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Research Note

Comparison of hyperspectral imaging with conventional RGB imaging for quality evaluation of *Agaricus bisporus* mushrooms

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The potential of hyperspectral imaging in the Vis-NIR range (400–1000 nm) for evaluating the quality of button mushrooms was compared to conventional RGB imaging using a digital colour camera. Regression models were built to correlate hyperspectral and RGB imaging data with measured Hunter L colour values. Prediction maps were generated from both hyperspectral and RGB imaging data to compare performance of the models at pixel level. Results presented showed that hyperspectral imaging is more suitable than conventional RGB imaging for evaluating mushroom quality.

1. Introduction

Hunter L-value measurement (Gormley & O'Sullivan, 1975) is the most commonly applied method for mushroom quality grading. Hyperspectral imaging (HSI) is a combination of 2 non-destructive quality evaluation techniques, imaging and spectroscopy (Mahesh, Manickavasagan, Jayas, Paliwal, & White, 2008) to simultaneously acquire both spatial and spectral information from an object. This technology has recently been applied as a process analytical tool for rapid, non-contact and non-destructive inspection of internal and external attributes of food and agricultural products including mushrooms (Gowen, O'Donnell, Cullen, Downey, & Frias, 2007; Taghizadeh, Gowen, & O'Donnell, 2009).

Red-green-blue (RGB) imaging systems are rapid, non-destructive and low-cost tools for the assessment of food product quality. They are widely employed in food quality control for the detection of surface defects and grading operations (Liming & Yanchao, 2010). Applications of such machine vision systems have been investigated for monitoring quality characteristics of a variety of food products such as olive fruit (Diaz, Faus, Blasco, Blasco, & Molto, 2000), cheese (Mateo, O'Callaghan, Gowen, & O'Donnell, 2010) and wheat kernels (Singh, Jayas, Paliwal, & White, 2010). Although conventional RGB imaging systems are valuable for many food grading operations, they can be poor identifiers of surface features sensitive to wavebands other than RGB.

The main advantage of RGB over HSI is its low cost of instrumentation and speed of image acquisition. This could make RGB-based imaging systems an attractive tool for the mushroom industry. Although HSI has been shown to perform well for quality evaluation of mushroom, it has not been compared with conventional RGB imaging for this task. The objective of this research was to compare hyperspectral and RGB imaging for the quality evaluation of mushrooms.

2. Materials and methods

2.1. Sample preparation

Agaricus bisporus mushrooms (Monaghan Mushrooms Ltd., Monaghan, Ireland) were exposed, with corresponding

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temperature changes, to simulated production conditions (including transport from farm to pack-house, and from pack-house to distribution depots and retail units) in October 2009. Mushrooms quality was measured at 3 time points in the production chain (days 2, 4 and 8 after harvest). In total 19 packages (approximately 8 mushrooms per package) were measured on each day; with a total of 57 packages measured over the 3 time points. L-value measurements and HSI and RGB imaging scans were carried out on a subset of 8 mushrooms from each package.

2.2. Hyperspectral imaging system

A hyperspectral imaging system (DV optics, Padua, Italy) in the Vis-NIR range (400–1000 nm) was employed in this study. The main components of this system are: objective lens, spectrograph (spectral resolution = 5 nm), CCD camera (spatial resolution = 580 × 580), acquisition system, moving table, and illumination via fibre optics (Gowen et al., 2007). A black sample holder was designed and used to provide contrast between mushrooms and the background. Eight mushrooms were scanned in each image (see Fig. 3), each scan taking approximately 80 s.

2.3. RGB imaging

RGB images of samples were acquired (sample arrangement shown in Fig. 3) using a digital camera (Canon PowerShot A560, Japan). A fluorescent lamp was used as a light source and the distance from camera to the sample was kept constant (600 mm).

2.4. Colour measurement

Hunter L values were measured using a Minolta Chromameter (CR-400, Minolta Corp., Japan).

2.5. Data processing and analysis

Each image contained 8 mushrooms from which the average spectrum (for each HSI image) and average RGB values (for each RGB image) were calculated. Corresponding average L-values were also calculated, resulting in 2 matrices of independent variables (X_HSI [57,101] and X_RGB [57, 3]) and 1 matrix of dependent variables (Y_L [57,1]) which were used to build prediction models.

Standard normal variate (SNV) and multiplicative scatter correction (MSC) were used as spectral pre-treatments to reduce the influence of scattering effects and other sources of variations such as differences in mushroom sample height and shape. The mean spectrum of each mushroom image was used as the target spectrum for applying MSC.

To estimate the potential of HSI and RGB imaging for mushroom quality evaluation, models for prediction of measured L-values were constructed. Partial least squares regression (PLSR) was applied to the mean raw (no pre-treatment), MSC and SNV pre-treated X data for both HSI and RGB images. Leave one out (LOO) cross validation was applied to the different data sets and root mean square error of cross validation (RMSECV) was calculated.

The 6 developed models (3 RGB-based models no pre-treatment, SNV pre-treated and MSC pre-treated) and 3 HSI based models (no pre-treatment, SNV pre-treated and MSC pre-treated) were then applied to all images to obtain L-value prediction maps as described by Taghizadeh et al. (in press).

3. Results and discussion

Fig. 1 demonstrates the effect of storage time on average HSI and RGB reflectance values. It can be seen that for both HSI and RGB-based data, reflectance values decrease with storage time suggesting the decrease in brightness of mushrooms which is associated with L-value.

The lowest RMSECV for each model is shown in Table 1. The lowest RMSECV for HSI based models was obtained for SNV pre-treated data and values obtained for both no pre-treated and MSC pre-treated PLSR models were very similar. Similar results were also obtained for RMSECV values of RGB-based PLSR models. Overall, HSI based PLSR models performed much better than RGB-based PLSR models when using the same number of latent variables as all RMSECV values obtained for HSI based models were noticeably lower than those of RGB-based models. The low correlation between RGB values and

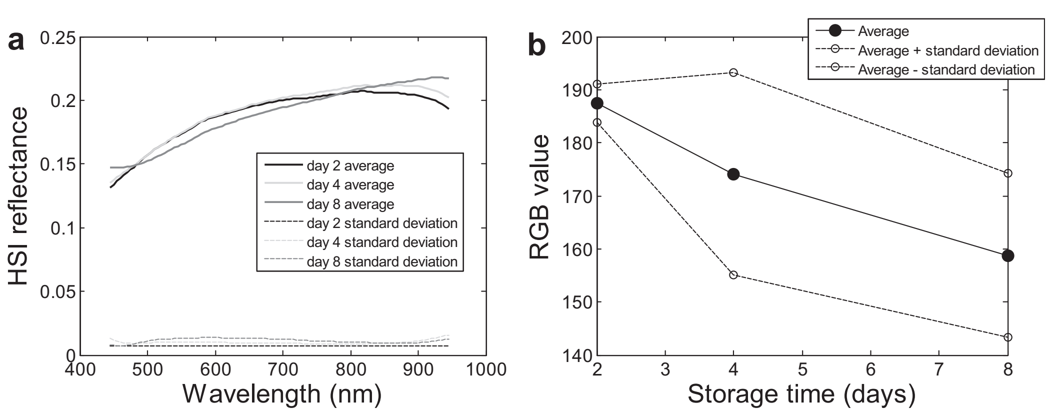

Fig. 1 – Effect of storage time on a) mean HSI reflectance spectra and b) mean RGB reflectance values of mushrooms.

Table 1 – RMSECV versus number of latent variables for different PLSR models based on HSI and RGB datas.

Dataset	Pretreatment	Number of Latent variables	RMSECV
HSI	None	10	2.8
HSI	SNV	7	1.5
HSI	MSC	10	2.8
RGB	None	2	6.0
RGB	SNV	2	2.4
RGB	MSC	3	6.0
RGB average	None	1	2.04

measured Hunter L-values could be due to the lack of a well controlled illumination system to provide homogeneous light emitted to the object. However, this need has been addressed by the application of fibre optics and light diffuser in HSI systems which provide uniform illumination. In addition, no calibration was done prior to RGB image acquisition while a white reference tile was used for both HSI and colorimeters prior to each evaluation.

To aid in the decision of the number of latent variables to include in the SNV pre-treated PLSR models for HSI images, the model was applied to a hypercube and the predicted images with the first 6 latent variables obtained. It was found that above 4 latent variables, the predicted images became noisy due to model over-fitting. Therefore, a 4-component SNV pre-treated PLSR model was selected for HSI analysis. The RMSECV corresponding to 4 LVs was 1.7.

For the RGB data, a linear regression model was also built using the average RGB value to predict L-values. This model performed better than the PLSR models based on RGB data, leading to an RMSECV of 2.04 (Table 1); this may be due to the linear relationship between each RGB channel. Therefore, the linear regression model was selected for further analysis.

In order to further compare the potential of HSI and RGB in predicting L-value for mushroom samples, the best HSI and RGB-based models were applied to images and L-value prediction maps were constructed at different time points (Fig. 2). Comparing the HSI and RGB predicted maps; it can be observed that HSI predicted images more clearly represented features on the surfaces of the mushrooms. The existence of bright regions on some of mushroom HSI predicted images at day 8, are due to luminosity saturation caused by differences in mushroom sample height and shape. Moreover, the changes in surfaces of the mushrooms over storage time can be clearly observed in HSI predicted maps as the mushrooms are becoming darker suggesting the decrease in L-value, while this is not as apparent in the RGB predicted images.

Mean predicted pixel values for both groups of predicted maps were calculated for all mushroom images (57 images) and plotted against the original L-values (Fig. 3.). These plots indicate the superior potential of hyperspectral imaging technique for the prediction of L-value in comparison with the conventional RGB imaging. This agrees with the results obtained for lower RMSECV in HSI based models in comparison with RGB-based models.

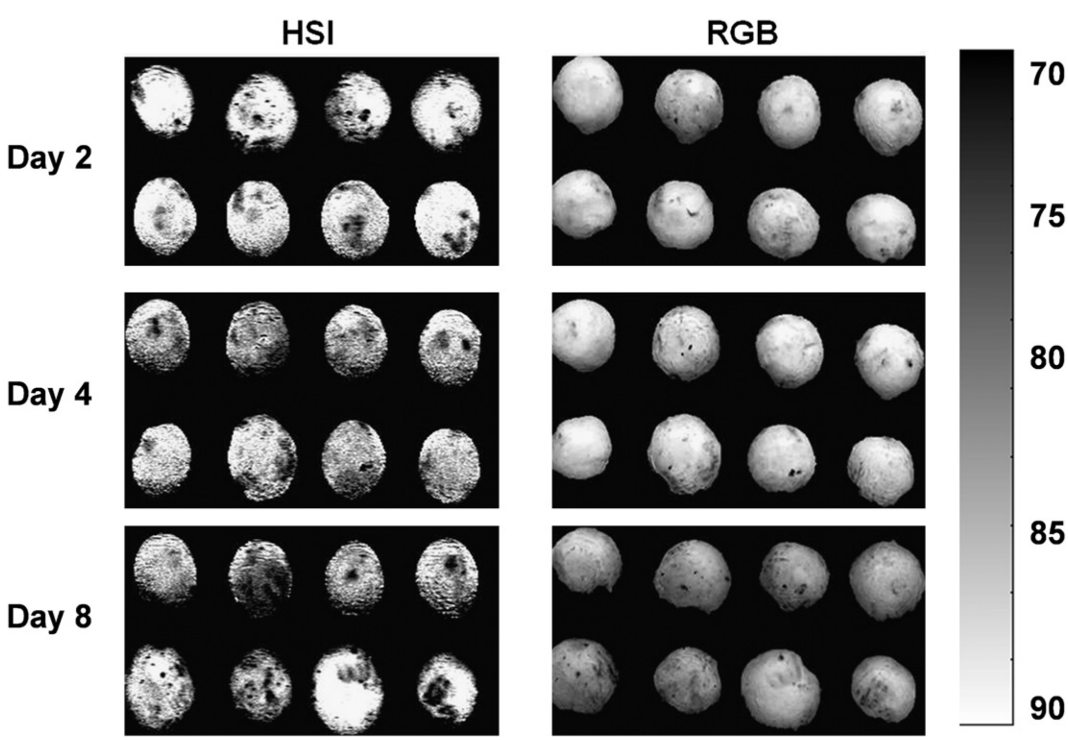

Fig. 2 – Prediction maps obtained from the best HSI and RGB-based models for 3 time points studied (image scale: range between minimum and maximum L-value calculated).

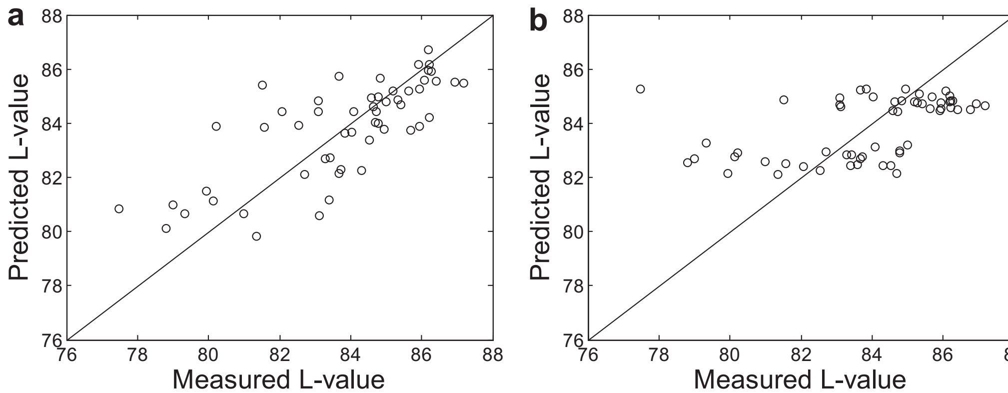

Fig. 3 – Predicted mean L-values against measured L-values for a) hyperspectral and b) RGB images.

4. Conclusions

The results presented demonstrated the greater potential of hyperspectral imaging technique compared with conventional RGB imaging for predicting L-value of mushrooms. Calculating different model performance indicators showed the reasonably high potential of HSI based models to predict L-value for mushroom samples; whereas RGB-based models showed limited potential. The prediction maps obtained by applying the best HSI based model contained more information on mushroom surfaces and the changes in the surfaces of mushrooms over storage time were clearly observed, indicating the decrease in mushroom quality over the storage period; whereas RGB predicted maps did not contain necessary information to evaluate the quality characteristics of mushrooms on their surfaces. In order to implement an enhanced mushroom grading system based on online HSI imaging, a multispectral approach which is cost effective and rapid is required. However, further work is required to identify the optimal wavelength regions for the development of such a multispectral system.

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