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Research Article

Evaluation of Reflectometry and Refractometry for Rapid Sugar Detection in Sweet Potatoes

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Abstract

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Sugar content, a key quality attribute of sweet potatoes, is influenced by cultivar, maturity, storage conditions, and processing methods. This study aimed to develop efficient methods for measuring sweet potato sugar content using the reflectometer and refractometer. Ten sweet potato cultivars with diverse tuber flesh colors were evaluated in raw and baked forms. A simplified water extraction method facilitated analysis with both instruments. The RQFlex20 reflectometer, coupled with Reflectoquant sucrose and total sugar (glucose and fructose) test kits, was used to measure the sugar concentrations in sweet potatoes. Results demonstrated two linear regression models between the reflectometer and the reference method for the corresponding sugar contents, with coefficients of determination (R^2) of 0.95 and 0.86, respectively. Additionally, the refractometer measured total sugar content, exhibiting a strong linear regression (R^2 = 0.91) with the reference method. Furthermore, it could predict maltose content in baked sweet potatoes with a linear regression model (R^2 = 0.90), thereby overcoming a limitation of the RQFlex20 without maltose. This study demonstrated that reflectometry and refractometry offered a rapid and cost-effective method for measuring sugar content in sweet potatoes. This provided a valuable alternative to traditional high-performance liquid chromatography (HPLC) techniques, particularly for the agricultural and food processing industries.

Key words: Sweet potato, Sugar content, Reflectometer, Refractometer.

INTRODUCTION

Sweet potato (*Ipomoea batatas* (L.) Lam.), a member of the Convolvulaceae family, is an important global crop with a worldwide production of approximately 90 million megagrams and grows particularly vigorously in tropical and subtropical regions (Šlosár *et al*. 2019; Allan *et al*. 2024; Food and Agriculture Organization of the United Nations, https://www.fao.org/faostat/en/#data/QCL). This root vegetable, known for its large, starchy, sweet-tasting storage roots, is rich in vitamins, minerals, dietary fiber, and bioactive compounds with various health benefits (Lai *et al*. 2016; Yoon *et al*. 2018). Sweet potatoes are valued for their sweetness, derived from endogenous sugars such as sucrose, glucose, and fructose. Maltose, hydrolyzed from starch by amylase enzymes during cooking, also contributes to their overall sweetness (Laurie

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et al. 2013; Kitahara *et al*. 2017; Nakamura *et al*. 2018; Allan *et al*. 2024). Several factors affect the sweetness, including cultivars, farming systems, postharvest processes, and food processing. The variation in sweetness and flavor among different sweet potato cultivars is notable. Cultivation conditions, such as fertilizer application and harvest timing, impact their sugar content and quality (Adu-Kwarteng *et al*. 2014; Krochmal-Marczak *et al*. 2020). Storage conditions are also crucial factors influencing the sugar content of sweet potatoes (Rees *et al*. 2003; Huang *et al*. 2014). Additionally, cooking methods, particularly baking, significantly alter sweet potatoes' sugar composition and sensory attributes (Adu-Kwarteng *et al*. 2014; Wei *et al*. 2017). Therefore, the sugar content in sweet potatoes has been considered as an index for quality.

Several methods are used to determine sugar content including indirect physical, enzymatic, or semi-empirical chemical approaches. These methods can be affected by various factors like color development wavelength, time, temperature, and detection range, leading to inaccuracies (Buiarelli *et al*. 2016; Yue *et al*. 2022). For the phenol-sulfuric acid method, calculating the specific total sugar content requires a standard curve based on standard monosaccharides, which can result in significant errors in sugar content determination (Yue *et al*. 2022). Other methods directly quantify specific sugars or total sugar content. High-performance liquid chromatography (HPLC) is a powerful analytical technique for determining sugar content due to its specificity, ability to simultaneously analyze multiple sugars, accuracy, and precision (Wei *et al*. 2017). It is the preferred method for most studies analyzing sugars in sweet potatoes (Chan *et al*. 2014; Huang *et al*. 2014; Krochmal-Marczak *et al*. 2020; Allan *et al*. 2024), but it requires a substantial upfront investment in equipment and often necessitates specialized training for operators.

Some studies have also employed alternative methods, such as using a refractometer (Suárez *et al*. 2016; Šlosár *et al*. 2019; Takahama *et al*. 2021). The refractometer is a widely used optical instrument for measuring the total soluble solids (Jaywant *et al*. 2022). The Merck Millipore RQFlex/Reflectoquant system is a portable instrument to analyze sucrose and total reducing sugars in plant juice. It utilizes glucose oxidase-peroxidase test strips for colorimetric detection, with the reflectometer measuring reflected light to determine sugar concentrations (Helgerud *et al*. 2016). Although commercially available, its application for quantifying sugar content in sweet potatoes remains relatively underexplored.

This study aims to develop a simple, cost-effective, and field-friendly method for rapidly detecting the sugar content of sweet potatoes. This method, utilizing a reflectometer and a refractometer, offers a promising alternative to existing approaches, facilitating faster decision-making for farmers and processors at the point of demand.

MATERIALS AND METHODS

Materials

Roots from 10 sweet potato varieties (Table 1), including the two major cultivars 'Tainung 57' and 'Tainung 66', were selected and grown separately during the fall (2022 and 2023) and summer 2023 cropping seasons at the Chiayi Agricultural Experiment

Table 1. Flesh color of sweet potato cultivars used in this research.

Cultivars	Tuber flesh color
Tainung 10	White
Tainung 31	White
Tainung 57	Yellow
Tainung 66	Red
Tainung 73	Purple
Tainung 74	Yellow
Kokei 14	Beige
Benimasari	Yellow
Beniharuka	Yellow
Suzuhokkuri	Yellow

Branch in Chiayi, Taiwan, following standard commercial cultivation practices. To obtain data on different sugar content, samples were collected periodically during the pre-harvest and post-harvest periods. The pre-harvest period spanned 2.5 mo before harvest, while the post-harvest period extended up to 4 mo after harvest. Samples were then divided into raw and baked treatments for analysis.

Baking treatment

Roots were baked on a stainless-steel tray in an electric oven (NB-H3801, Panasonic Taiwan Co., Ltd., New Taipei, Taiwan) at 200℃ for 60 min, following the method described by Huang *et al*. (2014). After baking, the sweet potatoes were placed on a stainless-steel plate to cool.

Sample preparation

Raw samples of even size and shape were selected, washed with tap water, peeled, and then mashed by a grater. Baked samples were peeled and mashed using a mortar and pestle. To ensure consistency, only the middle section of each root was used. Moisture content was calculated as the percentage ratio of dry weight to fresh weight following the method outlined by Lai *et al*. (2013). It was subsequently used to calculate sugar content on a dry weight basis.

Method for sugar extraction

The extraction method depended on the analysis technique, utilizing either water or ethanol extraction (Fig. 1). Each sample was extracted in triplicate to ensure accuracy.

For water extraction, 3 g of sweet potato mash was mixed with 9 mL of ultrapure water in a centrifuge tube, shaken vigorously for 20 s, allowed to stand for 5 min, and then filtered by Whatman No. 4 filter paper. The collected filtrate was then used for analysis with a reflectometer and a refractometer.

For ethanol extraction, adapted from Chan *et al*. (2014), 2 g of sweet potato mash was mixed with 10 mL of 80% ethanol in a glass tube. The mixture was then heated at 80℃ for 45 min, and 5 mL of 80% ethanol was added every 15 min. After heating, the mixture was filtered using Whatman No. 4 filter paper, diluted to 20 mL with 80% ethanol, and further filtered through a 0.22 μm membrane filter. The final filtrate was used for HPLC analysis.

Reference measurement

The HPLC system contained a pump (Model CM-5110, Hitachi, Ltd., Tokyo, Japan), a manual sample injector (Rheodyne 7725i, Thermo Scientific, Waltham, MA, USA), a polymer-based hydrophilic interaction liquid chromatography (HILIC) column (Asahipak NH2P-50 4E, 4.6 mm i.d. × 250 mm, 5 μm, Shodex, New York, NY, USA), and an evaporative light scattering detector (Sedex LT-ELSD Model 85LT, Sedere, Olivet, France). The mobile phase was a mixture of ultrapure water (20%) and acetone (80%), and the column temperature was maintained at 45℃. The injection volume for each sample was 20 μL, and the flow rate was set at 0.8 mL min^{-1}. The detector was set at 60℃ with a gain value of 6.0, and the pressure control was 51 psi. A series of stan-

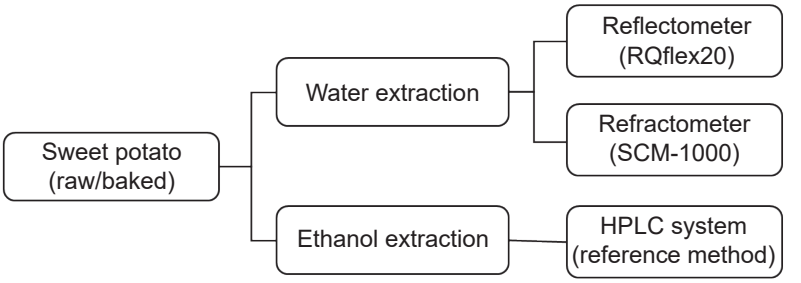

Fig. 1. Explanation diagram for extraction and measurement methods.

dard solutions was prepared by dissolving 10 mg of each sugar (fructose, glucose, sucrose, and maltose) in 1 mL of ultrapure water. These standard solutions were used to create a standard curve.

Reflectometer measurement

The Reflectometer RQflex20 (Merck & Co., Inc., Kenilworth, NJ, USA) was employed in conjunction with sucrose (saccharose) and total sugar (glucose and fructose) test strips, along with the corresponding reagents. The reflectometer was programmed using a bar-coded plastic strip provided with each batch of test strips.

The sucrose test (cat. no. 116141) utilized sucrose phosphorylase to cleave sucrose into fructose and glucose-1-phosphate. Glucose-1-phosphate was then converted by phosphoglucomutase into glucose-6-phosphate, which was subsequently oxidized by nicotinamide adenine dinucleotide (NAD) under the catalytic action of glucose-6-phosphate dehydrogenase to form gluconate-6-phosphate. During this process, the reduced nicotinamide adenine dinucleotide (NADH) produced reduced tetrazolium salt to blue formazan in the presence of diaphorase, which was then measured using the RQflex20. Similarly, in the total sugar test (cat. no. 116136), glucose and fructose were converted to glucose-6-phosphate, oxidized by NAD, and measured using the same method as the sucrose test.

Samples of the water-extracted filtrate were diluted to appropriate concentrations before analysis to ensure they fell within the measurement range. To ensure accuracy and reproducibility, all measurements were performed according to the manufacturer's instructions, including the RQflex20 reflectometer operating manual and user guides for the sucrose and total sugar tests. The measured values were multiplied by the dilution factor, converted accordingly, and presented as % DW (dry weight basis).

Refractometer measurement

This study used a portable digital refractometer (SCM-1000, HM Digital, Carson, CA, USA) with a measurement range of 0–55 degrees Brix to assess the sugar content of sweet potatoes. The measurement was conducted using the water-extracted filtrate, and the resulting values were multiplied by the dilution factor applied during extraction to obtain the final sugar concentration, expressed in degrees Brix (°Bx).

Statistical analysis

To evaluate the performance of the reflectometer and refractometer in measuring sweet potato sugar content, linear regression analyses were conducted using R (version 4.4.1). The sugar content measured by the reference method was the dependent variable, while values measured by the reflectometer and refractometer were used as independent variables. The analyses provided *P*-values, coefficients of determination (R^2), and regression equations for each model, facilitating the assessment of each instrument's performance.

RESULTS AND DISCUSSION

Performance of the reflectometer for determining sugar content in sweet potatoes

To increase the applicability of detection methods, 10 sweet potato cultivars with various tuber flesh colors were selected, including the two predominant varieties, 'Tainung 57' and 'Tainung 66', in Taiwan. Roots were collected at various stages of growth and storage, then divided into raw and baked categories to create samples with varying sugar concentrations. To streamline the extraction process, this study used water as the extraction solvent and eliminated the customary centrifugation step. Specifically, the RQflex20 reflectometer, in conjunction with the Reflectoquant sucrose (saccharose) and total sugar (glucose and fructose) test kits, was employed to analyze the sugar content of sweet potatoes.

Previous research by Lai *et al*. (2013)

found that sucrose was the predominant sugar in raw sweet potatoes, comprising approximately from 49.92 to 92.43% of the total sugar content, depending on the cultivars. This highlights the significance of sucrose content as a key factor influencing sweet potato quality. The detected sucrose content is shown in Fig. 2. Using the RQFlex method, the sucrose content ranged from 1.87 to 23.60% (DW), while the reference method (HPLC) detected a range of 2.00 to 31.84% (DW). The RQFlex data tended to be lower than those obtained from the reference method. The linear relationship between the reference method and the RQFlex method for 93 samples of sucrose content was illustrated. The simple linear regression model was highly significant ($P < 0.001$), with an intercept of -1.56 and a regression coefficient of 1.36. An R^2 of 0.95 indicated a strong relationship between the two methods for measuring sucrose content.

The results for the total sugar (glucose and fructose) test are shown in Fig. 3. Using the RQFlex method, the glucose and fructose content ranged from 0.51 to 7.99% (DW), while the reference method (HPLC) detected a range of 0.48 to 6.57% (DW). A linear regression analysis assessed the relationship between the RQFlex and the reference method for measuring glucose and fructose in 103 samples. The simple linear regression model was highly significant ($P < 0.001$), with an R^2 of 0.86, an intercept of 0.23, and a regression coefficient of 0.82.

Previous studies revealed that raw sweet potatoes contained sucrose, glucose, fructose, and maltose (Lai *et al*. 2013; Huang *et al*. 2014). However, most studies have used the summation of sucrose, glucose, and fructose for analysis (Kays *et al*. 2005; Wei *et al*. 2017; Allan *et al*. 2024). In this research, maltose was not detected in raw sweet potatoes, possibly due to variations in the extraction ratio and differences in the HPLC system configuration used for analysis. Consequently, the combination of water extraction, the RQFlex20 instrument, and sucrose and total sugar (glucose and fructose) tests offered a promising rapid detection method for measuring total sugar content in raw sweet potatoes.

Performance of the refractometer for determining sugar content in sweet potatoes

In modern analytical techniques, efficiency and ease of use are key factors. While the RQFlex20

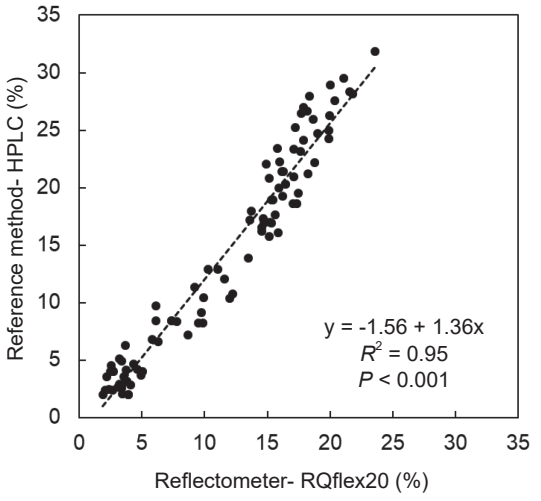

Fig. 2. Linear regression model for sucrose content (dry weight basis) in sweet potatoes analyzed by RQflex20 and high-performance liquid chromatography (HPLC).

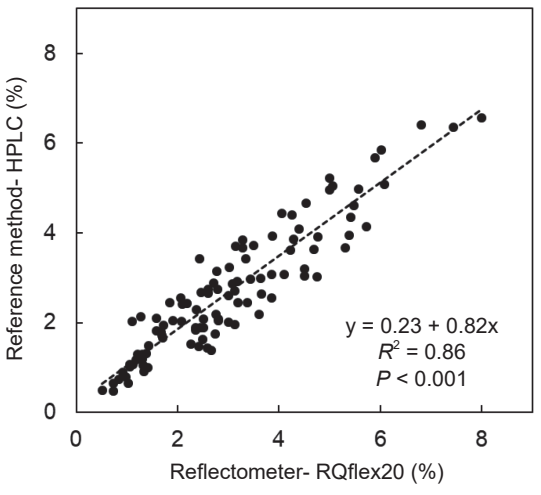

Fig. 3. Linear regression model for glucose and fructose contents (dry weight basis) in sweet potatoes analyzed by RQflex20 and high-performance liquid chromatography (HPLC).

reflectometer requires specialized equipment and a multi-step process, the refractometer provides a more streamlined approach. With a wider measurement range and minimal sample preparation, the refractometer is allowed for direct measurement after extraction, avoiding the time-consuming steps involved in the RQ-Flex method (Jaywant *et al*. 2022).

In this study, the refractometer was used to analyze the soluble sugar content, with measurements expressed in degrees Brix units. The total sugar content obtained by the HPLC method (analyzing sucrose, glucose, and fructose for raw sweet potatoes, and including maltose for baked sweet potatoes) served as a reference for evaluating the applicability of the refractometer method. Sample preparation followed the previous experiment. The results are shown in Fig. 4, with data of reference method expressed on a fresh weight basis for consistency with degrees Brix units. Refractometer measurements ranged from 3.3 to 32.8°Bx, while the reference method (HPLC) detected a range of 0.98 to 20.87% (fresh weight; FW). The refractometer data tended to be higher than those obtained using the reference method. A linear relationship (R^2 = 0.91) was observed between the reference method and the refractometer for measuring total sugar content in 126 samples. The simple linear regression model was highly significant (P < 0.001), with an intercept of -0.39 and a regression coefficient of 0.62. An R^2 of 0.91 indicated a strong relationship between the two methods for measuring total sugar content. Although the refractometer measurements showed some overestimation, consistent with the findings by Buiarelli *et al*. (2016), this method served as a simple and rapid screening tool, with an acceptable margin of error. Since a linear regression model had already been established in this report, it could be used as a calibration tool to correct the overestimation observed in the new method. By using the calibration curve, the refractometer data could be adjusted to more accurately reflect the true values obtained from the reference method, thereby improving measurement precision and minimizing the observed error.

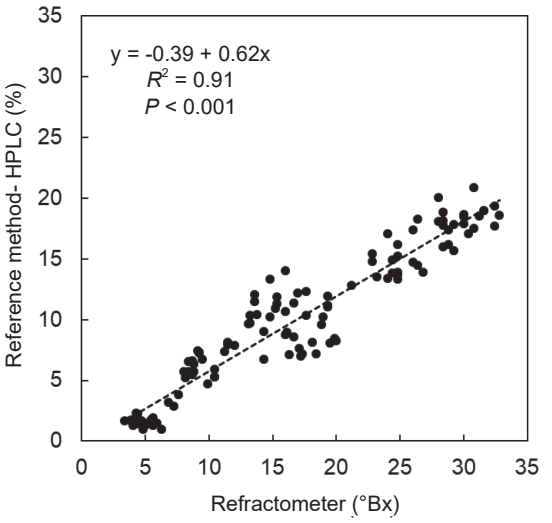

Fig. 4. Linear regression model for total sugar contents (fresh weight basis) in sweet potatoes analyzed by refractometer and high-performance liquid chromatography (HPLC).

The total sugar content significantly increased after baking treatment due to the formation of maltose. This increase primarily occurred because heat activated β-amylase within the sweet potatoes, which catalyzed the conversion of starch into maltose (Laurie *et al*. 2013; Kitahara *et al*. 2017; Nakamura *et al*. 2018; Allan *et al*. 2024). In this study, maltose was detected only in baked sweet potatoes, where it accounted for approximately 23.25 to 86.41% of the total sugars, depending on the cultivar. This study also conducted a regression analysis between the refractometer measurements for baked sweet potatoes and the maltose content measured by the reference method (n = 79) (Fig. 5). The linear regression model was statistically significant (P < 0.001), with an intercept of -4.54 and a regression coefficient of 0.63. The R^2 of 0.90 indicated a strong linear relationship, suggesting that refractometer results could be used to estimate maltose content in baked sweet potatoes. This result was similar to the findings by Nakamura *et al*. (2018), which reported comparable out-

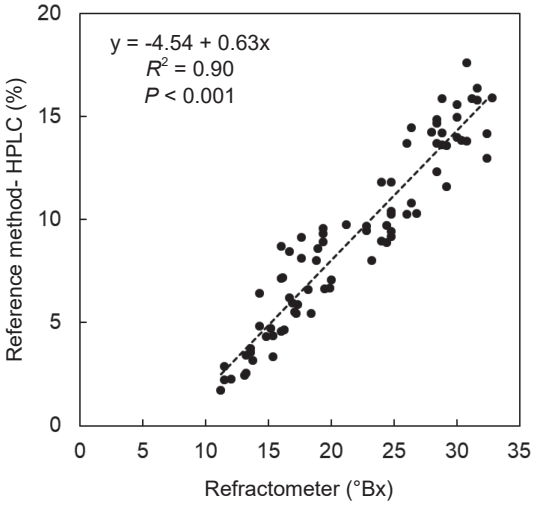

Fig. 5. Linear regression model for predicting maltose content (fresh weight basis) in baked sweet potatoes using the refractometer.

comes. Their research demonstrated that the sweetness of steamed storage roots (n = 221), measured using a refractometer, exhibited a linear correlation with maltose concentrations (%) in the roots of current Japanese cultivars, with a correlation coefficient (r) of 0.855.

While the refractometer had been used previously as a simple method for determining sugar content in sweet potatoes, existing methods primarily involved juicing raw sweet potatoes, with some studies also extracting sugars from steamed sweet potatoes using water (Suárez *et al*. 2016; Šlosár *et al*. 2019; Takahama *et al*. 2021). However, no regression studies had been conducted to establish a correlation between these methods and the HPLC method results. In this study, a water extraction method with a 1 : 3 solid-to-liquid ratio was used to determine the sugar content in sweet potatoes. Filtration through filter paper minimized the influence of suspended solids on the refractometer measurements. Regression analysis confirmed the applicability of this extraction method when it was used with the refractometer, showing that it could be applied to both raw and baked sweet potatoes. The regression equation could be used to convert measurements, yielding even greater accuracy.

CONCLUSION

This study assessed the efficacy of reflectometry and refractometry as rapid methods for analyzing sugar content in sweet potatoes, comparing them to HPLC. Because both methods showed strong linear relationships with HPLC results, refinements to the water extraction process expanded the applicability of these techniques to both raw and baked sweet potatoes, providing a cost-effective, reliable solution for sugar analysis.

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應用反射光度法及折射光度法於甘藷糖類含量快速檢測之可行性評估

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摘要

侯惠盈、黃哲倫、葉亦琪、賴永昌。2025。應用反射光度法及折射光度法於甘藷糖類含量快速檢測之可行性評估。台灣農業研究 74(2):151–159。

糖類含量為評估甘藷品質之重要指標，其受品種、成熟度、儲存條件及加工方式等因素而有不同的影響。本研究為開發可替代高效液相層析法 (high-performance liquid chromatography; HPLC) 之快速檢測方法，選用具有不同肉色的 10 種甘藷品種，利用簡化的水萃取法進行糖類萃取，並評估以反射式光度計與折射計檢測生鮮藷與烤藷糖類含量之可行性。試驗以反射式光度計 RQFlex20，搭配檢測試劑組進行分析。其糖類含量與參考方法 (HPLC) 之測值符合直線回歸模式，決定係數 (R^2) 分別為 0.95 (蔗糖) 與 0.86 (葡萄糖與果糖)，顯示此方法具有可應用性。折射計與參考方法亦符合直線回歸模式，R^2 為 0.91，能用以測定總糖 (蔗糖、葡萄糖、果糖及麥芽糖) 含量。另外，使用折射計能進一步預測烤藷中的麥芽糖含量 (R^2 為 0.90)，可克服 RQFlex20 缺乏專用麥芽糖檢測試劑組的限制。本研究應用反射式光度計與折射計，建立快速、經濟且高效檢測甘藷糖類含量的替代方法，有助於農民與加工業者在需要時更快地作出決策。

關鍵詞：甘藷、糖類含量、反射式光度計、折射計。

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