COMBINATION OF HYPERSPECTRAL IMAGING AND R STATISTICS FOR MONITORING MOISTURE IN JAPANESE BIG SAUSAGES UNDER DIFFERENT STORAGE CONDITIONS

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I. INTRODUCTION

Hyperspectral imaging (HSI), as an emerging technique and non-destructive detection method, combines spectroscopy and imaging for obtaining spectral and spatial information simultaneously from a subject [1]. Moisture content is a very important chemical attribute for sausage that can profoundly influence water activity, water holding capacity and microbial growth that related to shelf life of the processed meat products. Heretofore, the moisture content of meat has been determined conventionally by oven drying, microwave drying, freeze drying, and infrared moisture analysis [2]. These methods commonly depend on the average value of the samples. Therefore, a precise, rapid, and non-contact analytical method or tool is highly demanded to monitor moisture and HSI possesses the potential to address this issue. The environmental temperature of summer in Japan can reach up to 35 ^{o}C where the sausages can be spoiled. The objective of current study is to develop a simplified moisture prediction model of cooked big Japanese sausages stored in different conditions (4 ^{o}C, 35 ^{o}C for d1, 4, 7) based on partial least squares regression (PLSR) of HSI data. Accordingly, the optimal wavelengths will be identified and pixel-wise image processing algorithms will be developed for distribution maps.

II. MATERIALS AND METHODS

In total, 64 big cooked pork sausage slices (diameter: 8.86 ± 0.37 cm; thickness: 0.12 ± 0.20 cm; mass: 6.85 ± 0.12 g) were purchased from a local supermarket (Platinum Don Quijote, Shirokanedai, Tokyo, Japan). The samples were randomly divided for storage in 4 ^{o}C (11 slices); 35 ^{o}C for d1 (14 slices), d4 (13 slices) and d7 (26 slices), respectively. The detailed information of the system and acquisition processing can be found in Feng et al. [3]. Forty-three samples were used for a calibration group while twenty-one samples were employed for a validation group. Spectral data were analysed by using Unscrambler software (X 10.3, CAMO Software Inc., Trondheim, Norway). The coefficients of determination (R_c^2 for calibration and R_p^2 for prediction) and root mean square error (RMSEC for calibration and RMSEP for prediction) were used to evaluate the precision and predictive capabilities of the model. Distribution map was obtained by conducting a program written in a R (Version 3.4.3, GNU project, The R Project for Statistical Computing).

III. RESULTS AND DISCUSSION

The moisture values of Japanese big cooked sausages were predicted using PLSR from the spectral data using the full spectra range (380-1000nm). Models derived from raw spectra performed satisfactory outcome, with R_c^2 of 0.84 and RMSEC of 0.47. According to the large absolute values of regression coefficients, ten wavelengths (385, 410, 425, 445, 580, 655, 815, 905, 935, 970 nm) were selected as feature wavelengths [Fig. 1(a)]. It was reported that the subtle absorption bands (i.e. 780 and 980 nm) were related to the water absorption bands and corresponding to the third and second overtones of O-H stretching [4]. A new PLSR model based on the feature wavelengths was developed as follows:

$$Y_{moisture} = 65.16 + 440.1\,\lambda_{385} - 333.1\,\lambda_{410} - 613.2\,\lambda_{425} + 511.1\,\lambda_{445} + 76.48\,\lambda_{580} - 144.4\,\lambda_{655} - 3.625\,\lambda_{815} + 118.1\,\lambda_{905} + 373.4\,\lambda_{935} - 515.84\,\lambda_{970} \quad (1)$$

where Y is the predicted moisture value while λ_{xnm} is the reflectance spectra at the wavelength of x nm. Although model developed by feature wavelengths showed slightly lower precision due to the decreased variables (R_c^2 = 0.78; RMSEC = 0.54), approximate 92% of wavelengths were reduced from the full wavelengths, which could be used to obtain the distribution map.

The predicted moisture values of sausages stored in different conditions were illustrated using a linear colour scale from blue to red [Fig. 1 (b)]. Upper row shows the four RGB images for different storage conditions and it is difficult to identify based on the naked eyes. Despite the differences between each sample with different storages were very small (up to 3.55%) as samples were packaged, distribution maps can still display the how much and where the different moisture values were located from spot to spot in different samples. In this work, the distribution map was for the first time produced by R statistics. Compared to Matlab, R statistics has free open access and so can be used by a wider group of researchers. It can also provide the predicted average value based on the inputted models, which may provide useful information for future research work.

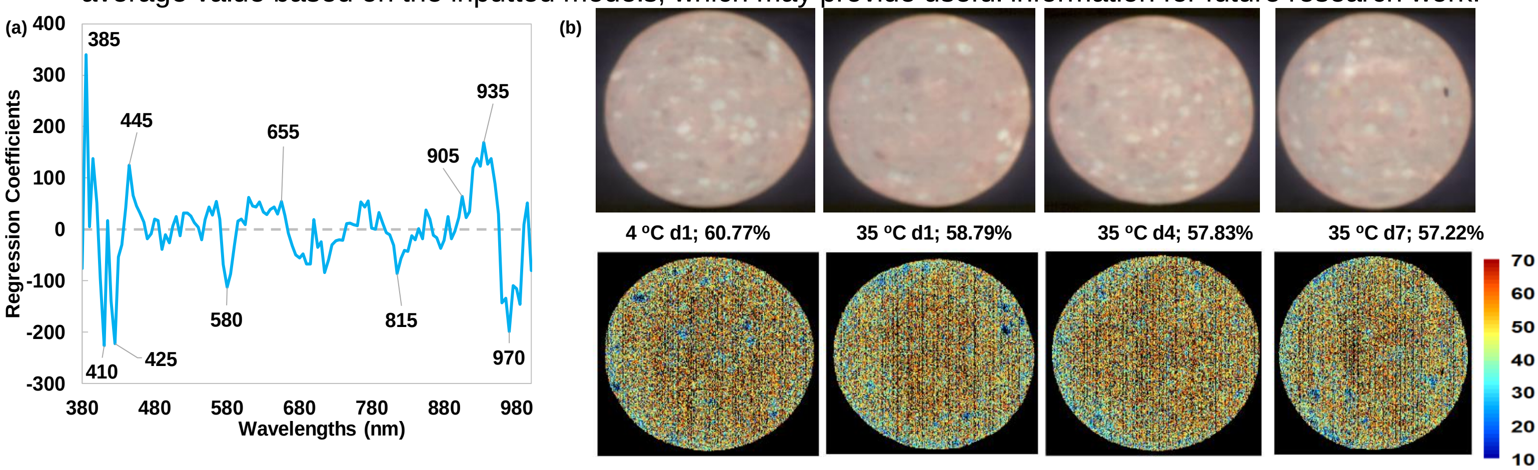

Figure 1. Feature wavelengths selection from the partial least square regression model (a) and RGB images and visualisation of moisture distribution map for sausages storage with difference conditions and moisture content (b).

IV. CONCLUSION

Ten important wavelengths (385, 410, 425, 445, 580, 655, 815, 905, 935, 970 nm) were selected according to the regression coefficients developed from the PLSR models. Feature wavelengths selection may facilitate the online industrial applications and may be applied to a simple cost-effective multispectral system. Distribution maps were for the first time developed by R statistics to visualise the moisture variation of sausages under different storage conditions. The overall results suggest that HSI possessed not only powerful prediction ability but also fast analysis in online and off-line inspections.

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