Near infrared spectroscopic quality analysis of pre- and post-harvest sugarcane

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Introduction

The quality of sugarcane grown on Australia's northeast tropical coast (16° 15′–18° 15′ S Lat.) has declined markedly in the past seven years. This reduction has been linked to dilution of mill-supply cane with increasing levels of non mature-stalk material, or extraneous matter, consisting of leaves and sucker culms. Extraneous matter is undesirable in mill-supply cane because of the high fibre levels and the associated increases in processing and production costs. The reasons for increased levels of extraneous matter in mill-supply cane are higher than average harvest-season rainfall and its effect on crop condition, record or near record crop yields and cyclones. Heavy sugarcane crops are predisposed to lodging (falling over), resulting in an open canopy and increased light levels, triggering sucker, or water shoot, development. Current harvesting technology is inefficient, particularly in lodged crops, resulting in sub-standard cane being delivered for milling. This paper reports results of research that primarily aimed to examine the transition from the pre-harvest, in-field crop to the harvested material sent for processing, in terms of quality and crop composition.

Materials and methods

Fifty-four random crop sites were sampled (17 in 1999 and 37 in 2000) and encompassed a wide range of variables including crop (cultivar and crop class) and environmental factors (edaphic, topographic, climatic and temporal). Ten quadrat samples (2 m row length) were taken from each site immediately prior to harvest. These were partitioned into four crop fractions—sound and unsound mature stalks (culms), sucker culms (water shoots) and extraneous matter (leaves). Ten pail samples (45 L) were taken from the mill-consigned material, immediately after harvest at each site. These also were partitioned into four fractions—sound and unsound billets (culm pieces), culm spindle pieces (cabbage) and leaf. In 2000, before the harvest season, 14 additional sites were sampled monthly, on three occasions, between March and June. Erect stalks, (standing between 0° and 45° from vertical), and non-erect (lodged) stalks, (lying between 60° and 90° from vertical) were divided further into sound and unsound classes.

All samples were processed immediately, or, if necessary, stored at 4°C until required. Samples were weighed, disintegrated using a Brazilian sugarcane disintegrator (Dedini Codistil, Piracicaba, SP) and mixed in a rotary stainless steel drum mixer for 90 s to ensure homogeneity. Prepared samples (≈ 3 kg) were presented to an NIRSystems (Silver Spring, MD, USA) remote reflectance module using the BSES large cassette module[1,2] in which a one metre long, bottomless cassette moved over a quartz plate window. The remote reflectance module was linked fibre-optically to an NIRSystems Model 6500 spectrophotometer fitted with a fast motherboard. Ninety-five sample scans were taken along the entire length of the cassette, with 32 reference scans being taken after the sample scans. The

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average spectra of the scans was stored and, by using the *H* and *t* statistics, was classified as normal, or either a spectral, (*H*), or component, (*t*), outlier.

Near infrared (NIR) spectroscopic analyses were developed for the rapid determination of the sugarcane quality components:- Brix (soluble solids, g kg^{-1}), commercial cane sugar (CCS; g kg^{-1}), fibre (insoluble carbohydrates, g kg^{-1}), moisture (g kg^{-1}) and polariscope reading (optical rotation, °Z). The material was classed into three broad groups for calibration: culm (mature-stalk and sucker culms; $n = 639$), non-culm (leaf material and culm spindle pieces; $n = 496$) and combined (all crop fractions) (Table 1). Calibrations were developed on the 1999 harvest season population ($n = 1{,}135$) using these three material groups. Two random sub-sets ($n = 178$ and 190), consisting of approximately 10% of the pre-harvest-season and harvest-season populations analysed in 2000 also were subjected to full routine laboratory analyses and later incorporated into these calibrations.

Calibrations were developed using two elimination passes for the removal of *H* and *t* statistic outliers. Samples were scanned using the wavelength range 800 to 2200 nm, with 2 nm increments. All calibrations were developed using SNV and Detrend scatter and various math treatments up to the second derivative were applied. Cross-validation was performed over four groups. The culm and combined calibrations were developed further to include additional samples collected in 2000.

Results and discussion

Calibration development was based on the three material classes described above (Table 1). Samples collected during the 2000 pre-harvest season consisted of culm material only and samples collected during the harvest season for both years consisted of all crop fractions. The 1999 combined calibrations were excellent. However, the culm calibrations produced consistently lower standard errors. The non-culm calibrations were marginally better than the combined calibrations for only CCS and pol. reading (Table 2). The performance of the combined calibration developed in 1999 was acceptable when used to predict, at-line, quality components of the captured spectral data from the 2000 harvest season. The standard errors of prediction ranged from 6.63 for pol. reading to 16.04 for CCS and correlation coefficients were good, ranging from 0.948 to 0.972. Recalibration, using additional data from 2000 ($n = 368$), improved the results considerably (Table 3) as evidenced by reduced standard errors, stronger correlations for all quality components, reduced bias and lower differentials between actual and predicted means.

Analysis of the 2000 culm data, using calibrations developed with 1999 and 2000 culm data, resulted in better predictions relative to the 1999 culm calibrations. Results of the 1999 culm calibrations, applied to the 2000 pre-harvest-season spectral population, showed (Table 4) standard errors of prediction were reasonably high and correlations between predicted and actual values were weaker for fibre and moisture. Re-calibration, using 298 additional samples from the 2000 culm population, produced consistently lower standard errors and stronger correlations for all components, except CCS (Table 4).

Table 1. Three approaches to calibration development, based on 1999 data.

Group	*n*	In-field	Post-harvest
Combined	1,135	stalks, tops, trash, suckers	billets, cabbage, leaf
Culm	639	stalks, suckers	billets
Non-culm	496	tops, trash	cabbage, leaf

Table 2. Development of the combined, culm and non-culm calibrations, from 1999.

Group	Component	Treat.	# terms	*SEC*	R^2	Mean	*CV%*
Comb.	Brix	1,4,4,1	11	4.17	0.995	156.29	2.67
	CCS	2,8,8,1	14	4.09	0.997	71.76	5.70
	Fibre	1,4,4,1	10	6.87	0.995	199.07	3.45
	Moisture	1,8,8,1	12	5.45	0.996	670.46	0.81
	Pol. reading	2,8,8,1	15	1.71	0.998	46.73	3.66
Culm	Brix	2,8,8,1	9	3.07	0.996	189.40	1.62
	CCS	1,8,8,1	13	3.65	0.996	123.74	2.95
	Fibre	1,8,8,1	12	5.25	0.913	132.41	3.96
	Moisture	2,8,8,1	11	3.63	0.995	705.34	0.51
	Pol. reading	1,4,4,1	10	1.46	0.997	69.09	2.11
Non-culm	Brix	1,8,8,1	9	4.38	0.971	107.90	4.06
	CCS	1,8,8,1	16	3.73	0.922	–3.30	–112.84
	Fibre	1,8,8,1	13	7.82	0.990	310.15	2.52
	Moisture	1,8,8,1	14	5.14	0.996	609.71	0.84
	Pol. reading	1,4,4,1	15	1.64	0.947	13.18	12.47

Table 3. Combined calibrations applied to 1999 and 2000 harvest season spectral populations.

Calibration	Component	*SEP*(*C*)	Bias	r^2	Means	
					RLA	NIR
Comb. 1999 (*n* = 1,135)	Brix	10.50	–1.61	0.972	154.48	156.08
	CCS	16.04	–14.61	0.948	86.44	101.05
	Fibre	11.35	–6.54	0.964	152.51	159.04
	Moisture	12.10	6.16	0.955	715.68	709.52
	Pol. reading	6.63	–6.83	0.960	50.75	57.58
Comb. 99-00 (*n* = 1,503)	Brix	8.85	0.98	0.979	154.48	153.49
	CCS	12.20	–0.05	0.969	86.44	86.50
	Fibre	9.67	0.36	0.972	152.51	152.14
	Moisture	9.18	–1.83	0.974	715.68	717.50
	Pol. reading	4.46	0.07	0.981	50.75	50.68

Table 4. Culm calibrations applied to 1999 harvest season, and 2000 pre-harvest season culm populations.

Calibration	Population	n	Comp.	SEP(C)	$\bar{x}$	r^2
1999 (n = 639)	2000	298	Brix	8.67	163.03	0.962
			CCS	22.09	98.72	0.903
			Fibre	15.09	117.48	0.620
			Moisture	21.76	744.02	0.846
			Pol. reading	4.32	56.80	0.965
	1999 + 2000	937	Brix	8.72	179.80	0.968
			CCS	16.17	114.84	0.925
			Fibre	10.37	129.27	0.748
			Moisture	13.89	118.62	0.938
			Pol. reading	4.65	64.67	0.968
1999 + 2000 (n = 937)	2000	298	Brix	6.60	163.03	0.978
			CCS	23.56	98.72	0.863
			Fibre	9.09	117.48	0.831
			Moisture	11.40	744.02	0.949
			Pol. reading	3.56	56.80	0.976
	1999 + 2000	937	Brix	8.15	179.80	0.972
			CCS	16.74	114.84	0.917
			Fibre	8.13	129.27	0.841
			Moisture	9.10	718.62	0.973
			Pol. reading	4.34	64.67	0.972

The results obtained from the 2000 pre-harvest season sampling (Table 5) showed that CCS of lodged cane was 7.6% lower than CCS of erect, sound cane. Similarly, a 12.2% reduction in CCS was apparent when unsound cane was compared. In combination, these two undesirable traits resulted in a CCS reduction of 24.1% (Table 5). From results obtained during the 2000 harvest-season (Table 6), potential CCS of mature culms and billets is high, at 147.2 and 144.2 g kg^{-1}, respectively. These concentrations are being heavily discounted by dilution with extraneous matter, resulting in an 18.5 g kg^{-1} and 16.9 g kg^{-1} reduction, respectively, in in-field and post-harvest CCS. The CCS of the harvested material was fractionally lower than the CCS of the entire in-field crop, with a reduction of 1.4 g kg^{-1}. In-field extraneous matter, not including dead leaf clinging to the stalks (trash), constituted 13.3% of the

Table 5. CCS values of combinations of crop condition and crop habit.

Condition	Erect	Lodged
Sound	109.94	101.63 (92.44)
Unsound	96.52 (87.79)	83.42 (75.88)

Table 6. Summation of crop fractions and commercial cane sugar (CCS) distribution based on 2000 harvest season data.

Sample origin	Groups	Individual components	%	CCS	Weighted CCS	
					Groups	Overall
In-field	Mature stalks	Sound stalks	53.5	164.5	154.6	110.6
		Unsound stalks	16.7	122.8		
	Extraneous matter	Sucker culms	10.8	19.8	1.8	
		Extraneous matter	18.9	–8.1		
Post-harvest	Mature stalks	Sound billets	72.2	148.5	141.7	117.6
		Unsound billets	8.9	85.6		
	Extraneous matter	Cabbage	10.5	15.2	14.3	
		Leaf	8.4	10.5		

sample weight, which, after harvesting, was reduced marginally to 13.1%. Of the total in-field sample weight, trash constituted 7.0, increasing the actual extraneous matter quantity from what is reported here.

Conclusions

Assessment of quality components in pre- and post-harvest sugarcane using NIR (combined calibration) was more cost effective than routine laboratory methods. Outcomes from this NIR-facilitated research will have important economic consequences for the Australian sugarcane industry. Potential CCS present in mature culms is being discounted by dilution with leaves and sucker culms, threatening farm viability. The CCS of harvested cane was improved only marginally over that of the entire in-field crop. The results question the efficacy of current harvesting technology, highlighting a need for either supplementary, innovative pre-mill processing or a design revolution to improve mill- supply cane quality and, therefore, whole-of-industry economics. NIR facilitated analyses during the growth or pre-harvest-season, quantified the benefits of growing erect, sound crops. Loss of CCS, therefore, can be minimised only by a combination of crop improvement and agronomic solutions applied as part of sound, on-farm management regimes.

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References

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