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A portable near infrared spectrometer as a non-destructive tool for rapid screening of solid density stalk in a sugarcane breeding program

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ABSTRACT

The aim of this study is to estimate the solid density of cane stalk using the short-wave near infrared spectroscopy across mobile near infrared spectrometer with the wavelength of 570–1031 nm. The idea was to follow up the change of individual sugarcane stalk weight using non-destructive method, then the knowledge of solid density was required. The sugarcane stalk weight could be calculated by multiplication between solid density and its volume, which could be calculated from cane stalk diameters and its length 40 cm.

The model was optimized using PLS regression. To get the effective model, the effect of waxy cover, different integration time, different wavelength range, and various pre-processing technique were considered. The result showed that original sample model gave poor performance because of the effect of waxy cover. Meanwhile, NIR spectra without waxy cover model provided a good performance. The best model was achieved where the NIR spectra scanned with integration time of 200 ms, wavelength of 700–1000 nm, and with smoothing moving average were applied. The standard error of prediction (SEP), relative standard error of prediction (RSEP) were 22.131 kg/m^3 and 2.000%, respectively. It could be applied for screening. Hence the outcome showed that NIR spectroscopy could be used as a non-destructive technique to follow up the mass change of individual cane stalk. For cane breeding and mass yield programs, the knowledge could be used to estimate the growing rate when the environmental condition was changed. The model would benefit to breeding with time and cost consumption reduction.

1. Introduction

Variety improvement is an essential role in the prosperity of sugarcane industries and sugarcane-producing countries. The main purpose in cane breeding were the improving cane yield, sugar content, and sustaining fiber level for milling [1]. In the future, the trend of breeding programs will be focused on the improving a cultivar that was especially matched to a particular growing location [2]. In fact, even though the same species, different location plant and different environment condition can affect the mass yield and quality. To achieve cane yield, suitable variety with its corresponding area should be developed, therefore the variety improvement program must carry on regularly.

Sugarcane stalk density was the one of essential parameters, which it has been introduced into cane breeding program. Individual cane density is corresponded to cane yield and growth rate that is the requirement parameters for breeder.

The improvement in sugarcane yield can be succeeded by breeding program, however, it has had high economic value and time consuming. Currently, to check sugarcane yield during breeding, the breeder cut the canes stalk to the ground and weigh to measure the mass yield but cannot measure the growing rate because the sample was destroyed. Therefore, breeding program required more samples for experiment which leads to long time and high cost consumption.

The NIR spectroscopy technique has more advantage such as non-destructive, rapid, environmental friendly and limited sample preparation [3], it has commonly been used to assess the quality evaluation of fruit such as durian [4], pineapple [5], and mangosteen [6].

In addition, it has been also used to evaluate the wood density of basic wood properties of Norway Spruce (*Picea abies* (L.) Karst.) [7], wood chemical properties and pulp yield of *Eucalyptus camaldulensis* in Thailand tree plantations [8], wood density and chemical composition

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of tropical hardwood samples [9], and basic density and moisture content of loblolly pine (*Pinus taeda* L.) disks [10]. For sugarcane, many researchers presented a high possibility of NIR spectroscopy such as Taira et al. [11], they used a portable NIR spectrometer with transmittance mode for direct measurement pol value of whole stalk sugarcane though scanning cane surface, root mean square error of prediction was 1.1% Pol. Nawi et al. [12] predicted the °Brix content of sugarcane based on skin scanning using visible and shortwave near infrared, the PLS model provided a coefficient of determination (R^2) and root means square error of predictions (RMSEP) of 0.91 and 0.721°Brix, respectively. Nawi et al. [13] assessed the Brix, fiber content (FC) and moisture content (MC) of sugarcane by directly scanning the skin of internode samples using a visible-shortwave near infrared spectroradiometer (VNIRS) under black box condition, the result is represented by coefficient of determination (R^2) were 0.88, 0.93 and 0.90 for °Brix, FC, and MC, respectively. Previous results gave that the VIS/NIR method could be used to estimate cane quality with good performance and it is a suitable technique. Alves et al. [14] used near infrared optimized using PLS regression to predict density of *Pinus pinaster* and *Larix* × *eurolepis* wood, they recommended that a good result related to the number of scans obtained from a single spectrum, a higher number of scans per sample can reduce noise ratio of the NIR spectra which was more useful for PLS calibration.

Unfortunately, there have been no study of the use of NIR spectrometer regarding the surface scanning technique for density in individual sugarcane stalk in order to use for improving breeding program. This technique can measure mass yield based on the principle that when the solid density and its volume of individual cane is known, then can be converted to be individual weight stalk. Therefore, breeder can measure cane weight and growth rate while cane is surviving.

From the literature review, there were no study about the use of NIR spectroscopy to evaluate the solid density of cane stalk. Hence the effect of various pre-processing technique, wavelength range, and waxy covering on the cane surface were investigated.

The aim of this study was to develop the calibration model with cane breeding samples in order to estimate individual cane stalk density, which solid density could present the cane weight per stalk. The optimal method for evaluating solid density of cane stalk using NIR spectroscopy was researched. This idea could follow up the growing rate of individual cane stalk when the plant condition was changed such as climate, underground, rainfall and so on. The non-destructive method will support a breeder to follow up the cane weight of the same stalk without stalk destruction.

2. Material and method

2.1. Sample preparation

Sugarcane at 8 to 12 months ages of the KK3 (108 samples), LK92 (3 samples), K88-92 (3 samples), LK92-11 (6 samples), K07-037 (6 samples), K95-84 (3 samples), 95-2-213 (3 samples), TP1 (9 samples), UT-15 (24 samples) and breeding samples (15 samples) species were investigated. The 60 sugarcane stalk samples were collected from northeast of Thailand (Field Crops Research Center, Khon Kaen), Ban Non Ruang, Muang District, Khon Kaen Province. The sugarcane stalks were randomly cut 5 cm above the ground and then removed the leave, then it was taken to laboratory of Agricultural Engineering, Khon Kaen University. The sugarcane stalk samples were kept at the room temperature of 25 ± 2 °C for 1 h until the sample temperature was constant. Then, each cane stalk was divided equally into three sub parts including top section, middle section, and bottom section. Each sample or each sub parts was approximately 40 cm in length. Therefore, the total samples equal to 180. Fig. 1a demonstrated the top, middle, and bottom section sample on whole stalk.

2.2. Near infrared spectra scanning

After sample preparation, each cane sample (each sub parts) was scanned using a Mobile-NIR spectrometer (HKN Engineering, Hokkaido, Japan) in interactance mode, across the wavelengths range between 570 and 1031 nm, with the integration time of 200, 300, and 400 ms. Before scanning, a spectrometer was calibrated using a black sheet reference and a white Teflon reference, the assumption was the reflectance of a black and a white reference was the zeros percent and 100%, respectively. The size of sensor head (length × height × width) was 100 × 45.5 × 34 mm. The distance of the light source and detector were fixed at 24 mm (see in Fig. 2).

The first step, each cane samples was scanned at upper the 1st node (4-positions scanned around the stalk) and 2nd node (4-positions scanned around the stalk). Then, there were the total of 8 spectra for each sample, and they were averaged to be one spectrum. Fig. 2 illustrates the scanning point around the cane sample, point 1 to 8 were respectively scanned. Naturally, the cane sample (original sample) is covered by wax. In our assumption, cane wax may affect the absorption, this aspect may impact the model development. Therefore, wax covering on its surface was scraped off and it is called prepared sample. It was scanned again at the same positions for collecting NIR spectra. Fig 1b and c show the original sample and prepared sample of cane stalk.

After scanning, the reproducibility of NIR spectra for cane stalk were calculated, it was the standard deviation of absorption value collected from 8th re-scanning and re-loading (8 positions were shown in Fig. 2). The reproducibility of NIR spectra of original sample and prepared sample were compared. The main obvious peaks strongly impact to NIR radiation were selected and their absorbance value were used to calculate the reproducibility, the selected wavelength was 670, 760, and 980 nm. They related to vibration band of water and they displayed the biggest change where the scanning and sample conditions were changed.

2.3. Density measurement

After scanning both of original sample and prepared sample, the solid density of cane sample was calculated. The density (d) was calculated as:

$$d\ (\mathrm{kg/m^3}) = \frac{4 \times 10^6 \times M\ (\mathrm{g})}{\pi[D\ (\mathrm{mm})]^2 \times L\ (\mathrm{mm})} \tag{1}$$

where M is mass of cane stalk (g); D is diameter of cane stalk (mm); π is 3.414; and L is length of cane stalk (mm). M of cane sample was measured using digital weight (SB8001, Mettler Toledo, Switzerland). L is measured using the measuring tape (Tylon Tape 5 m, Stanley, Japan). Particularly, D is measured using Vernier caliper (Digital Caliper Vernier Gauge 0-150MM, Sanki, China) for three positions along the length of each sample at middle of internode, which was 400 mm in length and averaged.

2.4. Determination of outliers of the reference data

All solid density data calculated from standard method were checked an outlier. It was rough screening and was calculated following equation:

$$\frac{(X_i - \overline{X})}{SD} \geq \pm 3.00 \tag{2}$$

where X_i is reference value of sample i, $\overline{X}$ and SD is mean of reference value and standard deviation of density of the sample, respectively. When this equation is satisfied, sample as an outlier was removed from data set.