

Analyses of blended fabrics by near-infrared spectroscopy: fibre identification and determination of blend ratios

Akihiro Shigetani,^a Norio Yoshimura^b and Masao Takayanagi^{b,*}

^aGraduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8, Saiwai-cho, Fuchu, Tokyo 183-8509, Japan

^bInstitute of Symbiotic Science and Technology, Tokyo University of Agriculture and Technology, 3-5-8, Saiwai-cho, Fuchu, Tokyo 183-8509, Japan.

E-mail: masaot@cc.tuat.ac.jp

Introduction

Fibre identification of blended fabrics and determination of their blend ratios are critical issues in the control of conformity of textile products, and in quality checks in the market. Non-destructive, quick and simple test methods of blended fabrics are required, because existing reference analytical methods for indentifying and quantifying fabrics are destructive and time-consuming. Moreover, some of them require the use of undesirable chemicals to dissolve fibres. In this study, we have developed a new useful technique, as a replacement for existing tests by applying near-infrared (NIR) spectroscopy and chemometrics.

Experimental

Fabrics consisting of one, two, or three kinds of fibres among eight general fibres, i.e. cotton, hemp, rayon, silk, wool, polyester (PE), nylon, and acrylonitrile (AN), were used as samples. As the reference analyses, fibres were identified by observing cut planes at fibres constituting the samples under a microscope, while blend ratios of fabrics were calculated by differences of the anhydrous weights between unprocessed samples, and residues after dissolving them in acid and/or organic solutions.

Diffuse reflectance NIR spectra (1200–2400 nm) of the samples were measured on a UV/VIS/NIR spectrometer (V-570D, JASCO, Tokyo, Japan) at a spectral resolution of 1 nm. Five spectra for each sample were averaged to compensate for the inhomogeneity of components and the variation of surface conditions. The spectra were transformed into absorbance units by Kubelka-Munk transformation, and then second derivative spectra were calculated by the Savitzky-Golay method after smoothing.

Data analyses were performed with MATLAB (Mathworks Inc., Natick, USA). Identification of fibres in the fabrics was performed by the combination of MLR (**m**ultiple **l**inear **r**egressions) and PCA (**p**rincipal **c**omponent **a**nalysis), while prediction of blend ratios was performed by MWPLSR (**m**oving-**w**indow **p**artially **l**east **s**quares **r**egressions).

Results and discussion

Identification of fabrics consisting of a single kind fibre

PCA score plots, which are not shown here, were applied to distinguish fabrics consisting of a single type of fibre. Eighty samples (ten samples for each of eight types of fabrics) were used for

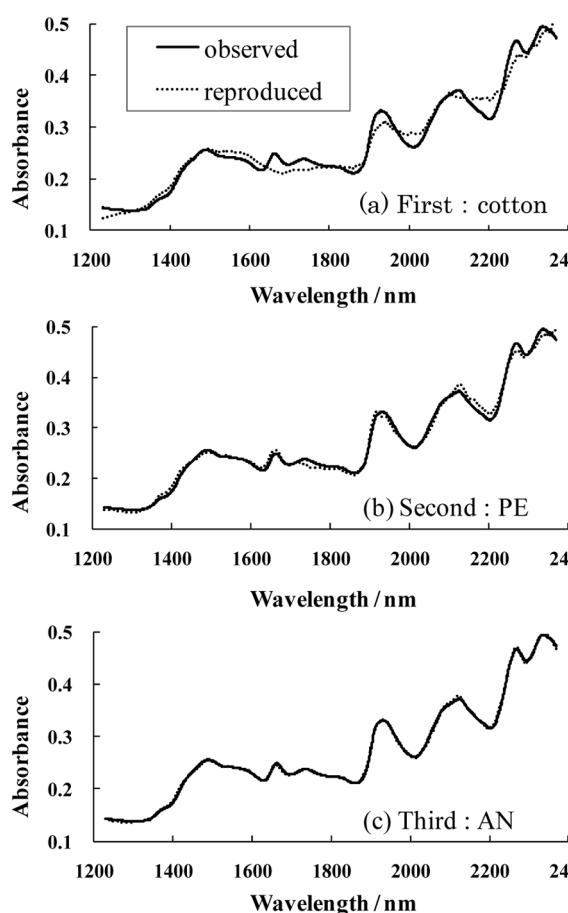


Figure 1. Examples of reproduction of an observed spectrum of a sample consisting of three fibres (cotton, PE, and AN; 60%/25%/15%, w/w). Correlation coefficients for reproduction of observed spectra were used to identify the candidates of components. (a) Reproduction only with the spectrum of cotton ($\gamma = 0.99712$). (b) Reproduction with the spectra of cotton and PE ($\gamma = 0.99918$). (c) Reproduction with the spectra of cotton, PE, and AN ($\gamma = 0.99996$).

the analysis. At first, PCA was performed for second derivatives of the spectra (1230–2370 nm) of all fabrics after being smoothed and mean-centred. On the PC1 vs. PC2 plane, plots for silk, wool, PE, nylon, and AN were found to make separate groups; fabrics of these fibres are clearly distinguishable from one another with the PCA plots. On the other hand, fabrics of cotton, hemp, and rayon, whose plots clustered in an almost inseparable small region, were not distinguishable by the PCA plots. Since the bulk of cotton, hemp, and rayon consists mainly of cellulose, their spectra so resembled one another that they could not be distinguished through the PCA of spectra of all the eight types of fibre. Fabrics of cotton, hemp, and rayon were found to be distinguishable by PCA only in the 1230–1300 nm region of the spectra of the three fabrics, where some differences were observed in the spectra. Even cotton, hemp, and rayon were found to be distinguishable by PCA if the wavelength region is properly selected.

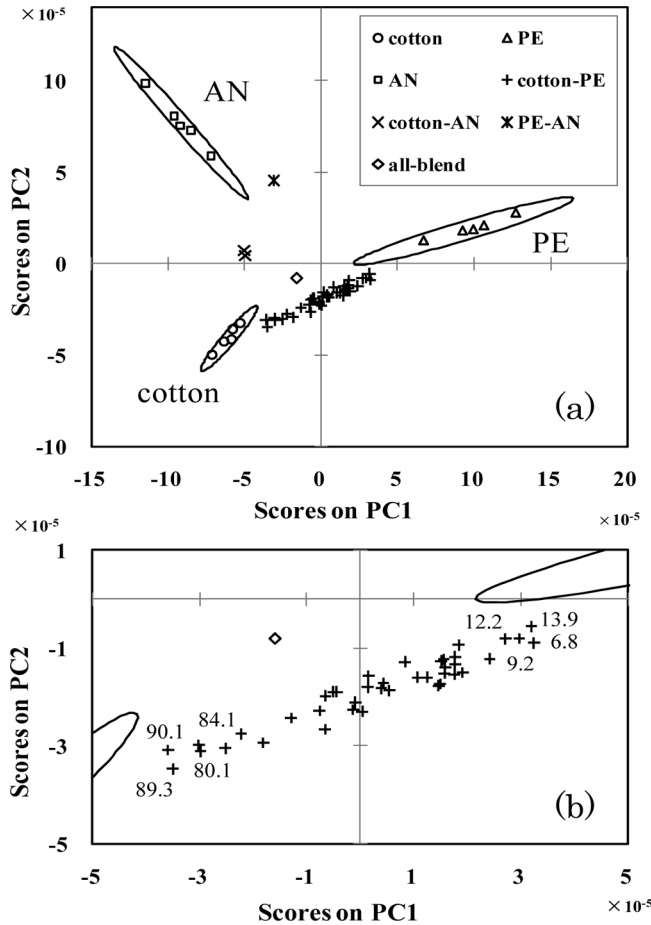


Figure 2. Fibre identification by PCA for blended fabrics made of 1–3 kinds of fibres, i.e. cotton, PE and AN. (a) PCA score plots of cotton-PE-AN blends (validation). Ellipses correspond to the 99.7% confidence areas calculated by pure fibres for calibration. (b) Plots for cotton-PE blends in (a) are shown in expanded scales. Numerical values in the figure represent cotton ratios of some blends.

Identification of fibres in blended fabrics

Fibre identification in blended fabrics was performed in two steps. Firstly, candidates of component fibres were identified by maximizing the correlation between the observed spectrum and the spectrum reconstructed approximately with spectra of pure fabrics measured in advance. These procedures are a kind of MLR, where spectra of blended fabrics are dependent variables, while the spectra of pure fabrics are independent variables. The reconstruction was evaluated with the correlation coefficients between the observed and reconstructed spectra. An example of the reconstruction for an observed spectrum of a fabric consisting of cotton, PE, and AN is shown in Figure 1.

Although accurate fibres constituting the sample fabric could be identified by MLR in this case, it was rather difficult to judge the existence of the trace components only by the MLR analyses, when the blend ratios of the second and/or the third components are low.

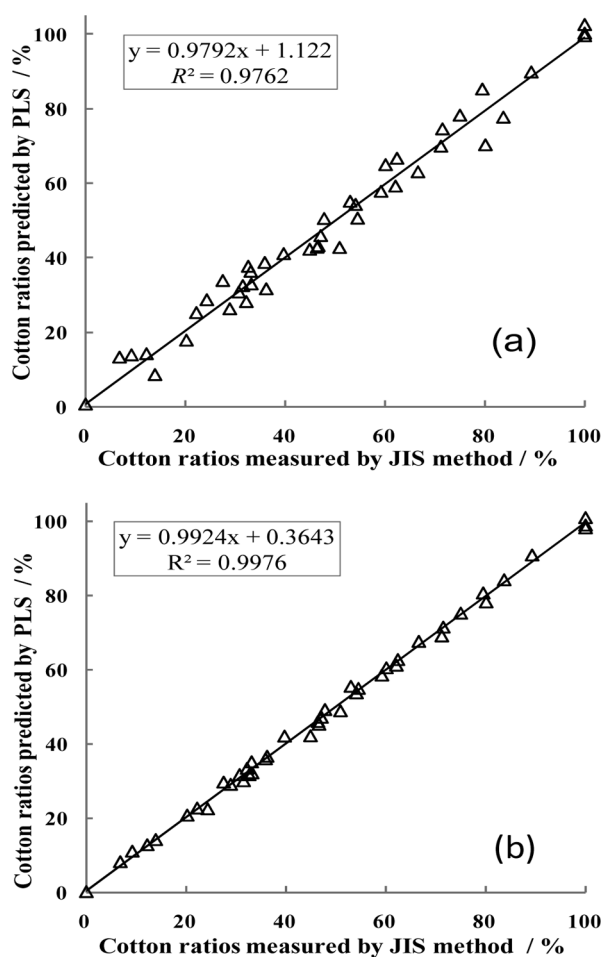


Figure 3. Scatter plots of predicted vs reference values for the cotton ratios in cotton-PE blends. (a) For PLS model constructed with the data in full spectral region. (b) For PLS model constructed with the data in spectral regions selected by MWPLSR.

PCA score plots (Figure 2) on the PC1 vs. PC2 plane for the spectra of candidate fibres were found to be effective to confirm the identification results by MLR. Plots for the blended fabrics were found to spread in the area surrounded by the plots for the fabrics consisting of the single component.

Prediction of blend ratio of cotton-PE blend

Quantitative analyses have been performed so far for the cotton-polyester blends whose blend ratios exist widely. Since quantitative analyses by ordinary PLS with a model constructed with the data in full spectral region did not provide favourable results [Figure 3(a)], MWPLSR was applied.

This procedure builds a series of PLS models in a window that moves over the whole spectral region and then locates useful spectral intervals in terms of the least complexity of PLS models reaching a desiring error level. At each window position, the PLS models with varying PLS component number (latent variable: LV) were built for the calibration samples. The sum of squared residues (SSR) were calculated with these PLS models and plotted as a function of the position of the window. The width of window of 46 nm was applied. Optimum dimensionalities of PLS models were determined by leave-one-out cross validation. Three wavelength regions for effective quantitative analyses were determined through MWPLSR by searching the ranges where small SSR was obtained (Figure 4).

By the PLS model built on the selected regions, estimation of cotton-polyester blended ratios within errors of 1.2% (average) and 2.6% (maximum) could be achieved.

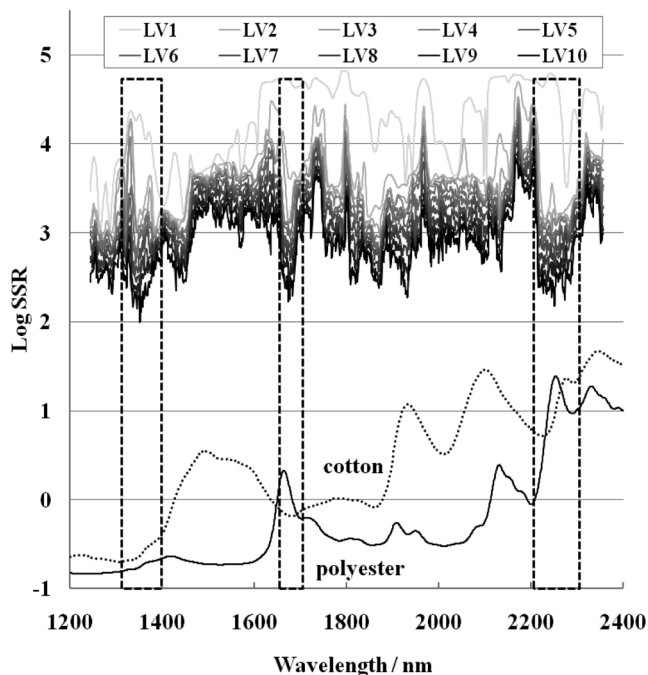


Figure 4. Residue lines obtained by MWPLSR of the spectra of cotton-PE blends for the calibration samples. LV: latent variable.