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Cow Milk Quality Determination Using Near-Infrared Spectroscopic Sensing System for Smart Dairy Farming †

Patricia Iweka [1,*], Shuso Kawamura [1], Tomohiro Mitani [2,*] and Takashi Kawaguchi [3]

1 Graduate School of Agricultural Science, Hokkaido University, Japan; shusokawamura@gmail.com
2 Field Science for Northern Biosphere, Hokkaido University, Japan
3 Orion Machinery Co., Ltd., Nagano, Japan; kawaguchi-takashi@orionkikai.co.jp
* Correspondence: patricia.iweka.agric@gmail.com (P.I.); tmitani@agr.hokudai.ac.jp (T.M.)
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Abstract: This study investigated the accuracy of a near-infrared spectroscopic sensing system for predicting milk quality indicators in cow milk. The system determined three major milk quality indicators (milk fat, protein, and lactose), milk urea nitrogen (MUN), and somatic cell count (SCC) of two Holstein cows at Hokkaido University dairy farm. The results showed excellent accuracy for milk fat and protein contents, while sufficient accuracy for lactose, MUN, and SCC. This suggests that the NIR spectroscopic sensing system could be used for online real-time milk quality determination, aiding dairy farmers in effective individual cow management and smart dairy farming.

Keywords: near-infrared spectroscopy; sensing system; calibration models; milk quality; milk urea nitrogen; somatic cell count; smart dairy farming

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1. Introduction

Smart dairy farming technologies are used to continually and in real time determine cattle milk and health quality indicators in order to maximize nutrition, productivity and to discover health problems at an early stage [1–4]. The ability to determine the three major milk quality indicators such as milk fat, protein, lactose, and milk urea nitrogen (MUN) which is the nutritional indicator, and also somatic cell count (SCC) which is the mastitis disease indicator from milk samples taken during milking using near-infrared spectroscopy (NIRS) has grown in popularity [5–7].

NIRS is an appropriate technology for assessing milk quality during the milking process due to its non-invasive, quick, user-friendly, time-saving, and pretreatment-free characteristics [8]. NIRS has been utilized to determine agricultural items such as rice, wheat, pomegranate, and other vegetables, and to offer qualitative and quantitative information [9–12]. In Japan, NIRS has been used to determine rice quality [9].

Quite a number of studies have been carried out on the development of online near-infrared (NIR) sensing systems that could help dairy farmers to navigate the challenges that comes with individual cow management but there has been a difficulty in developing an efficient and sustainable NIR sensing system [13–16]. According to Iweka et al., [17,18], the NIR spectroscopic sensing system developed could be used to determine the milk quality of individual cow during milking in real-time with acceptable precision and accuracy. However, the practical use of NIRS for real-time online determination of individual cows during milking has yet to be realized. One of the major reasons is the measurement accuracy of the sensing system [19].

Therefore, we developed an experimental online NIR spectroscopic sensing system for milk quality determination of individual cow during milking. The goal of this study was to investigate the precision and accuracy of the novel NIR spectroscopic sensing system developed in our study for individual cow milk quality determination in every 20 s during milking.

2. Materials and Methods

2.1. Description of the Near-Infrared Spectroscopic Sensing System

To determine the quality of each cow's milk during milking, an experimentally-based online NIR spectroscopic sensing system was created. The system included an NIR spectrum sensor, an NIR spectrometer, a milk flowmeter, a sampler, and a laptop (Figures 1 and 4). The system was linked between a teatcup cluster and the milking system's milking bucket. Through a bypass, raw milk from the teatcup cluster was constantly flowing into the milk chamber (sample cell) of the NIR spectrum sensor. The extra milk flowed down a line tube past the milk flowmeter and into the bucket (Figures 1 and 4). The volume of the milk in the NIR milk chamber is about 30 mL (Table 1). The optical axes of halogen lamps A and B were positioned at the same height as the optical fiber, whereas the optical axes of halogen lamp C were set 5 mm higher (Figures 2 and 3). The milk chamber of the NIR spectrum sensor has a path-length of 100 mm with a diameter of 16 mm (Figure 2). The NIR spectrum sensor collected absorbance spectra via the milk. Spectra data were taken at 1 nm intervals every 20 s during milking in the 700 nm to 1050 nm wavelength range. The milk flow rate was also recorded on the laptop computer.

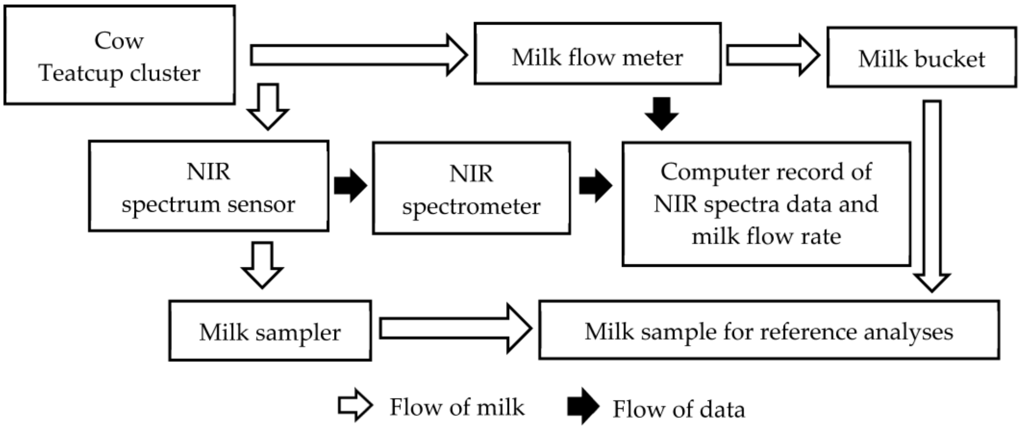

Figure 1. Flow chart of an on-line real-time near-infrared spectroscopic sensing system for determining milk quality indicators during milking.

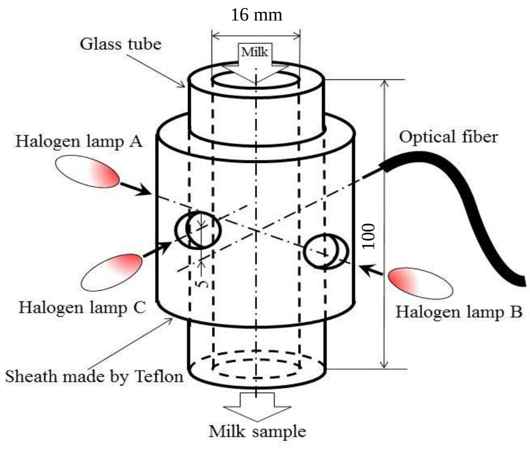

Figure 2. Schematic of the optical system of the milk chamber of the NIR spectrum sensor.

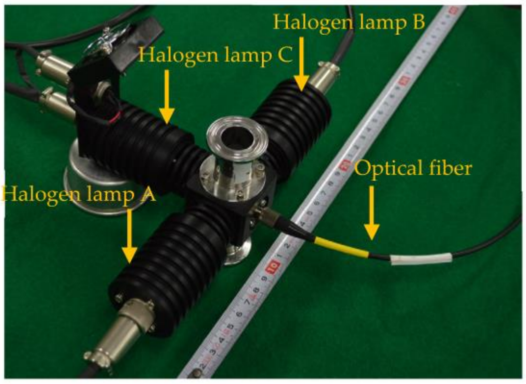

Figure 3. Original NIR spectrum sensor.

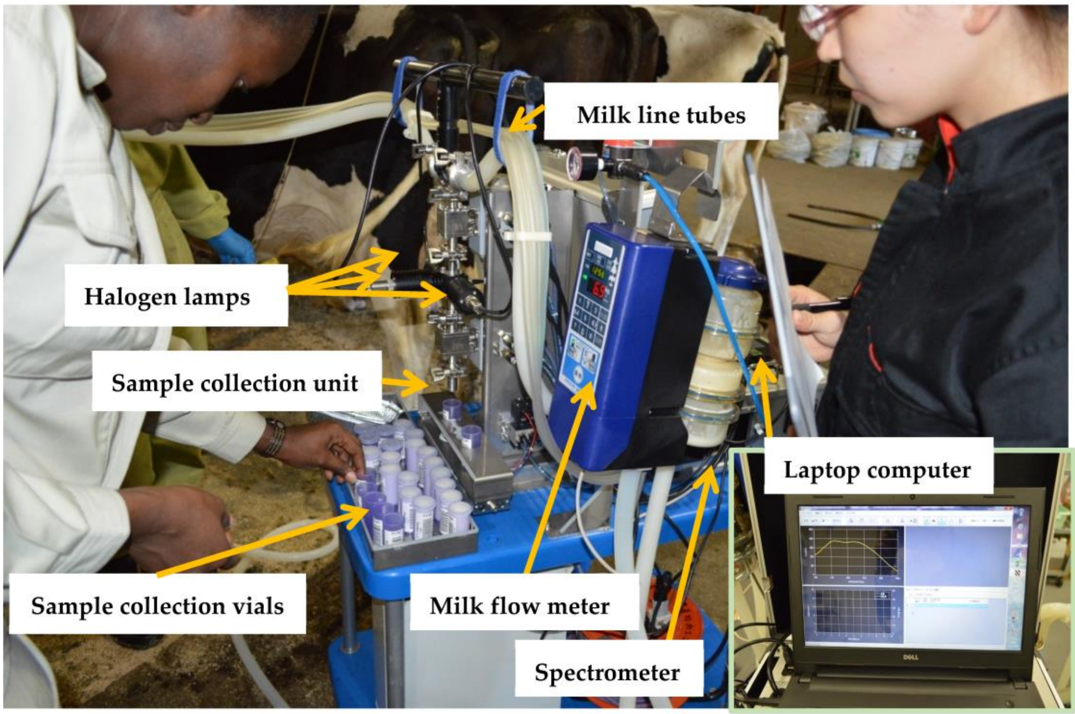

Figure 4. Overview of the NIR spectroscopic sensing system.

2.2. Holstein Cows and Milk Samples

In this study, we used two Holstein cows belonging to Hokkaido University dairy barn, Japan. The lactation phases of these cows varied. During the experiment, the measurements were taken during two consecutive milkings, one in the evening and one in the morning. In the Hokkaido University dairy farm, cows were milked using a pipeline milking system. Milk spectra and flow data were collected, and raw milk samples were drawn from the milk sampler every 20 s during milking.

2.3. Reference Analysis

MilkoScan instrument was used to determine the three major milk quality indicators and MUN while Fossomatic instrument was used for SCC. Both instruments are from Foss Electric, Hillerod, Denmark. A total of 142 milk samples were used for the reference analyses.

2.4. Chemometric Analysis

Statistical analyses were performed to develop calibration models for each milk quality indicators and to confirm the precision and accuracy of the models. The analyses were carried out using the spectra data analysis technique, the Unscrambler ver. 10.3 from Camo AS Trondheim, Norway. The total data from the reference analyses were used to develop calibration using the full cross validation method. The calibration models were built using the partial least squares regression (PLSR) method from the absorbance spectra and reference data. No data pretreatment method was used for this analysis.

Table 1. Specifications of the near-infrared (NIR) 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 raw milk spectra are shown in Figure 5. The NIR spectra indicated two bands, with peaks at 740 and 840 nm, respectively. These bands reflect overtone absorptions by C-H and C-C bands, which are linked to the distinct absorption bands of milk components such as fat, protein, and lactose. The O-H functional groups in water showed a significant absorption peak in water which distinguished the spectra band around 960 nm [15].

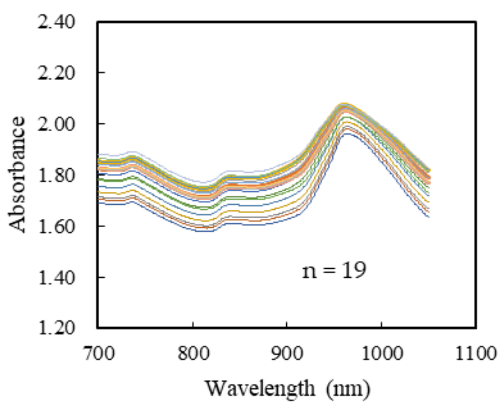

Figure 5. Original spectra of raw milk from cow number 1256 during milking.

3.2. Calibration Models Precision and Accuracy

Table 2 summarizes the validation results of the NIR spectroscopic sensing system for the quality determination of milk quality indicators. The correlations between reference and NIR predicted values of the milk fat content and SCC are shown in Figures 5 and 6 respectively.

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

Milk Quality Indicators	n	Range	R^2	SEP	Bias	RPD	Regression Line
Fat (%)	142	2.1–6.8	0.98	0.12	0.00	8.05	y = 1.00 x + 0.01
Protein (%)	142	3.3–3.8	0.92	0.03	0.00	3.58	y = 0.99 x + 0.04
Lactose (%)	142	3.9–4.7	0.70	0.09	0.00	1.83	y = 0.96 x + 0.18
MUN (mg/dL)	142	8.9–13.8	0.45	0.60	0.00	1.35	y = 0.92 x + 0.97
SCC (log SCCmL^{-1})	142	5.2–6.8	0.60	0.22	0.00	1.58	y = 0.94 x + 0.36

n: number of validation samples. R^2: coefficient of determination value of validation set. SEP: standard error of prediction. RPD: Ratio of SEP to standard deviation of reference data. Regression line: Regression line from predicted value (x) to reference value (y). MUN: Milk urea nitrogen. SCC: Somatic cell count.

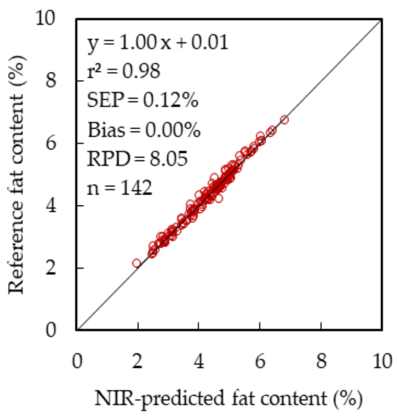

Figure 5. Correlation between reference fat content and NIRS-predicted fat content.

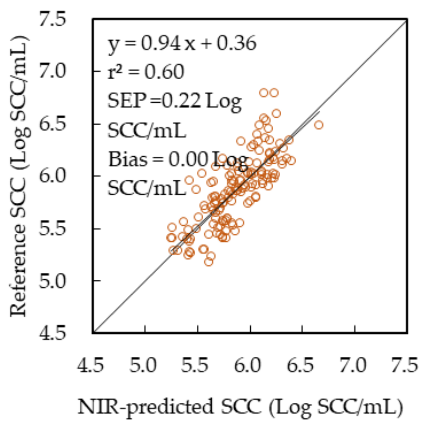

Figure 6. Correlation between reference SCC and NIRS-predicted SCC.

For predicting milk fat, protein, lactose, MUN and SCC, the coefficient of determination (r^2), standard error prediction (SEP), and bias were 0.98, 0.12% and 0.00% for milk fat content, 0.92, 0.03% and 0.00% for milk protein content, 0.70, 0.03% and 0.00% for milk lactose, 0.45, 0.60% and 0.00 mg/dL for MUN, and 0.60, 0.22 log SCC/mL and 0.00 log SCC/mL respectively. The high r^2 values, low SEP and bias values were indicative of high precision and accuracy. The calibration model for milk fat performed very well. The exceptionally high accuracy was made possible by the fact that triacylglycerol's carbon-hydrogen strings were well-represented in NIR spectra. These findings suggested that the NIR could be used to determine the three major milk quality indicators of raw milk, and MUN and SCC of each cow during milking. The level of precision and accuracy for predicting SCC was adequate. SCC is a globally recognized indicator of cow subclinical mastitis disease, and the calibration model created for SCC could be used to diagnose subclinical mastitis.

3.3. Near-Infrared Sensing System

The accuracy for determining the three major milk quality indicators, MUN and SCC was very good most especially for milk fat and protein as compare to the accuracy of the previous NIR sensing system [6]. The cylindrical structure of the NIR spectrum sensor contributed to the high accuracy by reducing the effect of air bubbles and fluctuations in milk flow. Another explanation is that the NIR spectroscopic sensing system used in our work has three halogen lamps that were used as near-infrared light sources to irradiate the milk samples from three directions with an exposure length of 200 msec, which was repeated ten times in one experimental run. It was discovered that our NIR sensor which is comprised of three halogen lamps accurately collected the near-infrared light by fat content, as opposed to the prior study's single halogen lamp [6]. As a result, a strong signal was produced. The exposure time ensured that the important bright part of the captured spectra was not lost, resulting in a reduction in various random and fixed pattern noise.

This indicates that the NIR sensing system might provide dairy farmers and vets with useful information on each cow's physiological state and milk quality, giving evaluation control for better dairy farm management. Deploying data from each cow, dairy farm management might proceed to the next step of smart dairy farming by using this NIR sensing technology.

4. Conclusions

The NIR spectroscopic sensing system created in this study might be utilized to determine the three major milk quality indices, MUN and SCC, of each cow during milking in real time. More work needs to be done and future research should be undertaken to improve the precision and accuracy of the proposed calibration models, allowing for the practical implementation of this NIR sensing technology, resulting in smart dairy farming.

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Data Availability Statement: The content of this paper summarizes all the new data obtained in this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Evangelista, C.; Basirico, L.; Bernabucci, U. An Overview on the Use of Near Infrared Spectroscopy (NIRS) on Farms for the Management of Dairy Cows. *Agriculture* **2021**, *11*, 296. https://doi.org/10.3390/agriculture11040296.
2. Diaz-Olivares, J.A.; Adriaens, I.; Stevens, E.; Saeys, W.; Aernouts, B. Online Milk Composition Analysis with an On-farm Near-infrared Sensor. *Comput. Electron. Agric.* **2020**, *178*, 105734. https://doi.org/10.1016/j.compag.2020.105734.
3. Zhu, Z.; Lin, B.; Zhu, X.; Guo, W. A Rapid Method of Identifying Mastitis Degree of Bovines Based on Dielectric Spectra of Raw milk. *Food Qual. Saf.* **2023**, *7*, fyad014. https://doi.org/10.1093/fqsafe/fyad014.
4. Iweka, P.; Kawamura, S.; Mitani, T.; Yamaguchi, T.; Koseki, S. Near-infrared Spectroscopic Sensing System for Online Real-time Milk Quality Evaluation in an Automatic Milking System. In Proceedings of the The Seventh Asian NIR Symposium (ANS 2020), Khonkaen, Thailand, 12–15 February 2020.

5. Tsenkova, R.; Atanassova, S.; Morita, H.; Ikuta, K.; Toyoda, K.; Iordanova, K.I.; Hakogi, E. Near Infrared Spectra of Cows' Milk for Milk Quality Evaluation: Disease Diagnosis and Pathogen Identification. *J. Near Infrared Spectrosc*. **2006**, *14*, 363–370. https://doi.org/10.1255/jnirs.661.
6. Kawasaki, M.; Kawamura, S.; Tsukahara, M.; Morita, S.; Komiya, M.; Natsuga, M. Near-infrared spectroscopic sensing system for on-line milk quality assessment in a milking robot. *Comput. Electron. Agric.* **2008**, *63*, 22–27. https://doi.org/10.1016/j.compag.2008.01.006.
7. Iweka, P.; Kawamura, S.; Mitani, T.; Yokoe, M.; Okatani, T. Effect of Milking Season on the Accuracy of Calibration Models for Milk Quality Determination using Near-infrared Spectroscopic Sensing System during Milking. In Proceedings of the The 5th Asian NIR Symposium, Kagoshima, Japan, 30 November–3 December 2016.
8. Iweka, P.N. Development of Near-Infrared Spectroscopic Sensing System for Online Real-Time Monitoring of Milk Quality during Milking. Ph.D. Thesis, Hokkaido University, Sapporo, Japan, 25 September 2019. Available online: https://eprints.lib.hokudai.ac.jp/dspace/bitstream/2115/75864/1/Iweka_Patricia_Nneka.pdf (accessed on).
9. Ohtsubo, K.; Kobayashi, A.; Shimizu, H. Quality evaluation of rice in Japan. *JARQ* **1993**, *27*, 95–101.
10. Du, Z.; Tian, W.; Tilley, M.; Wang, D.; Zhang, G.; Li, Y. Quantitative assessment of wheat quality using near-infrared spectroscopy: A comprehensive review. *Compr. Rev. Food Sci Food Saf.* **2022**, *21*, 2956–2009. https://doi.org/10.1111/1541.4337.12958.
11. Opara, U.L.; Arendse, E. Near-Infrared Spectroscopy for Pomegranate Quality Measurement and Prediction. In *Nondestructive Quality Assessment Techniques for Fresh Fruits and Vegetables*, Pathare, P.B., Rahman, M.S. Eds.; Springer: Singapore, 2022; pp. 211–232. https://doi.org/10.1007/978-981-19-5422-1_10.
12. Nicolaï, B.M.; Defraeye, T.; Ketelaere, B.; Herremans, E.; Hertog, M.L.; Saeys, W.; Torricelli, A.; Vandendriessche, T.; Verboven, P. Nondestructive measurement of fruit and vegetable quality. *Annu. Rev. Food. Sci. Technol.* **2014**, *5*, 285–312. https://doi.org/10.1146/annurev-food-030713-092410.
13. Tsenkova, R.; Atanassova, S.; Morita, H.; Ikuta, K.; Toyoda, K.; Iordanova, I.; Hakoji, E. Near infrared spectra of cow's milk for milk quality evaluation: Disease diagnosis and pathogen identification. *J. NIRS* **2006**, *14*, 363–370. https://doi.org/10.1255/jnirs.661.
14. Iweka, P.; Kawamura, S.; Mitani, T.; Koseki, S. Non-destructive determination of bovine milk progesterone concentration during milking using near-infrared spectroscopy. *CIGR J.* **2020**, *22*, 171–178.
15. Ozaki, Y.; McClure, W.F.; Christy, A.A. *Near-Infrared Spectroscopy in Food Science and Technology*, 1st ed.; Wiley: Hoboken, NJ, USA, 2006. https://doi.org/10.1002/0470047704.
16. Sato, T.; Yoshino, M.; Furukawa, S.; Someya, Y.; Yano, N.; Uozumi, J.; Iwamoto, M. Analysis of Near Infrared Milk Constituents by the Spectrophotometric Method. *Jpn. J. Zootech. Sci.* **1987**, *58*, 698–706.
17. Iweka, P.; Kawamura, S.; Mitani, T.; Kawaguchi, T.; Koseki, S. Cow Milk Progesterone Concentration Assessment during Milking Using Near-infrared Spectroscopy. *EAEF* **2021**, *14*, 30–36. https://doi.org/10.37221/eaef.14.1_30.
18. Iweka, P.; Kawamura, S.; Mitani, T.; Kawaguchi, T.; Koseki, S. Online Milk Quality Assessment during Milking Using Near-infrared Spectroscopic Sensing System. *Environ. Control Biol.* **2020**, *58*, 1–6. https://doi.org/10.2525/ecb.58.1.
19. Iweka, P.; Kawamura, S.; Mitani, T.; Koseki, S. Effect of Cow Individuality and Calving times on accuracy of near-infrared spectroscopic sensing system for milk Quality Determination during Milking. In Proceedings of the 33rd NIR Forum, JCNIRS; Japan Council of NIR Spectroscopy: Tsukuba, Japan, 2017; p. 83.