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Measurement of moisture, soluble solids, sucrose content and mechanical properties in sugar beet using portable visible and near-infrared spectroscopy

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ABSTRACT

Visible and near-infrared spectroscopy, coupled with partial least squares regression, was used to predict the moisture, soluble solids and sucrose content and mechanical properties of sugar beet. Interactance spectra were acquired from both intact and sliced beets, using two portable spectrometers covering the spectral regions of 400–1100 nm and 900–1600 nm, respectively. Both visible and short-wave near-infrared (400–1100 nm) and near-infrared (900–1600 nm) spectrometers gave excellent predictions for the moisture, soluble solids and sucrose content of beet slices with the correlations (r_p) of 0.89–0.95 and the standard errors of prediction (SEP) of 0.60–0.85. Lower prediction accuracies were obtained for intact beets, with the r_p values of 0.75–0.85 and the SEPs of 0.88–1.23. However, the two spectrometers showed a poor ability of predicting the compressive mechanical properties (i.e., maximum force, area and the slope for the force/displacement curve) of both beet slices and intact beets. Using simple correlation analysis, we also identified wavelengths that had strong correlation with the measured compositions of sugar beets. The portable visible and near-infrared spectrometry is potentially useful for rapid assessment of the moisture, soluble solids and sucrose content of sugar beet at harvest and during postharvest handling and processing.

1. Introduction

Sugar beet (*Beta vulgaris* L.) is the world's most cultivated crop for the production of sucrose for human consumption after sugarcane (*Saccharum officinarum* L.). The beet root contains a high level of sucrose, which varies between 12% and 21% on the fresh weight (FW) basis, depending on cultivar and growing condition (Trebbi, 2005). Traditionally, sugar beet breeding research has been focused on selecting cultivars with higher levels of sucrose. In the past two centuries, sucrose content has increased to more than 20% of FW (Asadi, 2006) to meet the human consumption need.

Sucrose, soluble solids, moisture content and mechanical property are important parameters in evaluating the suitability of newly developed sugar beet germplasm and/or varieties. Generally speaking, the post-harvest mechanical properties (e.g., maximum force, force/displacement area and slope under compression) of sugar beet are important in the design and adoption of handling, cleaning, packaging, storing, processing and transportation equipment (Singh and Reddy, 2006). The composition, especially sucrose, of sugar beet as a source of food is a key consideration to the breeder, producer and processor. Beets with high moisture content are normally accompanied with lower sucrose content; as a result, they increase the cost of transportation. In beet breeding, sucrose and moisture content are usually tested from representative roots harvested at the end of a growing season. The limitation of this testing method is that it ignores the dynamics of sucrose accumulation during plant developmental stages. In addition, the current methods for measuring the moisture and sucrose content of sugar beet are destructive, time-consuming and expensive. For instance, polarimetry is the most commonly used method for sucrose analysis by the beet industry. Refractometry, on the other hand, is commonly used for soluble solids content determination for fruits and vegetables; the method is quick and easy to carry out, but it requires extraction of juice from the sample for measurement. A new method of measuring sucrose using enzymatic–fluorometric microtiter plate

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assay was developed, but it requires destruction of the sample prior to analysis (Trebbi and McGrath, 2004; McGrath and Fugate, 2012). Owing to its high sensitivity and specificity, high-performance liquid chromatography (HPLC) is also used in the sucrose analysis of sugar beet. But the technique is limited to a small number of samples due to time and labor cost for sample preparation and sequential analysis (approximately 12 min per sample). Hence, a fast, low-cost and non-destructive method of measuring the quality parameters of sugar beet samples is much needed for beet germplasm selection and breeding. This would allow to quickly and economically determine whether batches of sugar beets are suitable for sucrose extraction.

Visible and near-infrared spectroscopy (vis/NIR) with the wavelengths of 400–2500 nm has been shown to provide abundant useful information for qualitative and quantitative analysis of compositions and properties in food and agricultural materials. With proper illumination and instrumentation, vis/NIR can provide adequate prediction of such chemical compositions as protein, fat, moisture, ash, starch, soluble solids content (SSC) or acidity in raw agricultural and food materials (Lu, 2001; Liu et al., 2010; Subedi and Walsh, 2011; Collell et al., 2011; Xie et al., 2014). Vis/NIR has also been applied to determine other chemical compositions (e.g., sucrose and total sugar). Roggo et al. (2004) measured the sucrose content, using vis/NIR (400–2500 nm), for more than 2700 homogenized beet brei samples from 15 different factories and polarimetry readings were used as reference measurements. They reported excellent results with the standard error as low as 0.1%. So far, all reported studies based on the vis/NIR technique needed to destroy and homogenize beet samples in order to achieve good prediction results. Furthermore, these studies were often carried

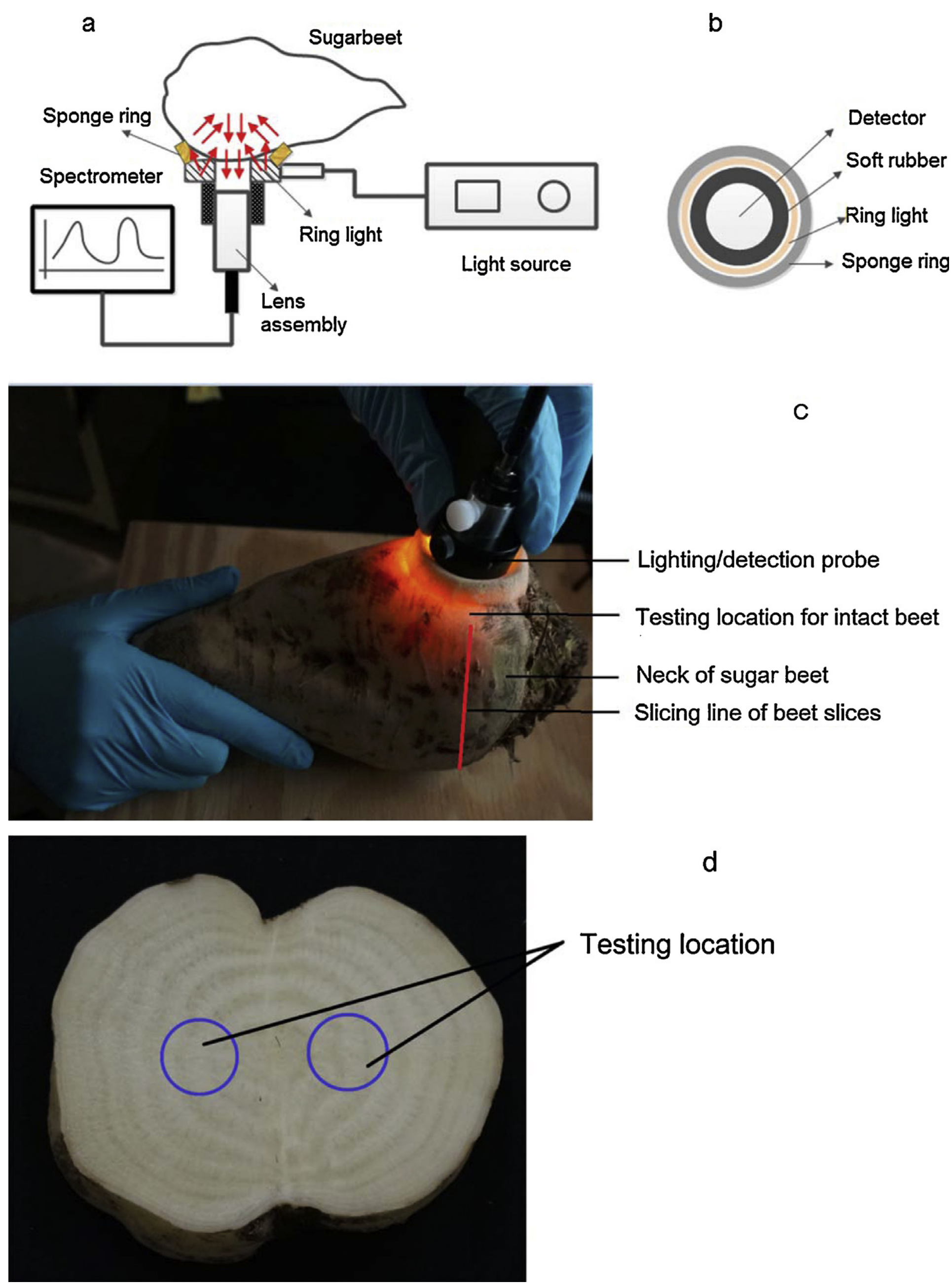

Fig. 1. Schematic of the visible and near-infrared spectral measurement systems (a), the configuration of the lighting/detection probe (b), the testing location on the intact sugar beet (c) and the sliced sugar beet (d).