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DEVELOPMENT OF NEW MEASUREMENT METHODS TO DETERMINE SUGARCANE QUALITY FROM STALK SAMPLES

A Dissertation submitted by

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Abstract

Recently, there has been a growing interest within the Australian sugarcane industry to measure sugarcane quality in the field to further improve product quality and value. However, conventional technologies for measuring sugarcane quality in a laboratory have limitations for uses in the field because they require sugarcane to be prepared as either juice or fibrated samples. In-field samples processing is very difficult and time-consuming, especially during harvest. Thus, the development of a rapid and efficient measurement technique which can be performed directly on stalk samples is highly desirable.

In this thesis, a new quality measurement method for fresh sugarcane stalk samples was developed using a visible and shortwave near infrared spectroradiometer (VNIRS) with the wavelength ranging from 350 to 1075 nm. A light-proof measurement box was developed and used as an instrument platform to evaluate the capability of the VNIRS to measure quality parameters of sugarcane samples. The box was used to determine quality parameters using two newly proposed scanning methods: the skin scanning method (SSM) and the cross sectional scanning method (CSSM). These methods were applied on both whole stalk and internode samples. No preparation mechanism was required prior to the quality measurement on stalk samples.

The selection of chemometrics methods used to optimise the regression models between spectral data and sugar content were also investigated. Partial least square (PLS) regression analysis with full cross validation (leave-one-out) technique was chosen to establish regression models between the spectral data and quality parameters. To improve the accuracy of the regression models, the spectral data was first pre-processed using the multiplicative scatter correction (MSC) method. Principal component analysis (PCA) was then used to extract useful information from the spectral data, decrease the noise and determine the optimum number of latent variables (LVs). The pre-processing methods, PLS and PCA exercises were run using Unscrambler V 9.6 software. The RPD (ratio of prediction to deviation) value was also used to evaluate the performance of the models.

For whole stalk samples, it was found that the R^2 for SSM and CSSM were 0.82 and 0.68, respectively. The calibration models for the fibrated, juice and whole stalk samples were developed using quality values obtained by standard industry procedures. For internode samples, the R^2 for SSM and CSSM were 0.91 and 0.87, respectively. The calibration models for internode samples were developed using °Brix values obtained from a handheld refractometer. The RPD values of the prediction models for

internode samples by both SSM and CSSM were 2, indicating that these newly proposed methods can be used for coarse quantitative prediction purposes.

The variation of sugar content (°Brix) along the length of the stalks and internode samples were also assessed. The understanding of these variations can provide a foundation toward the design and development of the quality measurement system in the field. In this study, sugar content was found to vary significantly between the first and last internodes, with their average °Brix values being 22.2 and 7.6, respectively. The variation of sugar content between node and internode areas was 7.6% (SSM method) and 8.7% (CSSM method), respectively.

To demonstrate the possible applications of the proposed methods on a harvester, a basic calculation and conceptual design for a proposed in-field quality measurement system was outlined using the VNIRS mounted on top of the elevator conveyor. The proposed system had the potential to sense billet samples based on SSM either by directly scanning the moving billets on the elevator or by scanning the billets supplied by a sampling mechanism using a vacuum system. This theoretical design has shown that it is technically possible to develop a quality measurement system on a sugarcane harvester. However, more work needs to be done before this proposed method can be successfully mounted on a harvester.

Overall, it is concluded that the accuracy of the new measurement methods based on stalk samples using portable and low-cost VNIRS developed in this thesis is adequate. The proposed methods have significant potential uses as a tool for measuring sugarcane quality parameters from stalk samples in the field.

Certification of Dissertation

I certify that the ideas, experimental works, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that this work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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List of Publications

The following articles have been published or submitted for publication from the research contained within this dissertation.

Refereed international journal articles

Nawi, N. M., Jensen, T. & Chen, G. (2012), 'The application of spectroscopic methods to predict sugarcane quality based on stalk cross-sectional scanning', *Journal of American Society of Sugar Cane Technologists* **32**, 16-27.

Nawi, N. M., Chen, G., Jensen, T. & Mehdizadeh, S. A. (2013), 'Prediction and classification of sugar content of sugarcane based on skin scanning using visible and shortwave near infrared', *Biosystems Engineering* **115**, 154-161.

Nawi, N. M., Chen, G. & Jensen, T. (2013), 'Visible and shortwave near infrared spectroscopy for predicting sugar content of sugarcane based on a cross sectional scanning method', *Journal of Near Infrared Spectroscopy* **21**(4), 289-297.

Nawi, N. M., Chen, G. & Jensen, T. (2013), 'Application of spectroscopic method to predict sugar content of sugarcane from internode samples', *Journal of Tropical Agriculture and Food Sciences* **41**(2), ***in press***.

Nawi, N. M., Chen, G. & Jensen, T. (2013), 'Quality measurement technologies and sampling strategies for precision agriculture in sugarcane industry: A review', accepted for publication in the journal of '*Precision Agriculture*' on 15 July 2013, subject to revisions.

Nawi, N. M., Chen, G. & Jensen, T. (2013), 'Determination of sugarcane quality from juice samples using visible and shortwave near infrared spectroscopy: Comparison between transmittance and transflectance measurement modes', under preparation and will be submitted to Journal of Mechanical Engineering and Sciences.

Refereed full-length conference articles

Nawi, N. M., Jensen, T., Chen, G. & Baillie, C. (2011), 'The application of spectroscopic methods to predict sugarcane quality based on stalk cross-sectional scanning', *SEAg 2011: Diverse Challenges, Innovative Solutions*, 29-30 Sep 2011, Gold Coast, Australia.

Nawi, N. M., Chen, G., Jensen, T. & Baillie, C. (2011), 'Transferring technology of measuring sugarcane quality from the laboratory to the field: what is possible?', *SEAg 2011: Diverse Challenges, Innovative Solutions*, 29-30 Sep 2011, Gold Coast, Australia.

Nawi, N. M., Jensen, T., Chen, G. & Baillie, C. (2012), 'Prediction of sugar content along the height of sugarcane internodes using Vis/NIR', *CIGR-AgEng 2012: Agriculture and Engineering for a healthier Life,* 8-12 July 2012, Valencia, Spain.

Nawi, N. M., Chen, G., Jensen, T. & Baillie, C. (2012), 'Potential technologies to measure sugarcane quality in the field', *CIGR-AgEng 2012: Agriculture and Engineering for a healthier Life*, 8-12 July 2012, Valencia, Spain.

Nawi, N. M., Chen, G. & Jensen, T. (2013), 'Application of visible and shortwave near infrared spectrometer to predict sugarcane quality from different sample forms', *Proceedings of SPIE 8881, Sensing Technologies for Biomaterial, Food, and Agriculture 2013*, 23-25 April 2013, Yokohama, Japan.

Nawi, N. M., Chen G. & Jensen, T. (2013), 'Visible and shortwave near infrared spectroscopy to predict sugarcane quality from clear and raw juice samples', *SEAg 2013: Innovative Agricultural Technologies for a Sustainable Future*, 22-25 Sep 2013, Perth, Australia.

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Abbreviations

ACFA	Australian Cane Farmers' Association
ANN	Artificial neural network
AOTF	Acoustic optic tunable filter
ASM	Assisted (Pneumatic) scanning method
ASD	Analytical spectral device
BCH	Burnt cane harvesting
BSES	Bureau of Sugar Experimental Station
CA	Cluster analysis
CAS	Cane analysis system
CCD	Charge-coupled device
CCS	Commercial cane sugar
CJ	Clarified juice
CSSM	Cross sectional scanning method
CV	Coefficient of variation
DPLS	Discriminant partial least squares
DSM	Direct scanning method
EWs	Effective wavelengths
FOV	Field-of-view
FR	Full range
FRS	Full range spectroradiometer
FS	Fibrated sample
FWHM	Full width at half maximum
GCH	Green cane harvesting
GIS	Geographic information system
GLC	Gas-liquid chromatographic
GPS	Global positioning system
HPLC	High performance liquid chromatography
InGaAs	Indium Galium Arsenide
KNN	K-nearest neighbours
LDA	Linear discriminant analysis
LVs	Latent variables
MA3	Moving average with three segments
MA9	Moving average with nine segments
MIR	Mid infrared
MLR	Multiple linear regressions
NIR	Near infrared
MN	Mean normalization
MSC	Multiplicative scatter correction
PA	Precision agriculture
PbS	Lead sulfide
PCs	Principal components
PCA	Principal component analysis
PCR	Principal component regression

PDA	Photodiode array
PLS	Partial least square
QMSS	Quality measurement system for sugarcane
R^2	Coefficient of determination
RJ	Raw juice
RMSEC	Root mean square error of calibration
RMSEP	Root mean square error of prediction
RPD	Ratio of prediction to deviation/residual predictive deviation
SD	Standard deviation
SEC	Standard error of calibration
SEP	Standard error of prediction
SG1	Savitzky-Golay first derivative
SG2	Savitzky-Golay second derivative
Si	Silicon
SIMCA	Soft independent modelling of class analogy
SNV	Standard normal variate correction
SSM	Skin scanning method
SVM	Support vector machine
SWNIR	Shortwave near infrared
SW-NIR	Shortwave near infrared
TGM	Ternary growth model
UV	Ultraviolet
Vis	Visible
Vis-NIR	Visible and near infrared
VNIR	Visible and shortwave near infrared
VNIRS	Visible and shortwave near infrared spectroradiometer