Laboratory Scientific Report

Proof of Concept on Visualization of Cooking Degree of Boiled Yam by Hyperspectral Imaging

High-Throughput Phenotyping Protocols (HTPP), WP3

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ABSTRACT

In the RTBfoods project, it has been shown that cooking time in a very important quality trait for consumers of boiled yam and boiled cassava.

In this POC, the potential feasibility of using hyperspectral imaging (900-1700 nm) in the combination with chemometric tools and image processing for detection and visualisation of cooking degree in boiled yam at 0, 10, 20, 25, 30 and 35 min of cooking, has been investigated. PCA was employed to detect pixels of cooking region and the remaining raw region. In the next step, image processing techniques were applied to detect and visualise cooking degree in the score images obtained by PCA.

The current study showed that hyperspectral imaging is useful tool for detection and visualisation of cooking degree through water absorption during cooking process of boiled yam.

Key words: Hyperspectral imaging, PCA, Cooking degree, Boiled yam, Image processing

1 PRINCIPLE

Hyperspectral imaging (HSI) integrates the main advantages of the two original techniques. These techniques are Near Infrared spectroscopy which is useful to determine the product quality through the measurement of their optical properties and computer vision is able to measure the external features of products to attain spatial, spectral and multi-constituent information from an object. HSI system produces a stack of hundreds of images of the same object at different spectral wavelength band. Hence, each pixel in a hyperspectral image contains the spectrum of that specific position, which is a fingerprint useful to characterize the composition of that particular pixel **(Baiano, 2017)**. The major advantage of HSI is the time savings, not only for sample preparation but also for database registration. With conventional NIR techniques, one measure gives one average spectrum. Thousands of spectra can be obtained with HSI, providing a complete picture of the distribution of chemical compounds at the pixel level and the possibility of simultaneously getting the spectral and spatial description of the sample **(Dale et al., 2013)**.

In this POC, we describe the use of HSI to detect the cooking degree of pieces of boiled yam from sample preparation, cooking experiment to multivariate analysis applied to hyperspectral images. the results obtained will be also exposed and commented.

HSI analysis involves several steps. First, white and dark images of the sample are acquired, and then the hyperspectral image is corrected with a white and a dark reference **(ElMasry et al., 2007)**. The images pre-processing (image correction, thresholding, segmentation) and multivariate analysis are performed by using Matlab R2018b (The Mathworks Inc., Natick, MA, USA) along with PLS_Toolbox and MIA_Toolbox.

2 MATERIALS AND METHODS

2.1 Sample preparation and cooking experiment

For this work, healthy and non-defect with representative size (30 cm of length and 8 cm of diameter) yam tuber was purchased in the market at Montpellier (France). After purchase, this was stored under ambient temperature for about 24 h. The selected tuber was than peeled, washed and paper wiping to remove dirt of peeled surface. The proximal part of the the tuber was divided longitudinally into six cylinder slices with the same size of 7 cm of diameter and 2 cm of thickness.

The cooking was performed on the boiled tap water which keeped boiled during the cooking process (fig.1). One slice was considred as 0 min cooking. For the rest of slices, the boiled time was set to 10, 20, 25, 30 and 35 min. When each designed boiling time was reached one piece was taken out of the boiling water and put the alumnium plate with cover for cooling to ambient temperature. The cover was used to prevent water loss. After the yam slices were cooled to ambient temperature, they were used for hyperspectral image acquisition.

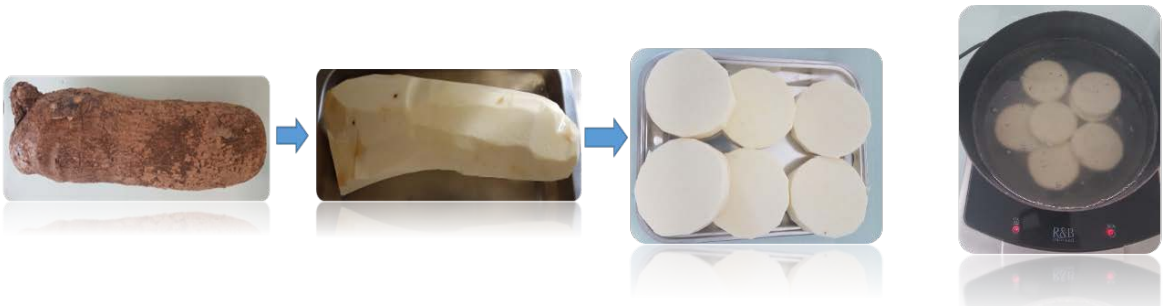

Figure 1: sample preparation and cooking process of yam slices.

2.2 Hyperspectral imaging system

The hyperspectral imaging system used in this POC is a laboratory-based pushbroom imaging equipment. The main components include (fig.2) : (1) a spectrograph with PGP optical structure (ImSpector, N17E, SPECIM, Finland), (2) a 12-bit CCD camera (V-light, Lowel Light Inc, USA), (3) 150-W tungsten halogen lamps (Fibre-Lite DC950 Illuminator, Dolan Jenner Industries Inc., Boxborough, MA, USA) and (5) a translation LabScanner with dimension (L × l) of 40 × 20 cm by a step motor. The harmonious work of the integral system is assured by using (5) control software LumoScanner (SPECIM, Finland).

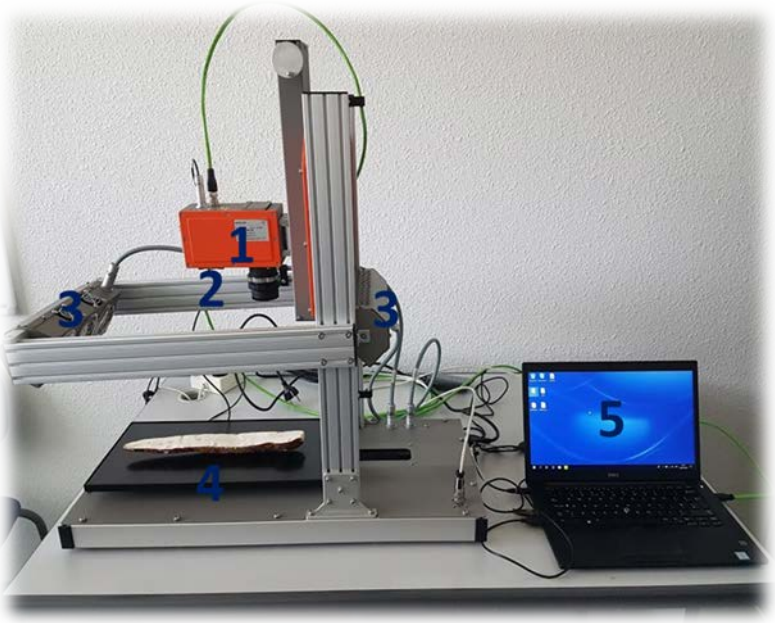

Figure 2: FX17 SPECIM hyperspectral imaging camera system

The assembly disperses the incoming line of light into the spectral and spatial matrices and then projects them onto the CCD. The optics, spectrograph and the camera, has high sensitivity from 900 to 1700 nm with a spectral resolution of 8 nm, and the exposure time is adjusted at 10 ms throughout the whole test. The distance between the lens and the surface of the imaged yam tuber is fixed at 22 cm, and the scanning speed is at 9.5 mm/s. After finishing the scans on a tuber, a three-dimensional (x,y,z) spatial (x,y) and spectral (z)data space are constructed. Images are binned during acquisition in spatial direction to provide images with spatial dimension (x×y) of (292×293) pixels with 224 spectral (900-1700 nm).

2.3 Image acquisition

Each piece of each boiling time was scanned at the surface. The white and dark references measurement were performed for each of them. The dark image (with 0% reflectance) is recorded first by turning off the lighting source with the lens of the camera completely closed, and then the white reference image (Teflon whiteboard with 99% reflectance) is recorded. After that, the hyperspectral image of the target sample is recorded. six images at 0, 10, 20, 25, 30 and 35 min of boiled time. The processing steps of these images will be described above.

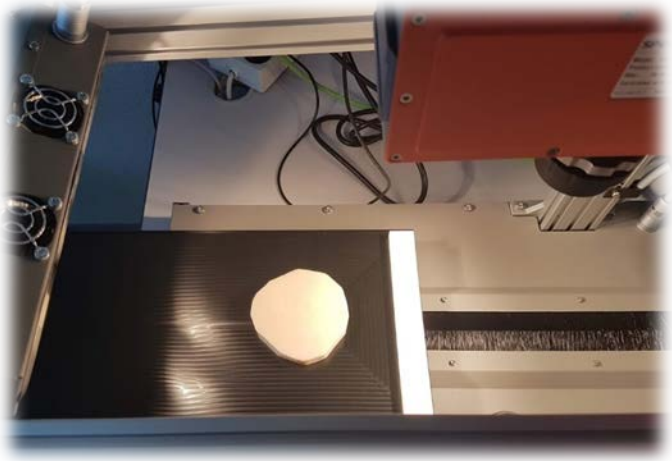

Figure 3 : piece of boiled yam and white reference on translation stage

2.4 Image processing

2.4.1 Image correction

The hyperspectral images were firstly corrected with a white and a dark reference. The dark reference was used to remove the effect of the dark current of the thermally sensitive CCD detectors. The corrected image (R) is estimated using Eq. (1):

$$R = \frac{\mathrm{R0} - \mathrm{D}}{W - D}$$

Where R0 is the recorded hyperspectral image, D the dark image and W is the white reference image. The corrected images R will be the basis for the subsequent image analysis to extract information about the spectral properties of boiled yam sample for optimizing surface characteristics identification, selection of effective wavelengths **(ElMasry et al., 2007)**.

2.4.2 Selection of the region of interest (ROI)

The spectral response of boiled yam samples could be used to characterize and identify the sample. To collect the spectral response of each sample, a binary mask is first created to produce an image containing only the fresh yam in the image, avoiding any interference from the background. Here, an image at 1230 nm wavelength is taken for this task because the tuber appeared opaque compared with the background and can be segmented easily by simple thresholding at the level of 0.3176. All active pixels in the segmented image are used as a mask to identify all pixels belonging to the yam sample (ROI) and set the others to zero background (fig.4). At each pixel of ROI, the relative reflectance is recorded at each wavelength from 900 to 1700 nm. Each segmented image contains more than 80000 pixels.

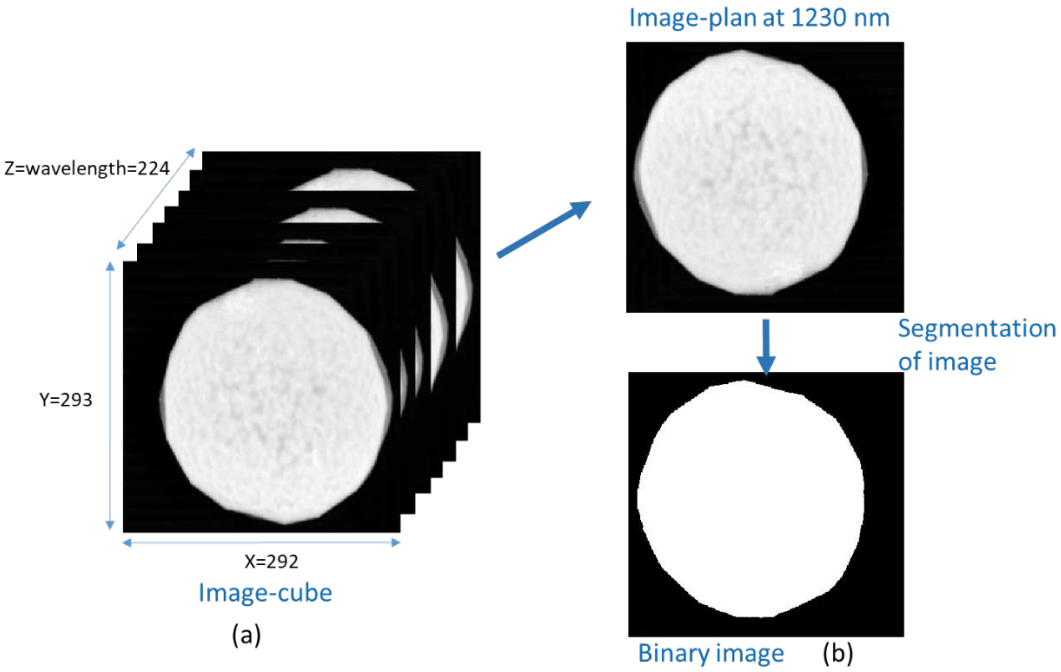

Figure 4 : Hyperspectral images of piece of boiled yam samples. (a) Corrected hyperspectral image, (b) sample mask resulting from thresholding the 1325 nm image at a value of 32 %.

2.5 Multivariate analysis of hyperspectral images

2.5.1 Unfolding the hyperspectral (hypercube) image (x, y, z) into a 2D matrix (z,x ×y)

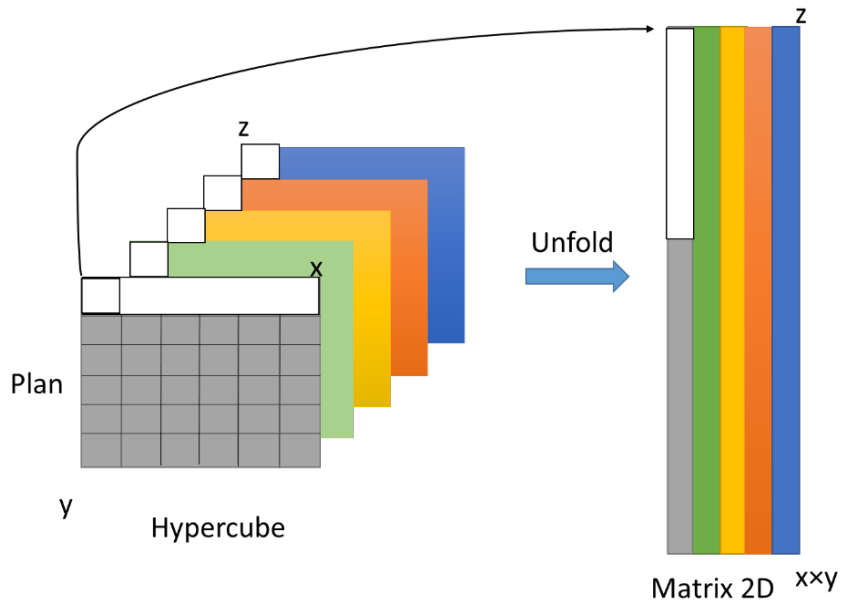

Figure 5 : schema of the unfolding of the hyperspectral image (hypercube) (x y z) to a 2D spectral matrix (z, x×y).

2.5.2 Principal component analysis of hyperspectral data

Principal components analysis (PCA) is a conventional multivariate analysis technique for dimensionality reduction and variable selection in spectral data. Typically, PCA finds fewer

independent components instead of the original variables through orthogonal transformation. In PCA, spectral data in the matrix X are decomposed into a loading matrix (P) and a score matrix (T). Where X is the N × K spectral data matrix, T is the N × A matrix of score vectors, P' is the K × A matrix of loading vectors, N is the number of examined samples, K is the number of variables (wavelengths), and A is the number of principal components (PCs) (fig.6). The scores of PCA represent the weighted sums of the original variables without significant loss of useful information, and the loadings of PCA (weighting coefficients) can be used to identify important variables that are responsible for the specific features appeared in the corresponding scores.

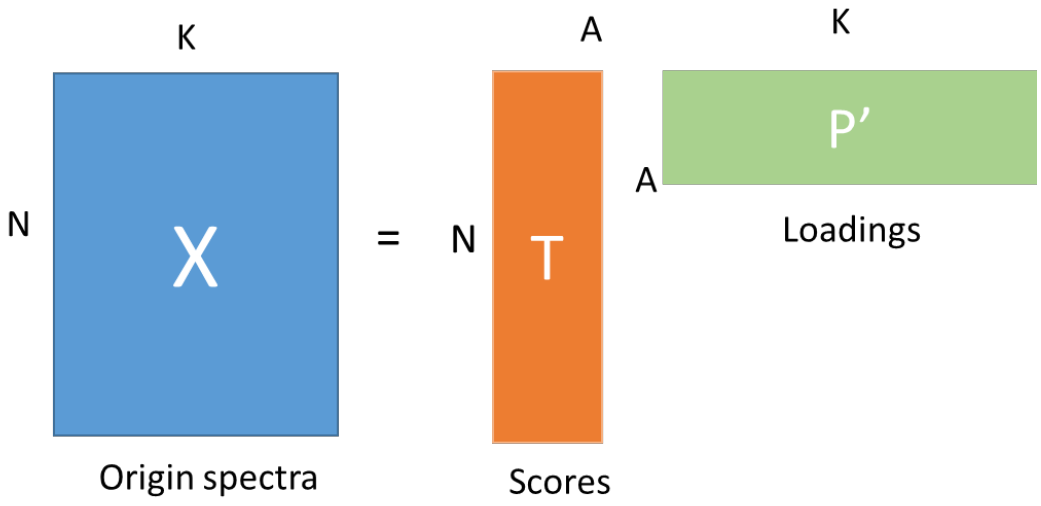

Figure 6: Shema of the principle of reduction of origin spectral data by principal component analysis, X is origin spectra, T is scores matrix, and P' is loading matrix.

3 RESULTS AND DISCUSSION

After unfolding, PCA is applied to 1000 spectra of each image randomly selected. In total 6 images × 1000 = 6000 spectra are used.

Loading plot of the first component of PCA is displayed in fig.6. This plot shows two strong positive bands at 1156 nm and 1375 nm (OH stretching the first overtone) were due to the presence of free water in the sample. That is means the variability explained by PC1 is strongly related to the variability of water absorbed by yam slices during cooking.

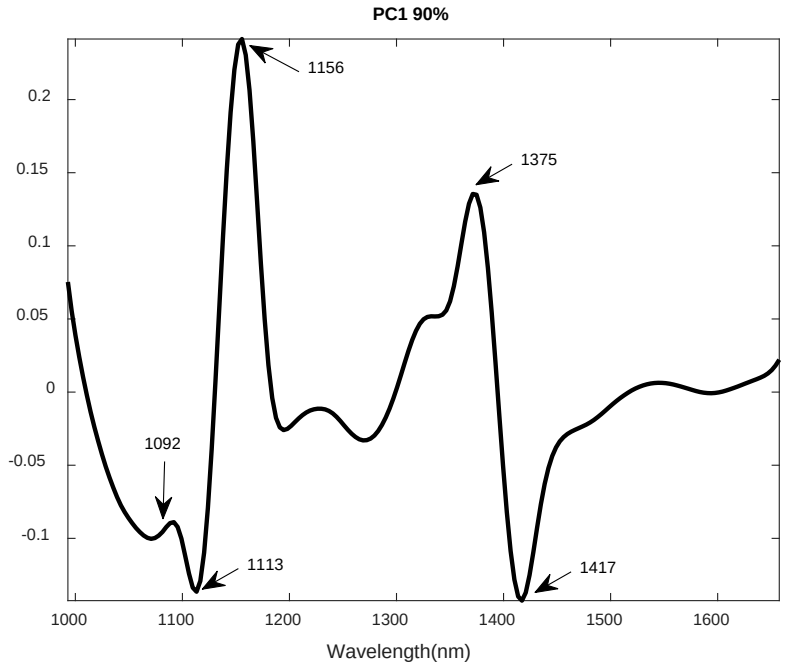

Figure 6: Loading plot for PC1 PC1 explain 90 % of variability.

After the projection of each pixel of the image to the PCA, the score value of each pixel is calculated and stored in the scores matrix. Moreover, each score vector was folded back to form a 2-D score image with the same dimensions of the single-band image. Score images were then further explored with image post-processing to obtain classification map, and the resulting classification map is displayed in colours. In the classification image, pixels belong to the same class will appear in the same colour. The fig.7 shows, the PC1 scores images of yam with different boiled time, as predicted by the PCA model, and the corresponding false colour images resulting from image processing are presented. The results shows when the boiled time increases, the absorbtion of water (red) evolves by all directions from the center toward the borders. The remaining part (blue) almost disappears after 35 min of cooking. At t0+25 min there is an important and heterogeneous increase of water absorption of the yam. Whereas at t0+30 min, we observe that the absorption part has taken over from the no water absorption part.

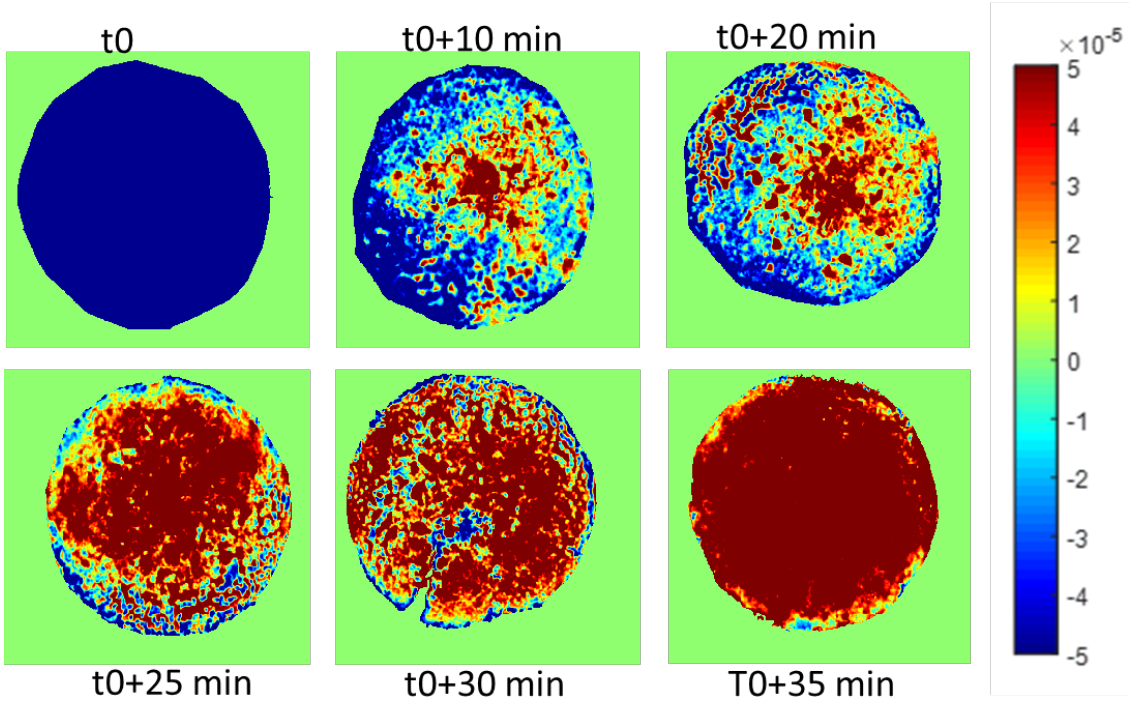

Figure 7 : PC1 score images of pieces of slices yam with different boiled time t0, t0+10 min, t0+20 min, t0+25 min, t0+30 min and t0+35 min predicted by the PCA model and corresponding false colour resulting from image processing.

4 CONCLUSIONS AND PERSPECTIVES

From this study, we conclude that the combination of HSI and chemometrics has potential tool to detect and visualize the cooking degree of boiled yam through absorption of water. Further research involving yam samples from different origins to predict the cooking quality (bad or good) at t0+30 min (optimum cooking time) from the sample before cooking (t0). However, HSI will be applied first in order to predict biochemical parameters (DM, starch, pectin and temperature of gelatinisation) of the pixels of the slices in order to understand the phenomenon of water absorption.

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