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ORIGINAL RESEARCH ARTICLE

NON-DESTRUCTIVE ONLINE REAL-TIME MILK QUALITY DETERMINATION IN A MILKING ROBOT USING NEAR-INFRARED SPECTROSCOPIC SENSING SYSTEM

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ABSTRACT

A near-infrared spectroscopic (NIRS) sensing system was developed on an experimental basis for the quality determination of three major milk constituents (fat, protein and lactose) and somatic cell count (SCC) of non-homogenized milk. The NIRS sensing system was used for acquiring NIR spectra of non-homogenized milk during milking in an automatic milking system (milking robot) over the wavelength range of 700 nm to 1050 nm. The three major milk constituents were analyzed for reference data using a MilkoScan instrument, while SCC was analyzed using a Fossomatic instrument. We developed calibration models using partial least square (PLS) regression analysis, and the precision and accuracy of the models was validated. The coefficients of determination (r^2), standard errors of prediction (SEP) and bias were 0.98, 0.23% and 0.00% for fat, 0.72, 0.25% and 0.00% for protein, 0.54, 0.15% and 0.00% for lactose, and 0.63, 0.48 Log SCC/mL and 0.00 Log SCC/mL for SCC respectively. These results show that the NIRS sensing system developed in this study could be used for online real-time determination of milk quality in a milking robot. The system can provide dairy farmers with information on milk quality and physiological status of each cow and therefore, give them feedback control for improving dairy farm management. By using the NIRS system, dairy farmers will be able to produce high-quality milk and precision dairy farming will be realized.

1.0 Introduction

Dairy farming involves a lot of work such as feeding, milking, livestock management, feed crop production and manure treatment. As usual, extensive dairy farmers manage their livestock in groups which is a system known as herd management (Svennersten-Sjaunja *et al*., 1997). However, a system known as individual cow management is essential for monitoring milk composition quality of each cow which is important for animal breeding, effective cow usage and feed management. Thus, this is the reason for the recent need for a technique that will enable dairy farmers to determine milk quality of individual cows during milking.

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The non-destructive, rapid, easy to use, time saving and pre-treatment free nature of near-infrared spectroscopy (NIRS) makes it an effective tool for analyzing milk quality during milking process, NIRS has been used to obtain qualitative and quantitative information of food and agricultural commodity such as rice (Kawamura *et al.,* 2003a; Natsuga and Kawamura, 2006), wheat (Natsuga *et al.,* 2001), and fruits and vegetables (Lakshmi *et al.,* 2017). NIRS has been practically used in automatic rice-quality assessment in Japan (Kawamura *et al.,* 2002; Kawamura *et al.,* 2003a). NIRS has also been use for milk quality determination (Sato *et al.,* 1987; Tsenkova *et al.,* 2001; Kawamura *et al.,* 2003b; Tsenkova *et al.,* 2006; Kawamura *et al.,* 2007; Kawasaki *et al.,* 2008; Tsenkova et al., 2009; Iweka *et al.,* 2016). However, the application of NIRS for online real-time monitoring of milk quality of individual cow has not been achieved.

In this study, an experimental online near-infrared (NIR) spectroscopic sensing system was developed for milk quality determination. Iweka *et al.,* (2016) reported that the NIR spectroscopic sensing system can be used for real-time determination of milk quality during milking with sufficient precision and accuracy. As a result of our findings, the NIR spectroscopic sensing system was installed in an automatic milking system.

The objective of this study was to examine the accuracy of the NIR spectroscopic sensing system for milk quality determination in an automatic milking system.

2.0 Materials and Methods

2.1 Near-Infrared Spectroscopic Sensing System

An experimental online near-infrared (NIR) spectroscopic sensing system was designed for analyzing milk quality of each cow during milking. The system consisted of an NIR instrument (NIR spectrum sensor and NIR spectrometer), milk flow meter, milk sampler and a laptop computer (Fig. 1). The system was installed in a milking robot system (GEA Farm Technologies, Westfaliasurge, Germany). Non-homogenized milk from the milking robot flowed continuously across a bypass into the milk chamber of the NIR spectrum sensor. Excess raw milk flowed past the milk flow meter and was then released through a line tube into the bucket. The volume of a milk sample in the chamber was about 30 mL. The optical axes of halogen lamps A and B and the optical fiber were set at the same level, but the optical axis for halogen lamp C was set at 5 mm higher the optical fiber (Fig. 2). The NIR instrument acquired absorbance spectra through the milk. Spectra were obtained in the wavelength range from 700 nm to 1050 nm at 1 nm intervals every 20 s during milking (Table 1). The milk flow rate was simultaneously recorded in the laptop computer.

2.2 Cows and Milk Samples

Twenty six Holstein cows belonging to a dairy farm at Tochigi Prefecture, Japan were used for this study. These cows were at their different lactation stages. The experiment was conducted throughout the whole day for two consecutive days, that is; on the 22nd and 23rd of February 2018. Milking was automatically started as soon as a cow walked into the milking robot. Milk samples were collected from the milking sampler every 20 s during milking.

2.3 Reference Analyses

Three major milk constituents (fat, protein and lactose) and somatic cell count (SCC) of non-homogenized milk were measured as milk quality items in this study. The milk constituents were determined using a MilkoScan instrument (Foss Electric, Hillerod, Denmark) and SCC were determined using Fossomatic instrument (Foss Electric, Hillerod, Denmark). The total number of samples used for reference analyses were 377 for milk constituents and SCC.

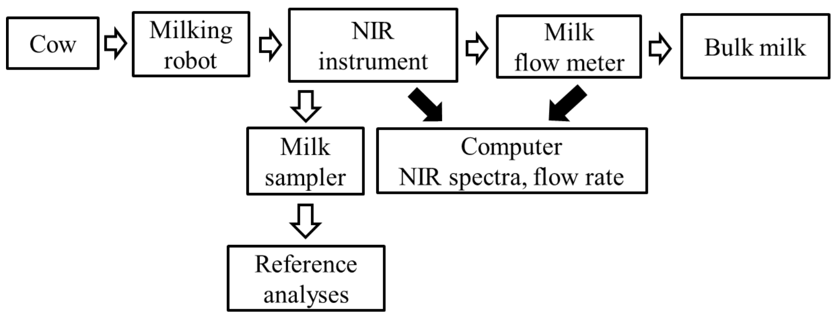

Figure 1. Flow chart of an on-line near-infrared spectroscopic sensing system for determining milk quality in an automatic milking system

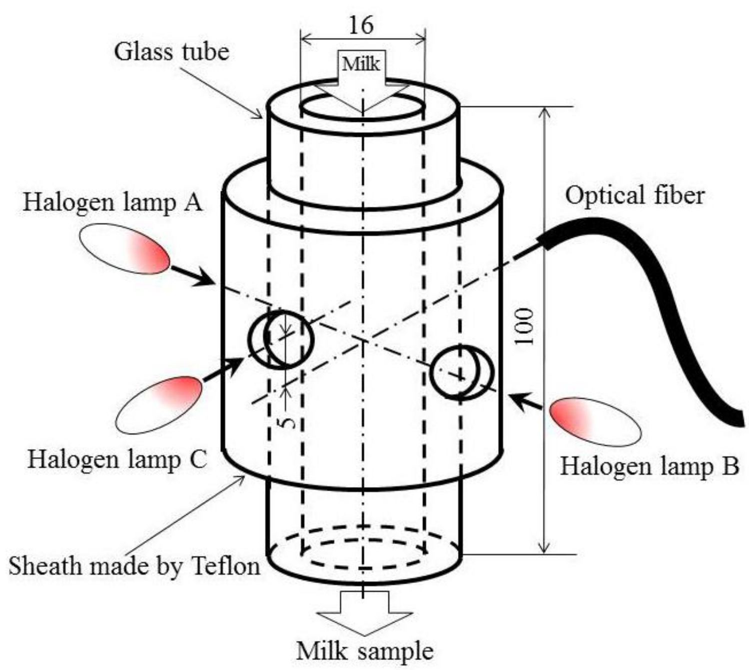

Figure 2. Schematic diagram of the optical system of milk chamber of the NIR spectrum sensor

2.4 Chemometric Analyses

Chemometric analyses were carried out to develop calibration models for milk quality parameters and to validate the precision and accuracy of the models. Spectra data analyses software (The Unscrambler ver. 10.3, Camo AS Trondheim, Norway) was used for the analyses. The total reference samples were used to develop calibration models. The calibration models were validated using full cross validation method. The statistical method of partial least squares (PLS) was used to develop calibration models from the absorbance spectra and reference data. The best model was obtained when we used the original spectra data thus, pretreatment techniques such as multiplicative scatter correction, 2nd derivative and smoothing was not used.

Table 1. Specifications of the near-infrared spectroscopic instrument

Devices	Specifications
NIR spectrum sensor	Absorbance spectrum sensor
Light source	Three halogen lamps
Optical fiber	Quartz Fiber
Milk chamber surface	Glass
Volume of milk sample	Approx. 30 mL
Distance between optical axis and milk level	55 mm
NIR spectrometer	Diffraction grating spectrometer
Optical density	Absorbance
Wavelength range	700 - 1050 nm, 1-nm internal
Wavelength resolution	Approx. 6.4 nm
Photocell	CMOS linear array, 512 pixels
Thermal controller	Heater and cooling fan
Data processing computer	Windows 7
A/D converter	16 bit
Spectrum data acquisition	Every 20 s

3. Results and Discussion

3.1 Near-infrared Spectra

The original spectra of raw milk are shown in Fig. 3. The NIR spectra showed two bands peaks at around 740 nm and 840 nm indicate the overtone absorptions by C-H bands and C-C bands that are related to the distinctive absorption bands of milk constituents such as fat, protein and lactose. There was a strong absorption peak of O-H functional groups in water such that band around 960 nm were prominent spectra.

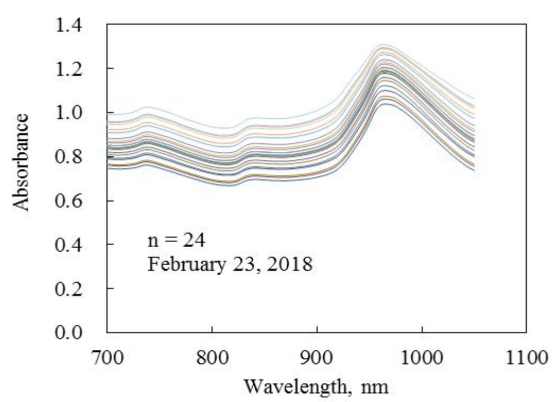

Figure 3. Original spectra of non-homogenized milk from cow number 1 during milking on February 23, 2018

3.2 Precision and Accuracy of Calibration Model

The validation statistics of the NIR sensing system for milk quality determination are summarized in Table 2. Correlations between reference and NIR-predicted values of milk fat, protein, lactose and SCC are shown in Figures 4 to 7 respectively.

The three major milk constituents are vital for milk quality determination. The quality of milk constituents are influenced by the physiological condition of each cow and cow feed. Thus, monitoring of milk constituents during milking everyday can be used for individual cow and feed management. The coefficient of determination (r^2), standard error of prediction (SEP) and bias were 0.98, 0.23% and 0.00% for fat, 0.72, 0.25% and 0.00% for protein, and 0.54, 0.15% and 0.00% for lactose respectively. The high r^2 values, small SEP values and the negligible bias values (zero) indicated that there were sufficient levels of precision and accuracy for predicting the three major milk constituents. The performance of calibration models for fat was excellent. The high performance of calibration model for fat was due to the fact that milk spectra had much information on fat content, starting from the scattering of light by fat globules to the absorption by C-H bands and C-C bands of triacylglycerol. The results showed that the NIR spectroscopic sensing system designed in our study can be used for online real-time milk constituent quality determination during milking by a milking robot.

SCC is a recognized standard for mastitis diagnosis and it is a very important indicator for health and milk quality. Milk SCC can show the level of cow infection and it consequence on the mammary gland of dairy cows which is related to mastitis (Satu, 2003). Milk produced from the udder of a healthy cow contains less than 100,000 somatic cells per mL (i.e., 4logSCC/mL) while cows with subclinical mastitis produce milk containing more than 200,000 somatic cell per mL (i.e., 5.3logSCC/mL) (Satu, 2003). The values of r^2, SEP and bias for SCC were 0.63, 0.48 Log SCC/mL and 0.00 Log SCC/mL respectively. The results obtained for SCC indicated that the precision and accuracy for predicting SCC was sufficiently high. Thus, the calibration model could be used for the diagnosis of subclinical mastitis

3.3 Dairy Precision Farming

The installation of NIR spectroscopic sensing system developed in our study into a milking robot system would facilitate the monitoring of milk constituents and diagnosis of mastitis of individual cows in real-time during milking. The NIR sensing system could provide dairy farmers and veterinarians useful information on milk quality and physiological status of each cow and thus, give them assessment control for improving dairy farm management. The application of this NIR sensing system could take dairy farm management to the next level of dairy precision farming on the basis of individual cow information.

4.0 Conclusions

The NIR spectroscopic sensing system developed in this study can be used for online real-time monitoring of fat, protein, lactose and SCC during milking by a milking robot with sufficiently high levels of precision and accuracy. By application, the NIR sensing system would enable dairy farmers to be able to produce high-quality milk and dairy precision farming will be actualized.

5.0 Acknowledgement

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Table 2. Validation statistics of the near-infrared sensing system for milk quality determination

Milk quality items	n	Range	r^2	SEP	Bias	Regression
Fat, %	377	0.98-8.54	0.98	0.23	0.00	y = 1.00 x + 0.00
Protein, %	377	2.73-4.46	0.72	0.25	0.00	y = 0.99 x + 0.04
Lactose, %	377	3.91-4.99	0.54	0.15	0.00	y = 0.98 x + 0.08
SCC, log SCC/mL	377	3.48-6.56	0.63	0.48	0.00	y = 0.98 x + 0.09

n: number of validation samples. r^2: coefficient of determination. SEP: standard error of prediction. Regression line: Regression line from predicted value (x) to reference value (y)

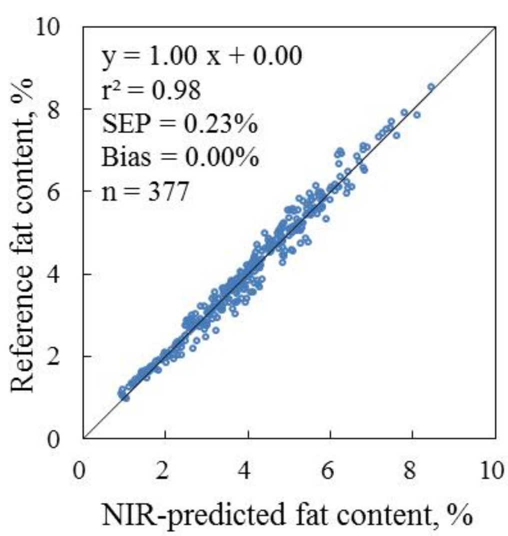

Figure 4. Correlation between reference fat content and NIRS-predicted fat content

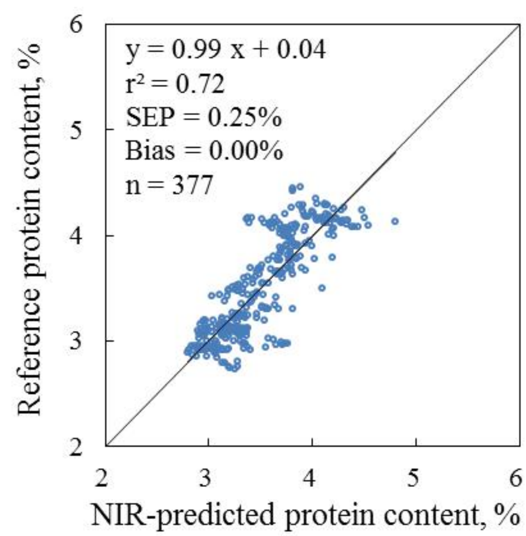

Figure 5. Correlation between reference protein content and NIRS-predicted protein content

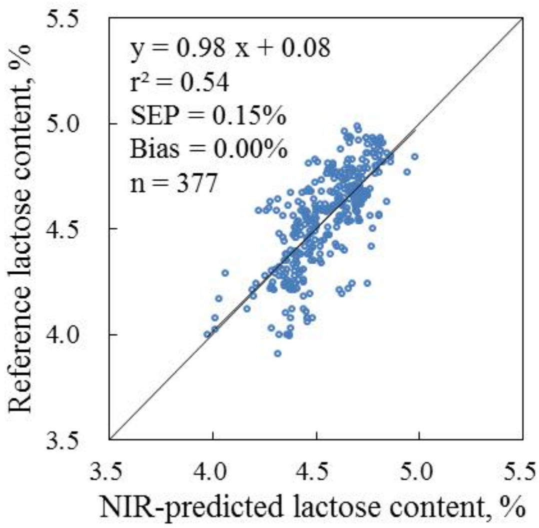

Figure 6. Correlation between reference lactose content and NIRS-predicted lactose content

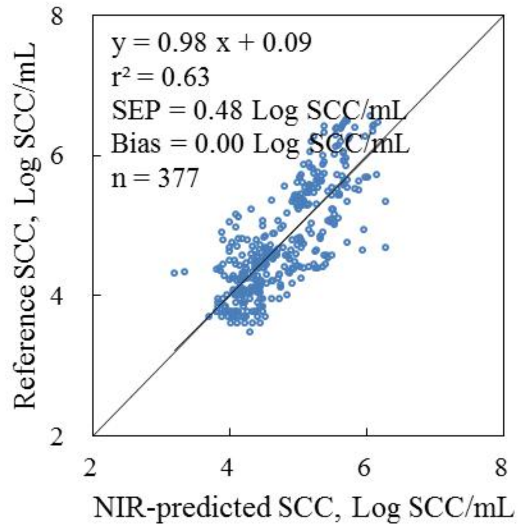

Figure 7. Correlation between reference SCC and NIRS-predicted SCC

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