

Evaluation of Near Infrared Spectroscopy for Sugarcane Quality Determination in Western Kenya

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Abstract

In Kenya, sugar is produced exclusively from sugarcane cultivated in Nyanza, parts of Rift Valley counties, Western Kenya and coastal region. Since the industry inception in early 1900s, farmer payments for delivered milling sugarcane has been based on tonnage delivered, with no consideration for quality of cane. However, in early 2000s, Kenya, attempted to put in place structures for paying farmers based on quality as measured by sucrose content amongst other factors. An effective, fast and accurate method of determining such quality has been missing, thus delaying implementation. Near Infrared (NIR) spectroscopy has been suggested as an accurate, non destructive and high-speed method for estimating the quality of milling cane. This research evaluated performance of a Matrix-F FT NIR spectrophotometer for estimation of cane quality in Nzoia Sugar Company, western Kenya. A total of 688 milling cane samples were obtained from randomly selected trucks delivering cane to the factory using a core sampler. The samples were finely shredded and analyzed by a method combining wet disintegration and core press as the primary measurements and NIR. The NIR spectrometer was calibrated using OPUS Lab Chemometrics software for pol, brix, fibre, moisture in cane. Results from wet chemistry were linearly regressed against the NIR results. The R^2 values were 0.9787, 0.9503, 0.8432 and 0.8725 for brix, pol, moisture and fibre, respectively. The results demonstrate that NIR spectroscopic analysis is an acceptable method for use in Kenya for quality based cane payment system.

Keywords: NIR spectroscopy, sugarcane quality, Kenya.

INTRODUCTION

Sugarcane (*Saccharum officinarum L.*) is an important commodity field crop in the tropics, contributing to economy as food, fodder, fibre, fuel and fertilizer (Lingle *et al.*, 2000). In Kenya sugar is produced exclusively from the plant grown in the Nyanza (Migori, Nyando and Kisumu Districts), parts of Rift Valley counties (Kericho and Nandi counties) Western Kenya (Mumias, Butere, Bungoma and Busia Counties) and Mombasa Kwale County. Since inception of the Kenya sugar industry in the early 1900s, payment to farmers for milling sugarcane delivered has been based on weight using pre-determined rates normally set by millers. However, in early 2000s, Kenya made an attempt to pay farmers using an objective system based on quality as outlined in the Kenya Sugar Act of 2001. This system was designed to use the sucrose content as the quality indicator. Sugarcane weight is influenced by many factors including variety, environment, age at harvest (Gilbert *et al.*, 2006), soil variability (Anderson *et al.*, 1999), agrometeorological factors (Rudorff and Batistita 1990), and post harvest handling (Solomon *et al.*, 2006), among other factors. Weight alone cannot determine the amount of final sugar from delivered cane. Consequently this payment system may not be objective and may be inappropriate for quality improvement in sugarcane production and processing.

Current methods of determining quality in the Kenya sugar industry are based on wet chemistry. This method is labour intensive and slow, and may not cope in factories where many trucks deliver cane as sampling and analysis of every load is impossible (Madsen II *et al.*, 2003). It is therefore necessary to establish faster and reliable methods that can withstand the rigour of large number of samples for use in the sugar industry. Analytical infrared (IR) spectroscopy involves measurement of the absorption (or reflection) of electromagnetic radiation with wavelengths in the range of 1 to 1000 μm . This spectral range can be divided into three groups: near IR (1 to 2.5 μm), mid IR (2.5 to 25 μm) and far IR (beyond 25 μm). Although the near infrared region of the electromagnetic spectrum does not show any specific absorption that yields structural information on the compound studied, it is important for quantitative applications (Gray *et al.*, 2009). NIR applications have been evaluated for use in the sugar industry for different purposes. In plant breeding trials, NIR spectroscopic techniques were developed for quality determination of shredded or fibred cane (Berding *et al.*, 1989; Brotherton and Berding, 1995, 1998). The NIR methods have also been used assess clonal sugarcane resistance to Fiji leaf gall (Purcell *et al.*, 2005, 2009), *Eldana* borers (Rutherford and Van Staden, 1996) and smut (Churchill *et al.*, 2006; Purcell *et al.*, 2010). Online NIR systems for analysis of cane, bagasse and sugar in sugar factories have also been reported (Staunton *et al.*, 1999, 2004; Bevin *et al.*, 2002; Staunton and Wardrop, 2006; Pollock *et al.*, 2007 Taira *et al.*, 2010). Indeed, NIR systems have been developed and demonstrated to be reliable in several countries Madsen II *et al.*, 2003; Edye and Clarke, 1996; Tiara *et al.*, 2010; Valderrama *et al.*, 2007). The NIR systems are fast and can analyse large number of samples within a short time (Madsen II *et al.*, 2003). It may be useful in an industry receiving sugarcane from variety of many farmers per day. The use of NIR system may therefore be useful for quality analysis in the Kenyan sugar industry. The objective of this research

was to evaluate NIR suitability for sugarcane quality analysis in Kenya.

MATERIALS AND METHODS

NIR techniques were used to evaluate sugarcane quality in western Kenya. A pilot cane testing unit was commissioned at the Nzoia Sugar Factory in November 2012 to assess the use of NIR for direct analysis of cane quality. Data acquisition reported in this paper for calibration began in May, 2013 and ended in February 2014 but continued in June 2014, when the factory opened after maintenance. Nzoia Sugar Company Limited (NSC) is located in Bungoma County, Bungoma South District, 5 Km from Bukembe, off the Webuye-Bungoma highway. It is situated at a latitude of 0°35'N and a longitude of 34°40'E and an altitude of between 1420-1490 meters above mean sea level.

Data Acquisition

Trucks were randomly selected for cane sampling by the core sampler. Each selected truck was assigned special test number. The test number corresponded to the trailer number which was viewed on a Cane Lab computer system connecting weighbridge and Cane Testing Unit (CTU) laboratory. Approximately 8 kg of cane was sampled by the core sampler (2011 Model 701) from each truck. The core sampler consists of a rotating 15.24 cm (6 inches) core tube fitted with a replaceable hard surfaced saw, mounted on a carriage car assembly. The unit is driven by an electro-hydraulic power pack. The complete assembly was mounted on a platform 5.61 m (18.4 ft) above ground level supported by a steel frame structure and concrete foundation.

The cane sample from each truck was coarsely shredded (Figure 2) followed by fine shredding (Figure 3) using a Jeffco shredder. The shredding provided homogeneous samples for both NIR and wet chemistry analytical work. Approximately 300 g of the finely shredded cane (preparation index of 88 % and above) was used for NIR analysis and another 2 kg for wet chemistry analysis.

Each wet chemistry sample was subjected to conventional analysis a combination of core press and wet disintegrator methods (Saranin, 1986) and the results were used as reference values for calibration. The brix values were obtained directly, using a digital refractometer with a precision of 0.01 ° brix. The pol measurements were obtained in a digital polarimeter with precision of 0.01. The samples of cane juice were initially cleared with lead sub-acetate ($Pb(CH_3COO)_2 \cdot Pb(OH)_2$) and filtered before the measurements. The degree of polarization of the sample, expressed as % of cane, was calculated based on the polarimeter reading using the following formula:

$$\text{Pol\% cane} = C * 100 - F / 100 * \text{Pol\% EJ}$$

$$C = 500 - G / 500 - 5F + \text{Pol\% DJ} / \text{Pol\% EJ} * G + E - 5F / 500 - 5F$$

$$F = \text{Fibre\% Cane} \quad \text{DJ} = \text{Diluted Juice} \quad \text{EJ} = \text{Extracted Juice}$$

$$G = \text{wt. of cake} \quad E = \text{Water added (Lts)}$$

Fibre% and moisture % were calculated as follows:

$$\text{Fibre\% Cane} = \text{WT. Dry fibre} / 5$$

$$\text{Brix\% Cane} = \text{Pol\% cane} / \text{purity} * 100$$

$$\text{Brix\% Cane} = \text{Pol\% cane} / \text{purity} * 100 \quad \text{Brix\% Cane} = \text{Pol\%}$$

$$\text{Moisture\%} = 100 - \text{Fibre\% cane} - \text{Brix\% cane}$$



Figure 2: Coarse Shredded cane sample



Figure 3: Fine Shredded cane

The OPUSLAB spectroscopy software (Bruker) collected all the data generated by the NIR instrument and displayed on a computer monitor. The generated data for pol % cane, brix % cane, fibre % cane and moisture % cane were thus stored in computer software. The data was then uploaded onto the Cane Lab system through a network link. The Cane Lab system was used for daily, weekly and monthly storage of analytical reports. The calibration of the Bruker MATRIX F duplex Instrument used a partial least square (PLS) fit method. A total of

1009 cane samples were used. The data from the NIR spectroscopy was lineally regressed against the wet chemistry data.



Figure 4: NIR analytical protocol for shredded cane at Nzoia Sugar Factory Pilot Cane Testing Unit.

Results and Discussion

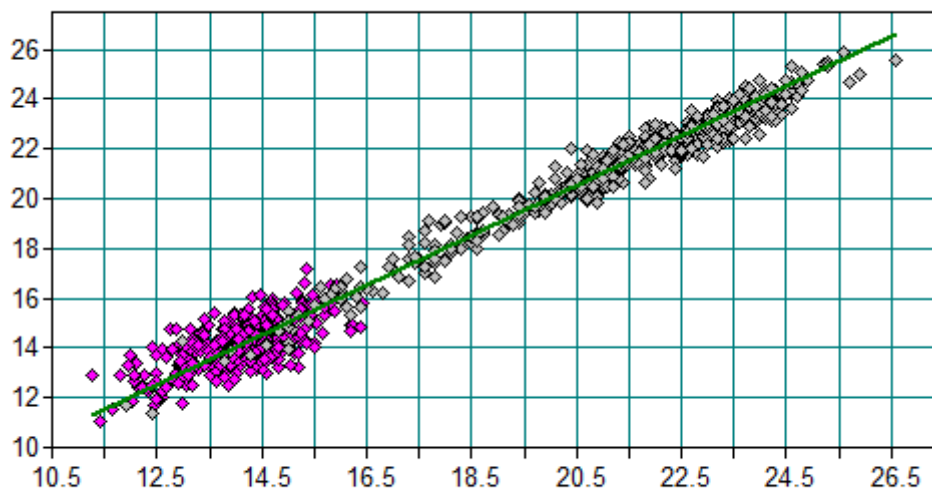
The plotted results of the regression using 688 samples are shown in Figures 6, 7, 8 and 9 for brix, pol, fibre and moisture contents of cane, respectively. Generally, there was good comparison between the actual data and the NIR predicted data. For brix and pol, the coefficients of determinations (R^2) were 0.95 and 0.98, respectively. The high R^2 values and low root mean square error of estimation (RMSEE) (Tables 1 and 2) were consistent with values previously observed in other studies (Meyer and Wood, 1988; Schaffer and Meyer, 1996; Madsen II *et al.*, 2003; Valderrama *et al.*, 2007; Nawi *et al.*, 2012; Habib *et al.*, 2001; Edey and Clarke, 1996; Staunton *et al.*, 1999; Larrahondo *et al.*, 2000). The high association shown herein and the other studies demonstrate the NIR systems can be used as reliable and fast method of prediction of brix and pol levels in sugar cane.

However, the coefficients of determinations (R^2) for fibre and moisture contents between the wet chemistry analysis and NIR predictions were slightly low at 0.87 and 0.84, respectively. Their root mean square errors of estimations were also slightly high of 0.77 and 0.97, respectively. These slightly lower levels of coefficients of determinations were also consistent with literature data on the two parameters (Meyer and Wood, 1988; Schaffer and Meyer, 1996; Madsen II *et al.*, 2003; Valderrama *et al.*, 2007; Nawi *et al.*, 2012; Habib *et al.*, 2001; Edey and Clarke, 1996; Staunton *et al.*, 1999; Larrahondo *et al.*, 2000). The level of fibre in cane is determined from the difference between moisture and brix contents. Consequently, all extraneous matter other than water and brix shall be included in the estimation of fibre. Sugar cane from the field is usually accompanied by some mud and/or trash. The NIR spectroscopy would have different reflectance wavelengths for these parameters. Consequently, the levels NIR predicted values for fibre and moisture contents will be at variance with wet chemistry data. Since different cane samples have varying amounts of these parameters, the relationship between the NIR predicted values and wet chemistry data will be lower/poorer. The errors appeared consistent leading to high root mean square error of estimation. However, the data obtained from the present study were

comparable with those obtained from countries where use of NIR system for estimating cane quality are recommended (Meyer and Wood, 1988; Schaffer and Meyer, 1996; Madsen II *et al.*, 2003; Valderrama *et al.*, 2007; Nawi *et al.*, 2012; Habib *et al.*, 2001; Edey and Clarke, 1996; Staunton *et al.*, 1999; Larrahondo *et al.*, 2000).

Sampling continued in the month of [June](#) 2014 after factory shut down for maintenance for an additional 321 samples resulting in an improved Root mean square error of estimation for all parameters (Table :3), showing that prediction by NIR improved with increase of numbers of samples.

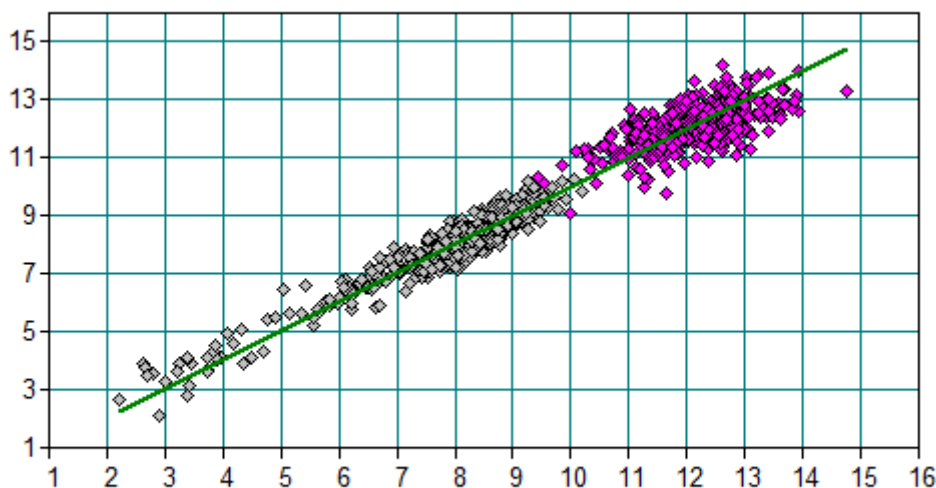
Fit vs True / Brix / Calibration



Rank: 21 $R^2 = 97.86$ RMSEE = 0.602 RPD: 6.84
Validation No 6 + Brix_Nzoia.q2

Figure 6: Data on brix %Cane: NIR predicted values vs. Actual wet chemistry data

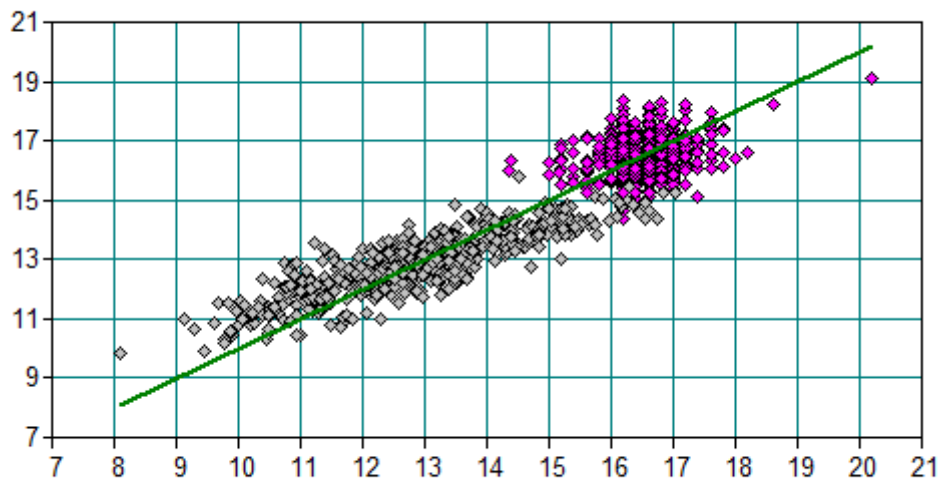
Fit vs True / pol / Calibration



Rank: 21 $R^2 = 95.03$ RMSEE = 0.528 RPD: 4.49
Validation No 6 + Pol_Nzoia.q2

Figure 7: Data on pol %Cane: . NIR predicted values vs Actual wet chemistry data

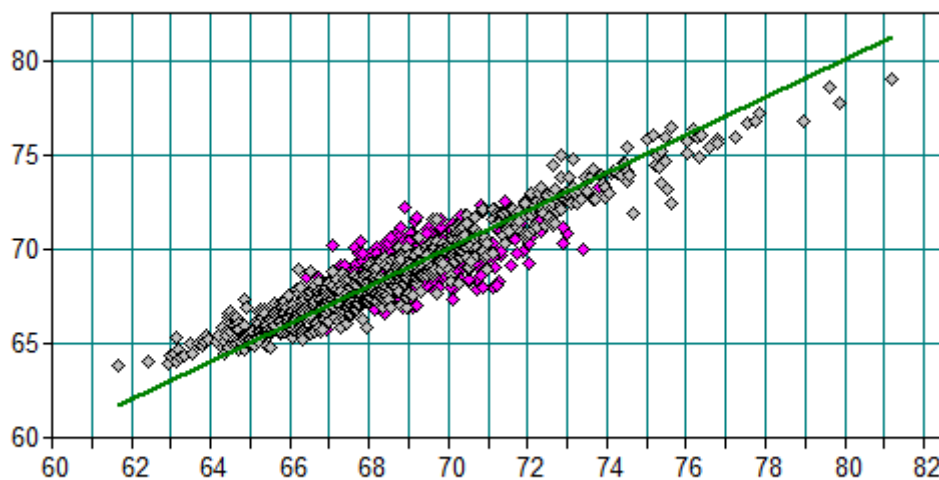
Fit vs True / fibre / Calibration



Rank: 18 $R^2 = 87.25$ RMSEE = 0.769 RPD: 2.8
 Validation No 4 + Fibre_Nzoia.q2

Figure 8: Data on fibre %Cane: NIR predicted values vs Actual wet chemistry data

Fit vs True / Moisture / Calibration



Rank: 18 $R^2 = 84.32$ RMSEE = 0.974 RPD: 2.53
 Validation No 2 + Moisture_Nzoia.q2

Figure 9: Data on moisture %Cane: NIR predicted values vs Actual wet chemistry data

The key quality parameters for cane quality estimation are pol and brix %. Both these parameters were predicted sufficiently using the NIR system. However, being preliminary further investigations using more samples over varied seasons and economic analysis are needed which are currently on going both at Nzoia and SONY sugar Companies. It is therefore concluded that with increased number of samples NIR predictions will be more accurate. The NIR system is a suitable tool for predicting sugarcane quality in western Kenya. After further economic analyses, the method can be used to set payment for delivered sugarcane from the farmers' fields.

Table 1: Statistical characteristics of samples

	Pol % cane	Brix % cane	Fibre % cane	Moisture % cane
R^2	95.03	97.86	87.25	84.32
RMSEE	0.5528	0.6020	0.7690	0.9740
RPD	4.49	6.84	2.80	2.53
Rank	21	21	18	18

Table 2: Comparison of NIR statistics and the average literature values*

Constituents	Number of samples		R squared (R^2)		RMSEE (Root mean square error of estimation)	
	Present work	From literature	Present work	From literature	Present work	From literature
Pol% Cane	688	970	0.95	0.94-0.99	0.528	0.14-0.44
Brix% Cane	688	985	0.98	0.95-0.99	0.602	0.25-0.44
Fibre% Cane	688	745	0.87	0.85	0.769	0.52-0.56
Moisture%	688	622	0.84	0.92-0.95	0.94	0.57

*Source: (Bentley *et al.*, 2001; Berding and Brotherton, 1999; Edye and Clarke, 1996; Larrahondo *et al.*, 2000; Staunton *et al.*, 1999).

Table 3: Statistical comparison of NIR Calibration Data

Constituents	Number of samples		R squared (R^2)		RMSEE(Error of estimation)	
	Our work	From literature	Our work	From literature	Our work	From literature
Pol% Cane	1009	970	0.96	0.94-0.99	0.46	0.14-0.44
Brix% Cane	1009	985	0.98	0.95-0.99	0.35	0.25-0.44
Fibre% Cane	1009	745	0.89	0.85	0.69	0.52-0.56
Moisture%	1009	622	0.90	0.92-0.95	0.73	0.57

*Source: (Bentley *et al.*, 2001; Berding and Brotherton, 1999; Edye and Clarke, 1996; Larrahondo *et al.*, 2000; Staunton *et al.*, 1999).

CONCLUSION

Increased number of samples for calibration improved the prediction ability of NIR
 NIR technology is accurate for use in the determination of quality for payment of farmers

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