NIR determination of sugar contents in potato tuber

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Introduction

Potatoes are used in the food industry to produce food products such as potato flakes, potato chips and French fries. In each instance, potatoes are presorted before being introduced to the processing line. Consequently, the composition of the potato must be measured for variables such as dry matter, carbohydrate and reducing sugar content (fructose and glucose) prior to determining its correct use, handling and processing.[1] In the fried products industry, the determination of the reducing sugars content is particularly important because the presence of high levels of reducing sugars not only causes browning, but also generates acrylamide by the Maillard reaction with asparagines during the high temperature heating process. Acrylamide is believed to be carcinogenic and poisonous to the nervous system, and is therefore a highly undesirable constituent for consumers.

Near infrared (NIR) spectroscopy has been used to estimate nondestructively the specific gravity of potato tubers[1] and dry matter in potatoes,[2] as well as the main constituents including the carbohydrate content in potatoes.[3–5] No study describing the nondestructive measurement of the sugar content in intact potatoes appears to have been carried out. The objective of this study was to ascertain whether NIR spectroscopy could be used to determine the reducing sugar content in intact potato tubers.

Materials and methods

Experimental sample preparation

Potatoes of one cultivar (May-Queen) were purchased on the 7th of September, 2008 from the Akita fruits and vegetables distribution market and were used as the experimental samples. The potato samples were grown at Hokkaido locations in Japan. A total of 100 potato samples were used. Potato samples were individually separated into two parts. One group was stored at 5°C,

whereas the other group was stored at 25°C for 4 months to provide a wide range of sugar concentrations in the sample groups. At bi-weekly intervals, five tubers were taken out of each storage room for testing.

Spectra acquisition

NIR spectra were measured on all intact potato samples using a spectrophotometer (NIRSystems Model 6500) equipped with a fiber optics interactance probe as shown in Figure 1.

NIR spectra in the wavelength range of 400–1100 nm at 2 nm intervals were collected as absorbance measurements. Prior to spectral measurements, each sample was placed in the measurement room (25°C) for about 12 hours.

Chemical analysis

After NIR spectra were measured, flesh of the potato tuber samples were cut and mashed by a mixer and the material was wrapped in gauze and the juice was extracted by squeezing. This juice was used as the sugar analysis samples. The sugar compositions (fructose, glucose, sucrose) of the potato juices were analysed using an HPLC method with a refractive index detector similar to Chen *et al*.[6]

Statistical analysis

Data analyses were carried out using the Unscrambler software (CAMO, Oslo, Norway) and Excel software (Microsoft Office 2003). Second derivative spectra (Savitzky–Golay algorithm, left and right averaging of 20 nm and 2nd order polynomial) were used. The partial least square (PLS) regression was used to develop calibrations for analysing the sugar compositions of intact potato tuber samples. PLS regression was performed in the wavelength range of 600 nm to 1100 nm where the absorption bands were assigned to the fourth, third, and second overtones of O–H and

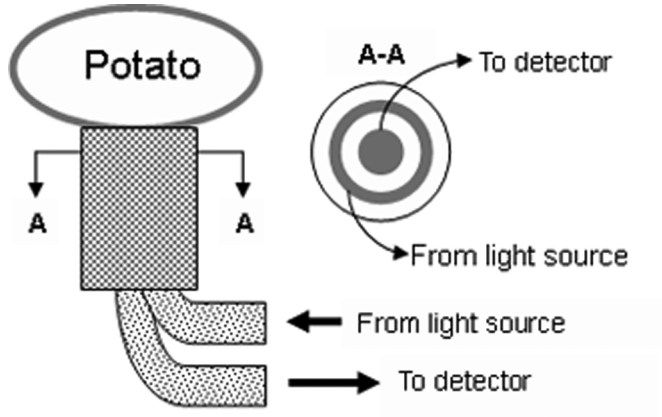

Figure 1. The configuration of the interactance probe used.

C–H fundamental bands or their combinations. Validation was performed by leave-one-out full cross validation.

Results and discussion

Variations in the sugar content of potato tubers during storage

Figure 2 shows the variations in the sugar contents (glucose and fructose) of the potato tubers stored at either 5°C or 25°C.

The sugar content values represented were the average of five potato tubers. In the case of material stored at 5°C, the glucose contents of the potato tuber samples significantly increased after the first week and continued to increase until the eighth week. Beyond the eighth week, the sugar contents of the potato tuber samples decreased. This observation suggests that the potato tuber samples had begun to germinate beyond the eighth week. Fructose levels in the potato tuber samples also exhibited an increase up to the eighth week. For samples stored at 25°C, large variations of the glucose and fructose contents of the potato tuber samples were not observed.

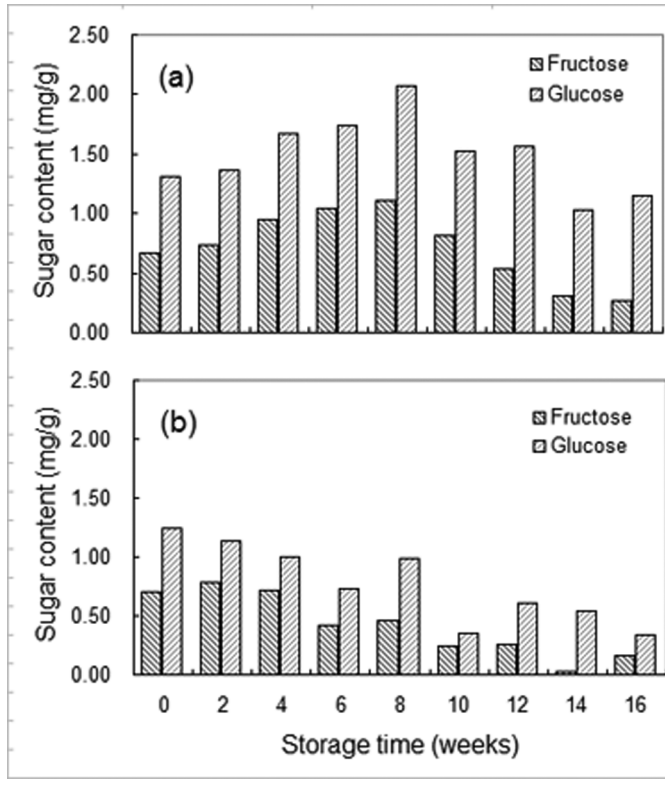

Figure 2. Observed changes in the amounts of reducing sugars in the potato tubers stored at the two different temperatures of (a) 5°C and (b) 25°C.

Variations of the NIR spectra during the storage process

The variance of the average NIR second derivative spectra of 15 potato tuber samples stored for 16 weeks was calculated and plotted as shown in Figure 3.

In the case of potato tuber samples stored at 25°C [Figure 3(a)], a peak around 970 nm due to water was observed; other peaks, such as the peaks at 670 nm, 710 nm 798 nm, 826 nm and 926 nm, were also observed. The observation at 970 nm indicates that the potato tuber sample has lost weight during the storage process. However, a relative large variation of the NIR second derivative spectra of potato tuber samples stored at 5°C was observed around 670 nm and also at 710 nm [Figure 3(b)]. The considerable variation around 670 nm and 710 nm may be associated with the sugar content in the potato tubers by the comparison between the variance plots (Figure 3).

PLS regression

PLS regression analysis was performed based on the sugar (glucose, fructose, sucrose and total sugar) contents and NIR second derivative spectra (600–1100 nm) of all potato tuber samples (total of 80: 40 stored at 5°C and 40 stored at 25°C). Table 1 shows the calibration and validation results of the sugar contents of the potato tubers.

As an index for determining the validity of the calibration models, the RPD (ratio of standard deviation of reference data in prediction sample set to SECV) is usually employed.[7] A RPD

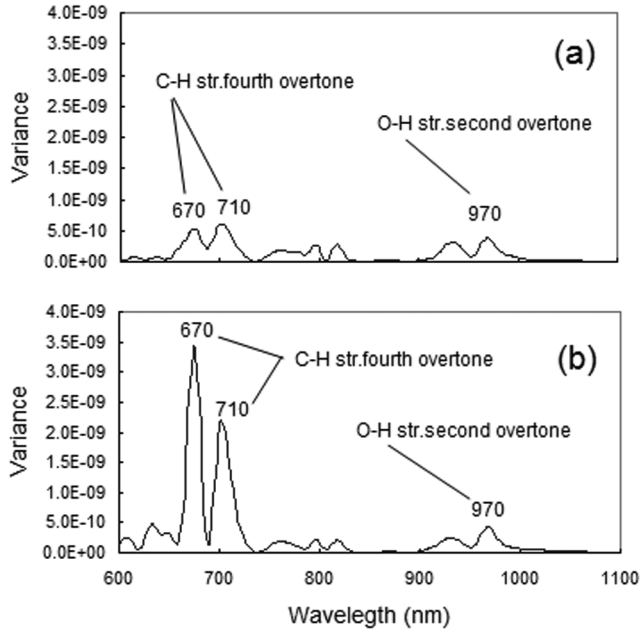

Figure 3. Variance of the average NIR second derivative spectra of 15 potato tuber samples stored for 16 weeks. (a): the potato tuber samples during storage at 25°C and (b): the potato tuber samples during storage at 5°C.

Table 1. Calibration and validation of the sugar contents of potato tubers.

	R	*SEC*	*SECV*	*RPD*
Fructose (mg/g)	0.71	0.23	0.26	1.42
Glucose (mg/g)	0.65	0.39	0.46	1.32
Sucrose (mg/g)	0.71	0.26	0.33	1.42
Total sugar (mg/g)	0.73	0.56	0.66	1.46

R, correlation coefficient of calibration; *SEC*, standard error of calibration; *SECV*, standard error of cross-validation; *RPD*, ratio of standard deviation of reference data in validation sample set to *SECV*.

value of 1.4–1.7 is regarded as adequate for rough screening and a value above 1.7 is regarded as satisfactory for screening. In this study, the RPD values more than 1.4 for fructose, sucrose and total sugar contents were obtained. As such, the NIR calibration models are suitable for rough screening of the sugar contents of the potato tubers.

Discussion of the NIR calibration models

Regression coefficients can be used to discuss the contributions of individual wavelengths to a PLS calibration model, because a regression coefficient spectrum shows characteristic peaks and troughs that can indicate which wavelength range is important for the calibration model.[8] The regression coefficients of the PLS calibration models of these sugar components showed many remarkable peaks, special important peaks at wavelengths of 670 nm and 710 nm. These peaks could be correlated to the absorption band of a C–H stretching fourth overtone and are likely to be associated with sugar content in the potato tubers by comparison with Figure 3. These results suggest that the PLS calibration models for estimating the sugar components of the potatoes were established based on the absorptions of the various sugar components.

Conclusion

It is concluded that NIR spectroscopy is a suitably for rough screening of the sugar contents of the potato tubers as a nondestructive determination method.

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