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主　論　文　の　要　旨

論文題目　Evaluation of Strawberry Quality using Near-Infrared Hyperspectral Imaging (NIR-HSI)
（近赤外ハイパースペクトラルイメージングによるイチゴの品質評価）

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論　文　内　容　の　要　旨

Developing non-destructive quality assessment techniques in agriculture enhances our understanding of the connection between human senses and farm products, aiding value determination, breeding, and crop improvement. Despite the development of sugar content sensors, destructive methods still largely dominate. The rise of non-destructive methods could provide accurate sensory evaluation estimates and assess ingredient distribution within farm products, improving quality control and value. In this study, we employed Near-Infrared Spectroscopy (NIR), a non-destructive evaluation technique that irradiates near-infrared light on a sample. Spectroscopy of the transmitted and reflected light discloses molecular vibration characteristics, such as O-H, C-H, and N-H. However, overlapping these absorption bands necessitates using a calibration model, created through analytical methods like chemometrics. Although NIR focuses on a point, the superior transmission properties of near-infrared light facilitate non-destructive measurements. Moreover, Near-Infrared Hyperspectral Imaging (NIR-HSI) expands upon NIR by providing a spatial measurement technique. With its planar spectroscopy characteristic, NIR-HIS is potentially suitable for evaluating agricultural products exhibiting varied spatial qualities.

In this study, we put forward a novel pretreatment in quality evaluation method for strawberry fruit, based on the region of interest (ROI) in the flesh part and the spectral feature differences between the flesh and achene. Other areas of focus include correcting hyperspectral data according to fruit shape, providing a 3D display, and evaluating the entire strawberry fruit surface - all of which have been overlooked in prior strawberry quality evaluation research

using NIR-HSI.

Our approach enables the visualization of the spatial distribution of sugar content in white strawberry fruit flesh, employing NIR-HSI (913–2166 nm). We scrutinized NIR-HSI data sourced from 180 samples of “Tochigi iW1 go” white strawberries. Identifying pixels corresponding to the flesh and achene on the strawberry surface necessitated principal component analysis (PCA) and image processing (PCA imaging), following the data's smoothing and standard normal variate (SNV) pretreatment. We applied Explanatory Partial Least Squares Regression (PLSR) analysis to develop a model to predict Brix reference values. This model, constructed from raw spectra extracted from the flesh ROI, exhibited high predictive accuracy, with root mean square error of prediction (RMSEP) and coefficient of determination of prediction (R^2p) values of 0.576 and 0.841, respectively, and with relatively low number of PLS factors. The Brix heatmap images and violin plots for each sample revealed characteristic sugar content distribution within the strawberries' flesh.

This study also incorporated the use of a line-scan hyperspectral camera and a laser displacement meter to capture the hyperspectral image and shape of strawberries of the 190 samples of “Tochigi i37 go”. Given the influence of the strawberry shape on the recorded hyperspectral image, we devised a method to correct the hyperspectral data. Corrections accounted for the distance through the light attenuation of the inverse square of the distance and the angle using the Lambert Cosine method. Furthermore, this correction changed the characteristics of the spectra. In addition, the flesh was extracted by PCA imaging. We conducted PLSR and optimal model search to validate the shape correction and spectral preprocessing. As a result, the highest prediction accuracy model (R2:0.813, RMSEP:0.687) was constructed after height and angle correction and smoothing spectral preprocessing. Utilizing this PLSR model, we created sugar content estimation mapping images for each condition, which were then compared using the Map score index, developed to assess the quality of the images. The model yielding the highest Map score of 52.5 combined height correction and smoothing spectral processing (R2:0.791, RMSEP:0.727). It was also discerned that second-derivative processing added noise to the images. By combining the mapping image and shape data, we developed a synthesized 3D sugar content image to illustrate the shape and sugar content distribution. In addition, we proposed a Strawberry deviation (T-score) to assess the sugar content value as NIR-HSI estimated.

To visualize sugar content distribution within the strawberry flesh section, we constructed a system where strawberries were affixed to a turntable, and

rotation scan measurements were conducted using a hyperspectral camera and a laser displacement meter. We obtained the 130 samples of “Tochigi i37 go” shape and hyperspectral data. We studied shape correction and spectral preprocessing from these measurements, constructed a PLS model and mapping, and found that the model with height correction and smoothing preprocessing demonstrated good prediction performance (R^2:0.892, RMSEP:0.503) and imaging result. As the measured data represented one full rotation of the fruit, we developed a 3D model for visualizing and understanding the sugar content of strawberry flesh by incorporating an angle and integrating the shape and sugar content mapping results in 3D.

In conclusion, this study successfully visualized the sugar content distribution of white strawberry flesh using NIR-HSI. It utilized PCA imaging to separate the fruit surface from the flesh, facilitating sugar content imaging and distribution evaluation. Additionally, it introduced a method for 3D sugar content imaging of strawberries, incorporating shape measurements into the NIR-HSI method. The study investigated the corrective effects of shape adjustment (height & angle) on hyperspectral data and created a 3D representation of shape and sugar content distribution. We proposed an evaluation method for the NIR-HSI mapping results and introduced a rotation-NIR-HSI method, establishing a complete rotational hyperspectral data measurement process for strawberries. We also developed a 3D model to visualize the sugar content distribution of strawberry flesh. This research's findings can inform practical application methods for tasks such as sorting, breeding, and variety improvement, and extending the shape and objective variables to other internal quality factors (e.g., acidity, sugar-acid ratio) will enable comprehensive quality evaluation.