REPORT BS151S
FACTORS AFFECTING THE INCIDENCE
OF AND DAMAGE CAUSED BY WEEVIL BORERS
by
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PR98004

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SUMMARY

This study has shown that sampling billets for weevil borer damage through the extraneous matter system of a sugar mill gives reliable data as it supports in field data collected by BSES. These data may allow the simple field assessments to be related to the entire mill area. This would benefit other mill areas who do not currently sample for weevil borer damage.

The Mulgrave mill data shows high susceptibility to weevil borer by some varieties such as Q113 and Q138 while Q117 has low susceptibility.

There is greater damage in green cane than in burnt cane which reflects historical data. Weevil borers were not a significant problem when pre-harvest burning of cane was standard practice prior to the introduction of green cane harvesting.

By continuing the sampling method undertaken by Mulgrave mill, a good comparison of weevil borer damage across years can be obtained. This may be useful in the long term for predicting weevil borer outbreaks. However, a large amount of data across years are needed to reliably predict outbreaks as damage is dependent on a number of factors such as variety, location and soil type.

By identifying districts and their levels of damage a management strategy for weevil borer control can be implemented.

The sampling method used at the mill changed many times during the season. The most accurate method commenced from week 18 onwards and this may bias the results.

1.0 BACKGROUND

Sugarcane weevil borer was the second most damaging pest of sugarcane prior to the introduction of pre-harvest burning in the 1940s. After burning before harvest became accepted as standard practice, weevil borer virtually disappeared as a pest of sugarcane. With widespread adoption of green cane harvesting and trash blanketing (GCTB), weevil borer has again increased to severe pest levels from Cairns to Tully. Localised infestations have been reported in the Mossman, Herbert and Mackay districts.

2.0 OBJECTIVES

The objectives of this study were to:

- Analyse data collected by Mulgrave mill to determine losses caused by weevil borer.
- Develop strategies for collection of data on weevil borer damage in future years.
- Determine factors that contribute to economic losses by weevil borer damage.
- Identify varieties with weevil borer resistance.

3.0 INTRODUCTION

Weevil borer damage in the northern mill districts in both 1993 and 1994 seasons caused annual losses of approximately $1m worth of raw sugar. Total losses to weevil borer exceed $3m per annum, with severe damage in parts of Mulgrave, Babinda, Mourilyan, South Johnstone and Tully mill areas. Boring by weevils reduces sugar by an average 1.1 ccs units, and allows the ingress of secondary rots. Impurities such as dextran which are associated with rots interfere with the production of raw sugar in the mill. Removal of these impurities imposes an additional cost to the millers. In addition, raw sugar shipped from the Mourilyan terminal is less acceptable to Singapore refineries due to reduced filterability. Sugar from the north is shipped from Mourilyan Harbour, and impurities from weevil borer damage have been suggested as the cause of changes in crystal structure of raw sugar from mills in this area.

Surveys have indicated that commercial clones have different levels of susceptibility or resistance to weevil borer damage. GCTB and the growing of susceptible clones in the north were the only farm practices identified in the surveys as predisposing cane to attack from weevil borers. Research in Hawaii resulted in the development and adoption of resistant clones, which in turn reduced weevil borer damage to low levels (Chang *et al 1970*). Commercial clones with a high level of resistance to weevil borer damage are required for the wet tropics to improve the economic and environmental sustainability of northern canegrowing districts. A return to trash burning to control weevil borer would jeopardise long-term benefits gained from GCTB.

4.0 MATERIALS AND METHODS

4.1 BSES Data

A study was conducted by Nils Berding from BSES Meringa to determine whether selection for resistance to sugarcane weevil borer would be possible. The findings of this research are published in the 1996 proceedings of ASSCT.

4.2 Mulgrave Mill Data

Mulgrave Mill samples 80% of the cane entering the factory for extraneous matter. During the 1995 season, in addition to sampling for extraneous matter, pest damage by weevil borer and rats was also recorded.

Extraneous matter samples were removed from the hopper above the shredder feed rolls using a small bucket. Samples were taken every four minutes which resulted in more than 30 000 samples taken per season (Pope and Johnson 1996). This individual rake data was converted to a block basis so it would be more manageable for statistical analysis. On the advice of Mulgrave mill staff, class 8 (standover) and districts 15 (Productivity Board) and 16 (Tablelands) were omitted prior to data analysis.

For all 24 weeks of the 1995 season, the following data were recorded:

- Week, farm, rake, district, variety, crop class, state, ccs, rake weight, gross weight of extraneous matter, net weight of extraneous matter, number of red billets, number of bored billets and the number of dead billets

In week 18 of the season, an improved method of cane quality assessment commenced. This was to examine the possibility that weevil borer was the major cause of red colouration in the cane supply. Billets were split to check for the presence of weevil borers and were separated into different damage categories and weighed. Hence, from week 18 onwards additional data available were:

- Number of rat damaged billets, weight of dead/rotten billets, weight of bored billets, weight of rat damaged billets, weight of rind cracks.

It was not until week 22 of the season that the weight of 10 average sized billets was obtained. This allowed the average weight of a sound billet to be determined and from this the number of billets per sample to be calculated.
Data used for statistical analysis were:

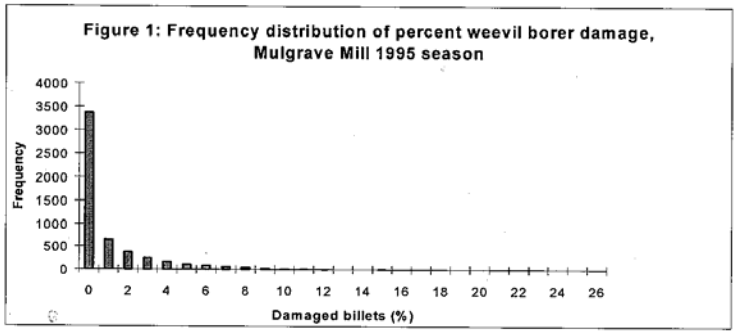
- Week, district, farm, block, variety, class, state, ccs, percent damaged billets due to weevil borers

Following Pope and Johnson (1996), analyses were undertaken on the seven major varieties viz: H56-752, Q113, Q117, Q120, Q124, Q138 and Q152. As the data set from Mulgrave mill was large but unbalanced, this necessitated simple statistical analyses to be undertaken. All analyses were performed using SAS (SAS Institute 1990). As percent weevil borer damage was not normally distributed, an arcsin transformation was applied to the data prior to analyses. In the results section, raw means are given in the Tables but the significance tests are based on arcsin transformed data.

5.0 RESULTS AND DISCUSSION

During the 1995 season at Mulgrave mill, the mean percent billets damaged due to weevil borers ranged from 0 to 27% with an average of 1.3%. Three quarters of the rakes analysed had damage levels less than 1.7% (Figure 1).

4



In 1995, Mulgrave mill crushed 1.39 million tonnes with an average ccs of 11.84. The loss due to weevil borer amounted to approximately $400,000 - $600,000. This was calculated as a loss of 7 units on 1.3% of the crop. CCS loss due to weevil borers was measured by Pope and Johnson in 1995. BSES measured an average loss of 1.1 units on whole stalks (unpublished data) and Pope and Johnson used billets. Not only does weevil borers have a direct effect by decreasing ccs, but there are also other costs to the industry that BSES has been unable to calculate. These include yield loss and costs associated with increased impurities in juice and sugar.

Figure 2 shows the weekly variation in weevil borer damage during the 1995 season at Mulgrave mill. The level of damage fluctuated during the season with the second half of the season having more damage than the first: viz 2.2% compared to 0.4%. This would be due to the better sampling method used from week 18 on giving more accurate results.

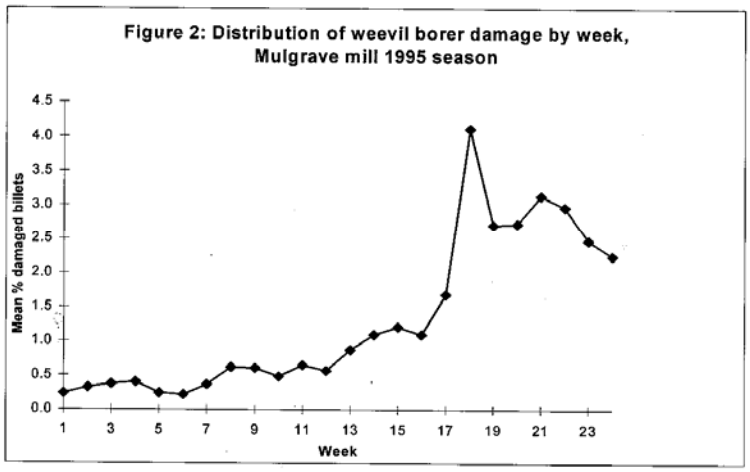


Table 1 gives the percent billets damaged by weevil borers for the major varieties in the Mulgrave mill area during the 1995 season.

From Table 1, it can be seen that the level of weevil borer damage in Q138 and Q113 were significantly greater than in any other variety ($p<0.05$). Q117 was the most tolerant variety and the level of damage was significantly less than in any of the other varieties ($p < 0.05$).

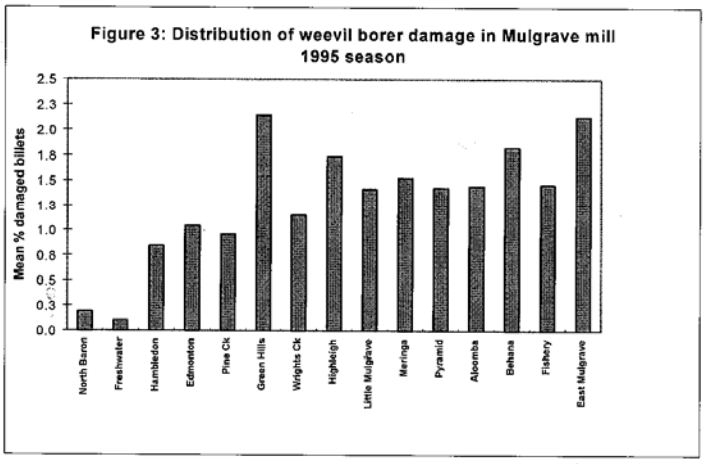
Table 1: Percent billets damaged by weevil borers for the major varieties, Mulgrave mill area, 1995 season.

Variety	Damaged billets (%)
Q138	2.08[a]
Q113	1.71[a]
Q120	1.10[b]
H56-752	1.02[bc]
Q124	1.00[bc]
Q152	0.85[c]
Q117	0.37[d]

Note: Means followed by the same letter are not significantly different $P > 0.05$

These results have also been shown by BSES through field sampling (BSES unpublished data). Consequently, BSES now breeds and selects varieties tolerant to weevil borers as part of a management strategy.

Figure 3 shows the distribution of weevil borer damage throughout the 15 districts in the Mulgrave Mill area.



The two northern-most areas of Freshwater and North Baron had the lowest amount of damage while Green Hill and East Mulgrave had the highest. Data from Pope and Johnson (1996) on the percentage of cane supply by district reveals that Freshwater and North Baron had the highest proportion of the least susceptible variety, Q117 and this was reflected in a low level of damage. Green Hills has highest percentage of the most susceptible variety, Q138. Data were not available for East Mulgrave.

Damage in each crop class is given in Table 3.

Table 3: Percent billets damaged by weevil borers for each crop class, Mulgrave mill 1995 season

Crop Class	Damaged Billets (%)
Plant	0.9^{c}
Replant	0.7^{c}
First ratoon	1.6^{a}
Second ratoon	1.3^{ab}
Third ratoon	1.5^{a}
Fourth ratoon	1.2^{b}
Other ratoon	0.9^{c}

Note: Means followed by the same letter are not significantly different $P > 0.05$.
Ploughout replant had the lowest level of damage but this was not significantly different to plant and other ratoon crops ($p > 0.05$).

The level of damage in green cane was 1.3 % and this was significantly greater than the 0.7% in burnt cane ($p < 0.05$). For burnt and green cane a comparison of the level of weevil borer damage in each variety was undertaken and this is summarised in Table 4.

Table 4: Percent billets damaged by weevil borer in burnt and green cane for the major varieties, Mulgrave mill 1995 season

	Variety – Damaged billets (%)						
	H56-752	Q113	Q117	Q120	Q124	Q138	Q152
Burnt	1.1	1.3	0.1	0.6	0.4	1.4	0.9
Green	1.1	1.7	0.4	1.1	1.1	2.0	0.9

The results of statistical analyses undertaken on the data in Table 4 revealed that there was no significant interaction between variety and harvesting condition. This means the differences in percent weevil borer damage that exist among varieties and between harvesting conditions can be examined independently. You do not have to examine the interaction between variety and harvesting condition.

5.1 Recommendations

At a meeting that was held at Mulgrave mill in June 1996 the following recommendations were made:

- The method of assessment for weevil borer damage during routine extraneous matter analyses would be enhanced during the 1996 season. The total number of billets in each sample would be counted. Damaged billets would be weighed during the 1996 season to allow BSES to determine yield loss estimates due to weevil borer.

- A report presenting the proportion of tonnes damaged and the severity of damage by weevil borer would be more beneficial to the industry than displaying the proportion of samples showing damage.

5.2 Comparison to other studies

The level of weevil borer damage BSES found in the Mulgrave mill cane supply was remarkably different to that reported by Pope and Johnson (1996). BSES analyses were based on the proportion of the cane supply damaged while Mulgrave mill staff reported the proportion of samples damaged. Their high levels indicate that damage is widespread throughout the district but this does not take into account the severity.

Mulgrave mill data compares well with the field data collected by BSES. Both data sets show varieties with different levels of damage as well as identifying zones within a mill area more prone to weevil borer damage. The large number of samples done by Mulgrave mill compared to the small number by BSES reinforced the field sampling methodology and its results.

5.3 Difficulties in project

There were many difficulties in this project and these are summarised below:

- There were large delays in receiving the data due to the workload of Mulgrave mill staff and the complexity of the data due to method changes in assessing damage during the 1995 season.

- The very large data files that needed to be downloaded from the Mulgrave mill mainframe to BSES PCs made manipulation difficult.

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APPENDIX 2 – Berding (1996) paper

PROCEEDINGS OF AUSTRALIAN SOCIETY OF SUGAR CANE TECHNOLOGISTS 1996

SUGARCANE WEEVIL BORER RESISTANCE: BREEDING STRATEGY DEVELOPMENT USING SURVEY DATA

By
Nils BERDING
BSES, Meringa

APPENDIX 3 - Procedure for determination of insoluble carbohydrate (IC) in rind and parenchyma

1. Weigh out 2 x 5 g samples from the oven-dried (OD) sample held in the oven.

   Transport the bulk OD sample from the oven to the balance in the desiccator.

   Once the samples have been weighed, store the remainder of the sample in the original container.

2. Place each sample in 200 mL of distilled water in an Erlenmeyer flask.

   Place one drop of non-ionic surfactant in each flask.

   Homogenize the contents of each flask for 5 min.

3. Bring the contents of the flask to the boil, and maintain for 2 min.

4. Prepare Büchner filter and pre-wet filter paper to the disc with distilled water.

   The weight of the filter paper and the sample number will be written on the upper surface of the filter paper prior to this operation.

5. Gently pour the hot contents of the flask to the centre of the filter paper with the vacuum on. Wash the inner surfaces of the flash with distilled water, repeatedly, with the washings being placed through the Büchner, until no residues remain in the flask.

6. Gently wash the filter paper with the adhering sample, still on the Büchner disc, with an additional 200 mL of boiling water, again with the vacuum maintained on.

7. Allow the filter and residue to dry for a period by maintaining the vacuum.

8. Remove the vacuum and carefully remove the filter paper, making sure **NO** sample is lost, and place in half a Perti dish. Place in the drying oven at 105°C until dry.

9. Record the dry weight of the filter paper and sample, as well as the weight of the filter paper. Compute the insoluble carbohydrate content of the sample as follows:

   $IC = 200 \times [M_{(\text{Weight of paper + residue})} - M_{(\text{weight of the paper})}]$ g kg^{-1}.

APPENDIX 4 – Telford (1997) publication

Sugarcane weevil borers — breeding for resistance

by extension officer
Debra Webster

SUGARCANE weevil borer causes severe damage to cane crops in north Queensland. BSES has been investigating this problem for the past three years. To date, research has identified a number of management techniques that will help reduce borer damage within green cane harvesting systems.

Borers introduced to Australia

Borers were accidentally introduced to Australia from New Guinea around 1900. Soon after their introduction, borer larvae began to cause extensive damage to north Queensland sugarcane crops. This damage was significantly reduced in the 1940s following the introduction of pre-harvest burning. However, since the adoption of green cane trash blanketing in the last decade, borers have again begun to cause serious damage to cane crops.

Varietal influences

In recent years, it has been observed that some varieties are more susceptible to borer damage than others. Two major northern varieties, Q120 and Q138, are among the most seriously damaged by borers. Seedlings in variety trials also receive different levels of borer damage. BSES now screens all seedlings for resistance and tolerance to borers in its variety breeding and selection program.

Finding resistant varieties

BSES plant breeders are currently investigating what makes some varieties resistant to borers, some tolerant and some susceptible. Trials have shown that most varieties with a soft rind in February receive more damage than varieties with a harder rind. Other factors, such as waxes on the rind, may also affect borer susceptibility. The Sugar Research and Development Corporation (SRDC) is now partly funding a project to look at what makes a variety resistant to borers and how this can be passed on by breeding.

As part of the SRDC project, leaf nitrogen, leaf colour, stalk height and rind hardness of each variety have been measured early in the year (when cane appears to be most susceptible to borer damage, refer Photograph 1). Damage assessments will also be made prior to harvest. This project will run for two years. The main objectives are to identify what mechanisms in cane make it resistant to borers and then develop varieties for future release to the industry or use in the BSES plant breeding program.

Another project investigating borer resistant varieties in the breeding system was planted in 1996. This BSES-funded project involved taking original seedlings from Meringa Sugar Experiment Station and planting them onto a farm susceptible to borer damage. This program is intended to run for five years, with the first planting on the Mourilyan sands last year. Taking seedlings at this early stage of the breeding system and selecting for borer resistance should accelerate the release of borer resistant varieties to the industry.

Borer management

One of the first steps in borer management is removing breeding material. Borers can breed in the tops, billets and whole stalks of the crop residue. Historically, borer management invovled pre-harvest burning and burning tops and trash. In green cane, practices that remove, reduce or modify crop residue help break the borer breeding cycle. Methods tested include trash mulchers in ratoons; shredder toppers at harvest; and reducing the loss of whole billets and stalks at harvest. Borers are also attracted to rotting cane. Rats, wind, cyclones, growth cracks, lodging and machinery can cause damage that leads to rotting and increases borer damage.

Combinations of management options in green cane systems can be used to manage borer damage at tolerable levels until resistant varieties are produced.

PHOTOGRAPH 1: Leaf colour is measured by research assistant, Jo Caltabiano, in a SRDC-funded borer trial.