A non-destructive sensing technique for sugarcane quality in terms of commercial cane sugar (CCS)

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Abstract
A dielectric sensing technique was evaluated for the non-destructive measurement of sugarcane quality in terms of commercial cane sugar (CCS). Measurements were made by a parallel plate capacitance sensor supplied by a function generator and monitored by a spectrum analyzer. The consumed power of the capacitance sensor was recorded as a function of frequency swept between 0-10 MHz as the dielectric power spectral data. 79 sugarcane internode samples from four commercial cultivars were first measured by the dielectric sensor and then analyzed for CCS in the laboratory. The sugarcane CCS ranged within 6-15% was precisely predicted by a multiple linear regression model from the dielectric power spectral data with RMSE and $R^2$ of 0.32% and 0.98, respectively. The technique evaluated here showed a great potential for the non-destructive monitoring of sugarcane quality.

Keywords: Sugarcane quality, Commercial cane sugar, Non-destructive, Dielectric

Introduction
Commercial cane sugar (CCS) is the most applicable sugarcane quality index that describes an estimate of the percentage of recoverable sucrose from fresh cane. It is the basis for pricing the sugarcane for a fair payment to sugarcane growers [1]. CCS is also a key selection criterion in sugarcane breeding programs [2]. Moreover, in-field measurement of sugarcane quality (CCS) is also important for the optimization of sugar value at harvest through the identification of cane block with the highest in-field CCS [3]. The in-field CCS values would also allow the optimization of production inputs and harvest schedules [4]. Sugarcane CCS can vary due to the sugarcane cultivar, age of the crop, and moisture, nutrient, or temperature stress.

The laboratory method of analyzing CCS by milling the sugarcane samples and extracting the sugarcane juice [5] is time-consuming and rather expensive. So far, the only potential technology for the non-destructive sensing of sugarcane quality has been NIR spectroscopy evaluated either for measurement of sugarcane juice samples [6] or rarely for cane stalk samples [7, 8].

A recent study by Naderi-Boldaji et al. showed the possibility of simultaneously measuring sugarcane Pol%, Brix% and water content by the dielectric power spectroscopy technique [9]. This led to the idea that sugarcane CCS can also be measured by the same technique. Hence, the aim of this study was to address the possibility of non-destructive measuring of CCS by dielectric power spectroscopy. This would present a non-destructive sensing technique for sugarcane quality which can be integrated in a pricing system for the input sugarcane to sugar factory or on a sugarcane harvester for on-line monitoring of sugarcane quality for precision agriculture applications.

Materials and Methods
There are a number of measurements that contribute to the sugarcane CCS i.e. Pol% (sucrose concentration) and Brix% (the concentration of total soluble solids) in cane. The Pol% and Brix% in cane can be approximated from the Pol% and Brix% in juice as [5]:

\[
\text{Brix in cane} = (\text{Brix in juice} \times 0.97) \times (1-\text{fiber}) \\
\text{Pol in cane} = (\text{Pol in juice} \times 0.95) \times (1-\text{fiber})
\]

where fiber% is the ratio of dried fiber to the initial weight of a stalk sample.

Pol% in juice describes the concentration of sucrose in sugarcane juice and is measured by a polarimeter which transmits a polarized light through the juice and measures the angle of rotation of the polarized light calculated then to Pol%. Brix% in juice is a measure of the concentration of total soluble solids in the juice i.e. fructose and glucose in addition to sucrose. It also reflects the non-sugar soluble solids. Brix% is determined by means of a refractometer which measures the refraction angle of light crossed through the juice sample. CCS is described by:
where impurities (i.e. non-recoverable sugars) in cane is the difference between Brix% and Pol% in cane.

In this study, 79 internode samples from four commercial sugarcane cultivars (i.e. CP-57, CP-48, CP-69 and IRC-9902) were measured by the dielectric setup as shown in Fig. 1 and then analyzed for Pol% and Brix% (in juice) and fiber% by the standard methods [5]. The setup shown in Fig. 1 consists of a sweeper function generator (0-10 MHz generator SFG-2100 Series, GWInstek, Taiwan), the parallel-plate capacitance sensor and a spectrum analyzer (model GSP-827, GWInstek, Taiwan). For more information on the instrumentation, the readers are referred to [9].

![Dielectric setup for sugarcane quality scanning.](image)

Figure 1. The dielectric setup for sugarcane quality scanning.

**Results and Discussion**

Fig. 2a, b and c show the dielectric power spectra (i.e. power versus frequency) in some sensitive frequency ranges for three sugarcane internode samples with 6, 11 and 15.1% CCS. The spectra show the decrease of power with increasing CCS. Some frequencies e.g. at 8 MHz (Fig. 2c) indicates a sharp decrease of power with increasing CCS. The decrease of dielectric power with increasing CCS is because of decrease in free water molecules when solved with sugar [9].

The dielectric power spectral data were analyzed with multiple linear regression models for prediction of CCS. Fig. 3 depicts the predicted versus observed CCS of the tested samples with respect to 1:1 line for calibration and predictions data sets. The RMSE of 0.27% confirms a very accurate prediction of CCS by the dielectric power spectral data. This supports a great potential of dielectric sensing technique for the non-destructive monitoring of sugarcane CCS which provides the possibilities for (i) a sensor-based pricing system for the input sugarcane to sugar factory and (ii) a CCS monitoring system on sugarcane harvesters for field mapping of sugarcane quality for precision agriculture applications.
Figure 2. Dielectric power spectra for three sugarcane samples with varying CCS within a) 0-1, b) 6-7 and c) 7-9 MHz frequency ranges.

Figure 3. Predicted versus observed CCS by multiple linear regression of dielectric power spectral data for a) calibration and b) prediction data sets.

Conclusions
Dielectric power spectroscopy technique was assessed for the possibility of non-destructively measuring the sugarcane quality in terms of commercial cane sugar (CCS) using a parallel-plate capacitance sensor. Power decreased with increasing CCS in some frequency windows within 0-10 MHz. The results showed a highly accurate prediction of CCS ($R^2 = 0.98$, RMSE = 0.32%) by a multiple linear regression model from the dielectric power spectral data.

Nomenclature
CCS Commercial cane sugar
Brix Refractometer index
Pol Polarization

References


