# Discrimination and quantitative analysis of watercore in apple fruit by near infrared transmittance spectroscopy

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## Introduction

In Korea, most consumers tend to prefer apples including watercore. Apples with watercore are sweeter and more expensive than apples without watercore. However, watercore is a kind of internal disorder[1,2] of apple fruit. It causes the fruit flesh to brown and tissue damage during storage[3] as shown in Figure 1. Finally, these apples will lose their value in the market.[4,5] So, watercore is a very important factor for the storage and sorting industry of apple fruit.[6] However, it is difficult to find apples which have watercore in them. A visual inspection is generally applied to evaluate the amount of watercore by randomly selection of apple fruits. Therefore, a rapid, accurate and non-destructive method is needed.

Previous studies reported on some methods such as X-ray imaging,[7,8] camera imaging,[9] machine vision,[10] magnetic resonance imaging[11] and near infrared (NIR) reflectance spectroscopy[12] for watercore. However, these methods did not obtain high accuracy.

In this study, we attempted the discrimination and quantification of watercore in apple fruit by using NIR transmittance spectroscopy.

## Materials and methods

### Apple fruits

Apple fruits (*Fuji* variety) were colleted for the 1999 harvest season in Kyungpook prefecture, Korea.

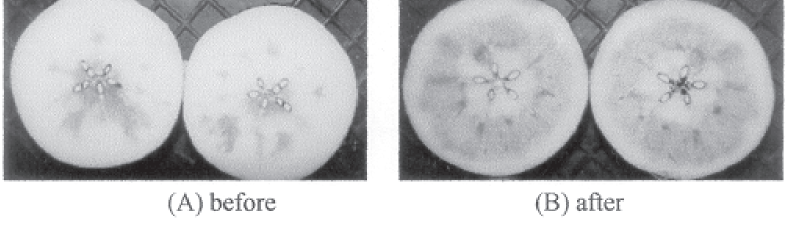


**Figure 1. Internal change of apple fruit having watercore (a) before and (b) after storage.**



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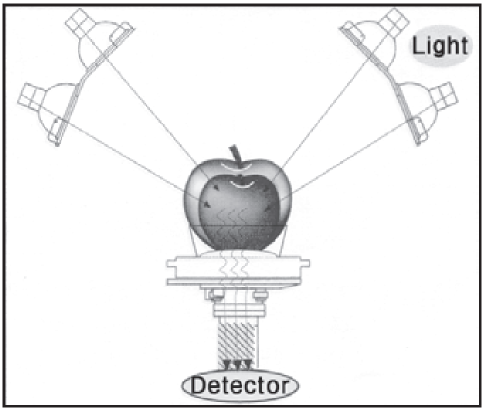


**Figure 2. Schematic for measuring NIR spectra of apple fruits.**

### Spectral analysis

The apparatus used in this study is shown in Figure 2. For the measurement of watercore, the apple fruit was illuminated by four 10 V halogen lamps (Philips Inc., The Netherlands). NIR transmittance spectra were collected using an AH-4240 instrument (American Holographic. Inc). The spectrometer provided 528 data points from 578 nm to 1106 nm. Reference spectra were obtained by measuring a polystyrene sphere. Partial least squares regression (PLSR) was performed using the Unscrambler (Camo Asa, USA). The accuracy of the calibration model was evaluated using the multiple correlation coefficient ($R$) and root mean square error of prediction ($RMSEP$).

### Measurement of watercore content

After measuring NIR spectra, samples were sliced at intervals of 10% thickness according to the cross section. Each slice was scanned by a scanner and then saved onto a computer. Each image was converted to gray scale and treated on the threshold with an image treatment program (Image-Pro PLUS, Media Cybernetics, USA). The process is as shown in Figure 3. The amount of watercore in each apple slice was measured using the threshold image and the watercore content was calculated by the following equation.

$$\text{Watercore content (\%)} = \frac{\text{Total watercore area}}{\text{Total apple area}} \times 100$$

## Results and discussion

Figure 4 shows the raw transmittance NIR spectra of apple samples. The spectral difference was found at 732 nm and 820 nm. The high-watercore apples tended to show a higher transmittance values than those of medium- or no-watercore apples. Figure 5(a) shows raw transmission spectra of 75 apple

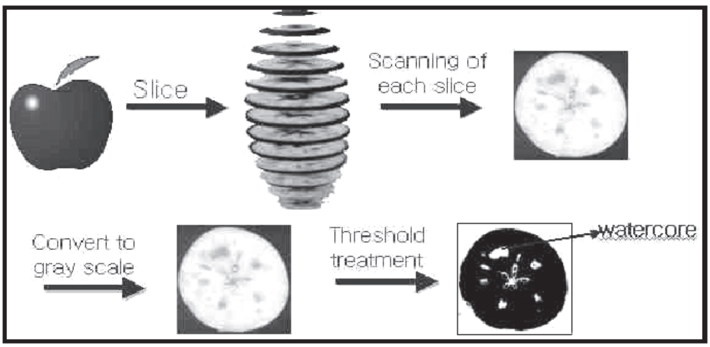


**Figure 3. Processing for measuring of watercore content.**

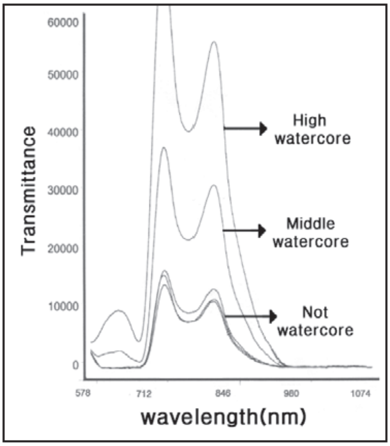


**Figure 4. NIR raw transmittance spectra of apple fruits.**

samples having a wide range of watercore content. First and second derivatives of spectra were used for an ideal data analysis. Figure 5(b) shows second derivative spectra of apple samples.

Table 1 shows the result of the PLSR calibration model and prediction for the quantification of watercore in apple fruit for each data pretreatment. The correlation coefficient ($R$) and *RMSEP* were 0.959 and 1.379% for raw spectra, respectively. The model was improved after pre-processing of spectral data. For the first derivative model, $R$ and *RMSEP* were 0.990 and 0.675% for the calibration set and 0.982 and 0.930%.

The second derivative model resulted in 0.975 of $R$ and 1.082% of *RMSEP*. The first derviative was more effective than the second derivative for determining watercore in apples. Fig-

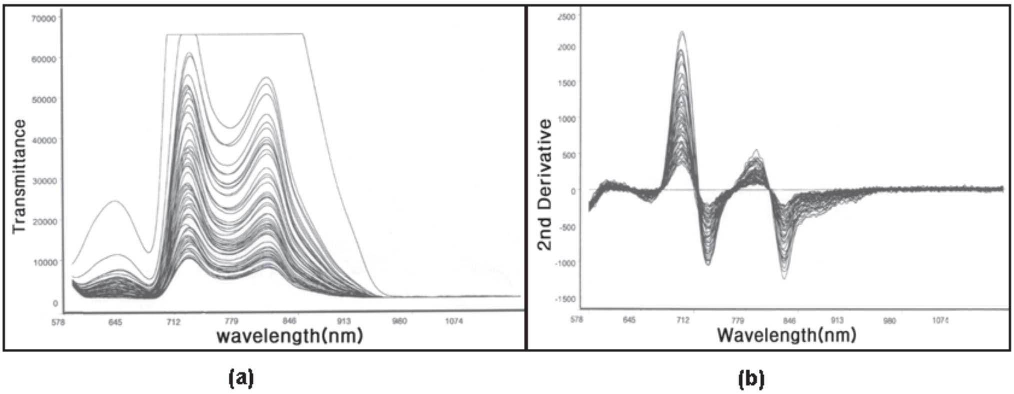


**Figure 5. (a) Raw and (b) second derivative NIR spectra of 75 apple fruit samples.**

**Table 1. Result of PLSR calibration and prediction for determining watercore content in apple fruit.**

| Data treatment | Wavelength region | Sample set | Sample no. | $R$ | *RMSEP*(%) |
|---|---|---|---|---|---|
| Raw | 578–1106 nm | Calibration<br>Validation | 45<br>30 | 0.978<br>0.959 | 1.015<br>1.379 |
| First derivative | 578–1106 nm | Calibration<br>Validation | 45<br>30 | 0.990<br>0.982 | 0.675<br>0.930 |
| Second derivative | 578–1106 nm | Calibration<br>Validation | 45<br>30 | 0.983<br>0.975 | 0.886<br>1.082 |

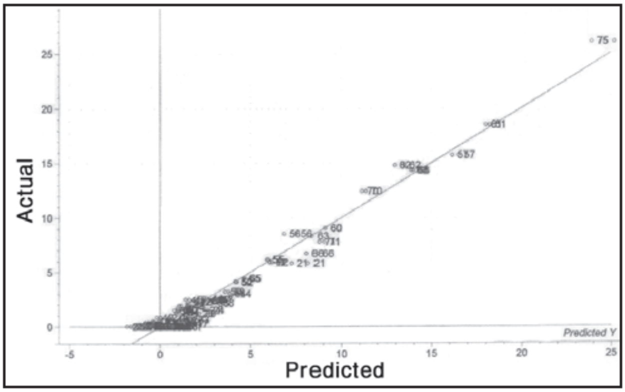


**Figure 6. Scatter plots of actual and NIR predicted watercore contents in apple fruit.**

ure 6 shows the relationship between actual watercore content and NIR predicted using the 1st derivative PLS model.

## Conclusion

The possibility of non-destructive evaluation of watercore in *Fuji* apple fruit using NIR transmittance spectroscopy was investigated and the calibration model was developed for quantification of watercore content. The PLSR model using the first derivative of the spectral data resulted in acceptable error level. The correlation coefficient (*R*) and root mean square error of prediction (*RMSEP*) were 0.990 and 0.930%, respectively. This result indicates that NIR transmittance spectroscopy could be used for discrimination and quantification of watercore in apple fruit.

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