Research Article

Analysis of NIR spectral reflectance linearization and gradient shift in monitoring apple and pear decay

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Abstract: Near infrared **(**NIR) spectroscopy is a physical, non-destructive high-precision technology and requires minimal or no sample preparation. NIR can be applied for online monitoring, such as in agriculture industry. Omar and MatJafri [1] performed an analysis on a single wavelength that can produce the best reflectance responsivity in monitoring apple and pear decay. The responsivity was measured in terms of the magnitude of linear correlation coefficient, R^2, that was produced between reflectance and time of measurement. As continuity from the previous experiment, this research introduced an alternative analysis in monitoring apple and pear decay. Two graphical analyses have been performed on NIR spectral reflectance, between 920nm and 980nm. Those analyses are the measurement of the magnitude of spectral linearization and spectral gradient shift against time (9 hours) of measurement. Both analyses produced a high R^2 ranging from 0.8456 to 0.9851. In this research it was found that by performing an analysis upon a range of spectral wavelengths, the results obtained are able to produce a better R^2 in monitoring apple and pear decay through time of measurement.

Keywords: fruit, post-harvest, linear correlation coefficient, spectroscopy**,** Malaysia

Introduction

Review of the earlier work

This research is a continuation from the earlier established experiment conducted by Omar and MatJafri [1]. The earlier experiment focused on the determination of a single wavelength that can be best used to monitor fruit decay. The intention is to assist in the selection of optical component parameters that are best suited for future development of optical sensors for the measurement of fruit quality [1]. The fruit were left in a room with a constant temperature of $26^{o}C$ and the reflectance measurements were taken every hour using an ASD Spectroradiometer (Model FieldSpec® Handheld, Analytical Spectral Devices, Inc., Boulder, CO, USA operates at wavelength between 325nm to 1075nm).. Four fruit were examined; red apple, green apple, yellow (snow) pear and green pear. The linear correlation coefficient, R^2 was recorded for every four parts of four different fruit as shown in Figure 1 and Figure 2. R^2 were computed between reflectance and 9 hours of measurement time. The range of R^2 achieved in the experiment is within the range of 0.4256 and 0.9564. NIR ranges from 960nm to 980nm produced the best R^2, with 975nm as the highest frequency to occur. Woodcock *et al* [2] and Suehara and Yano [3] identified that the peak absorbance wavelength for water is at 980nm and 970nm respectively. Further analysis has been conducted on the raw data gained in the previous research. This paper will introduce an alternative analysis in monitoring fruit decay. The purpose is to identify a different view on NIR spectral responsivity to produce a better analysis in manipulating existing data with the objective to gain a better R^2. The analysis was conducted on the NIR spectral wavelengths within the range of 920nm and 980nm.
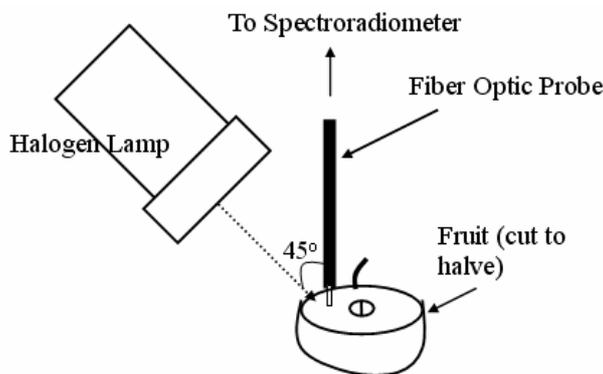

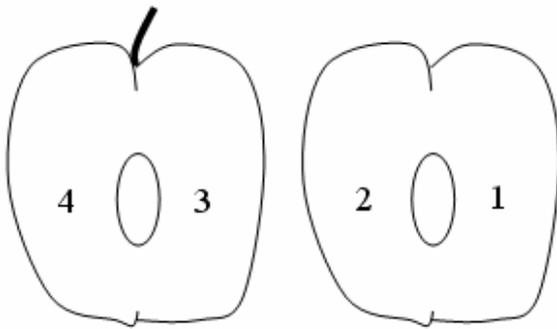**Figure 1.** The experimental setup for spectrum measurement of fruit decay (Omar and MatJafri, 2008).

Figure 2. Four parts of the fruit to be examined (Omar and MatJafri 2008).

NIR Reflectance Spectroscopy

The application of near infrared as a non-destructive technique for measuring quality characteristics of different agricultural products is gaining attention. NIR light is used to measure the optical, chemical and physical properties of the product, which can then be associated with the quality parameters of the targeted crop [4]. NIR spectroscopy is sensitive especially to molecules containing C-H, O-H and N-H groups. NIR range of the spectrum interacts in a quantifiable way with these bonds. Therefore, substances such as starch and sugars (C-H), alcohols, moisture and acids (O-H) and protein (N-H) can be quantified in solids, liquids or even slurries [4]. The interaction between NIR radiation and the sample examined changes as a function of wavelength. This characteristic allows for different parts of the NIR spectrum to be used for different analytical purposes. Derivatives are one of the common methods in treating the NIR spectrum. The first derivative will remove the baseline offset produced by the scattering effects. On the other hand, the second derivative eliminates the gradient of the spectrum [5]. For instance, Temma *et al* [6], used second derivative spectra to measure the sugar content of apple and apple juice. The application of the second derivative by Temma *et al* was to separate any overlapping absorption peaks, so that the selection of the most appropriate peak for measurement and analysis can be undertaken. However, in this study, different approaches will be taken to enhance analysis through different perspectives.

Methodology

The range of NIR spectral reflectance was retrieved between 920nm and 980nm. This range was identified from previous work as being the most suitable for the current analysis. The NIR spectral reflectance was simulated to retrieve its linear equation and linear correlation coefficient, R^2. Two analyses are introduced in this research. The first analysis is the monitoring of fruit decay through the changes of NIR spectrum gradient. It was observed that throughout 9 hours of measurement, the NIR spectrum gradient inclined for every hour, resulting in a lower gradient. This observation was then quantified in order to get the R^2 between the gradient shift and the time of measurement.

The second analysis is in the measurement of spectrum linearization during 9 hours of measurement. The value of R^2 between reflectance and time of measurement was observed to be higher for every hour, indicating that there is an improvement in spectrum linearity. This observation was then quantified to attain the value of spectrum linearization that is presented by each spectrum linear correlation coefficient, R^2 against time of measurement.

Results and Analysis

The analysis was conducted on four types of fruit; red apple, green apple, yellow pear and green pear. The results are shown in 3 graphical representations. The first graph shows the comparison between reflectance and NIR wavelength (920nm and 980nm) for 0 hour and 9 hours of time measurement. The graph shown is the measurement at portion '1' (refer Figure 2) of every fruit. The second graph shows the changes of spectrum gradient against time of measurement. The third graph shows the changes of spectrum linearity (R^2) against time of measurement. The second and third graphs are the result of two analyses conducted in monitoring fruit decay. For every measurement taken for every hour, the NIR spectral is presented as a linear line equation. The gradient and R^2 for every graph is retrieved and its linear behaviour analysed through 9 hours of measurement. All the main analyses are summarized and presented in the tables that show the linear correlation coefficient, R^2 attained for every measurement using the two analyses introduced in this research.
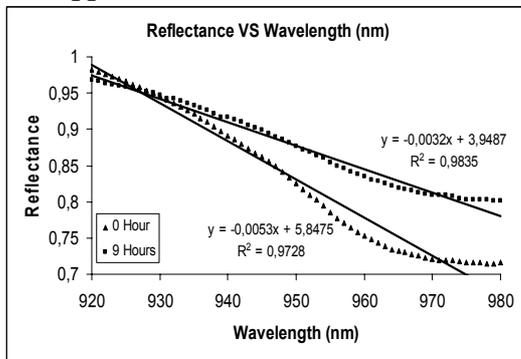
Red apple

Figure 3. NIR spectral response for red apple measurement of red apple decay.
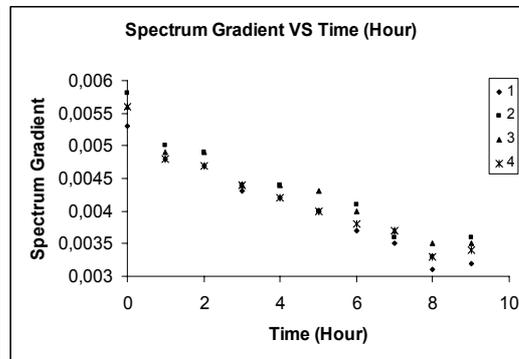
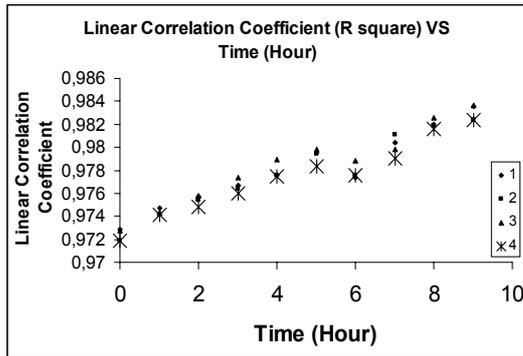**Figure 4.** Spectrum gradient shift for 9 hours between 920nm and 980nm.

Figure 5. Spectrum linearity for 9 hours measurement of red apple decay.

Table 1. Parameters of graphs based on the results shown in Figures 4 and 5.

	Part 1	**Part 2**	**Part 3**	**Part 4**
R^2 (Gradient vs Time)	0.9756	0.9042	0.945	0.935
R^2 (Linear Correlation Coefficient vs Time)	0.9299	0.9421	0.9391	0.9527

Through the 9 hours measurement, it was observed that the gradient of the spectrum between 920nm and 980nm is shifting up, hence reducing its value as shown in Figure 4. However, the range between 920nm and 930nm does not show significant change in the NIR reflectance as shown in Figure 3. Figure 5 indicates that the NIR spectrum is improving in its linearity. The entire analysis is written in Table 1. It shows that for the entire measurement for both analyses, the value of R^2 is high, indicating that there is a very good linear correlation between NIR gradient shift and linearization with time in measuring red apple decay.
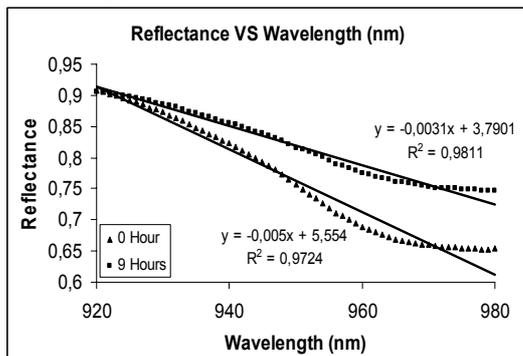
Green apple

Figure 6. NIR spectral response for green apple measurement of green apple decay.
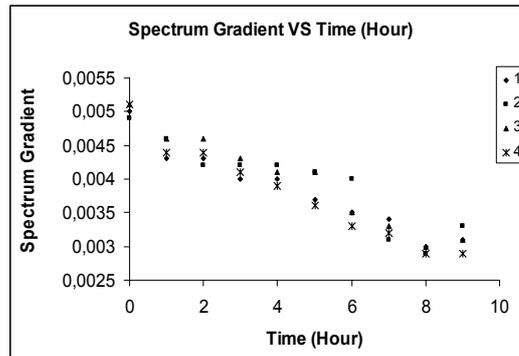

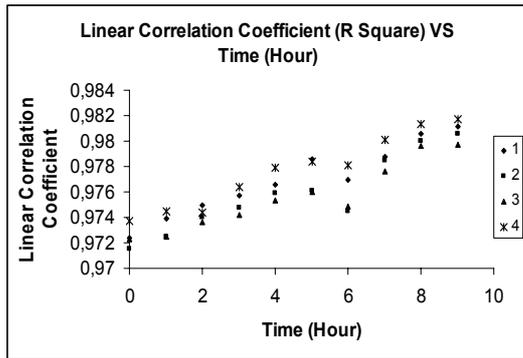**Figure 7.** Spectrum gradient shift for 9 hours between 920nm and 980nm.

Figure 8. Spectrum gradient shift for 9 hours measurement of green apple decay.

Table 2. Parameters of graphs based on the results shown in Figures 7 and 8.

	Part 1	Part 2	Part 3	Part 4
R^2 (Gradient vs Time)	0.9411	0.8456	0.9602	0.9651
R^2 (Linear Correlation Coefficient vs Time)	0.9459	0.8869	0.9161	0.9647

Spectrum gradient shift and linearization for green apple, as shown in Figure 7 and Figure 8, shows the same pattern of response as the red apple. However, there is no significant change for the value of reflectance at wavelength 920nm. This can be seen in Figure 6. The entire analysis is written in Table 2. There is a very good linear correlation between NIR gradient shift and linearization with time in measuring green apple decay.
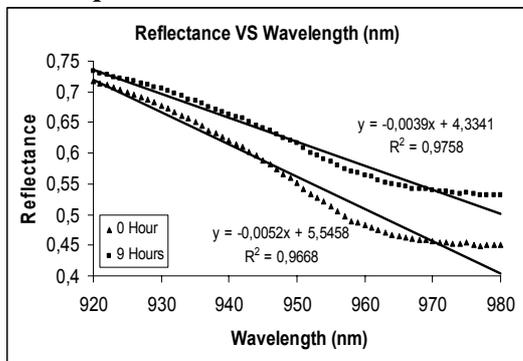
Yellow pear

Figure 9. NIR spectral response for yellow pear measurement of yellow pear decay.
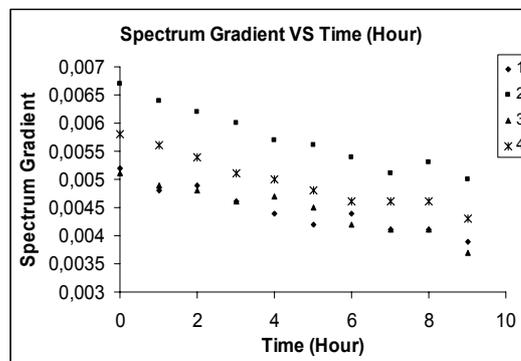
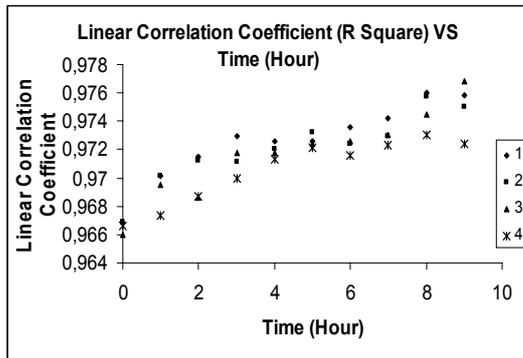**Figure 10.** Spectrum gradient shift for 9 hours between 920nm and 980nm.

Figure 11. Spectrum gradient shift for 9 hours measurement of yellow pear decay.

Table 3. Parameters of graphs based on the results shown in Figures 10 and 11.

	Part 1	Part 2	Part 3	Part 4
R^2 (Gradient vs Time)	0.9106	0.9578	0.9506	0.9559
R^2 (Linear Correlation Coefficient vs Time)	0.8659	0.8528	0.8936	0.8735

For yellow pear the spectrum gradient shift and linearization, as shown in Figure 10 and Figure 11, also shows the same pattern of response as red and green apple. There is less significant change for the value of reflectance at wavelength less then 920nm and the two spectra intercept at 877nm. A portion of the spectrum can be seen in Figure 9. The entire analysis is written in Table 3. There is a very good linear correlation between NIR gradient shift and linearization with time in measuring yellow pear decay.
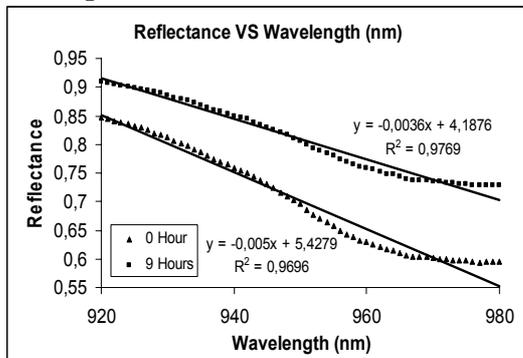
Green pear

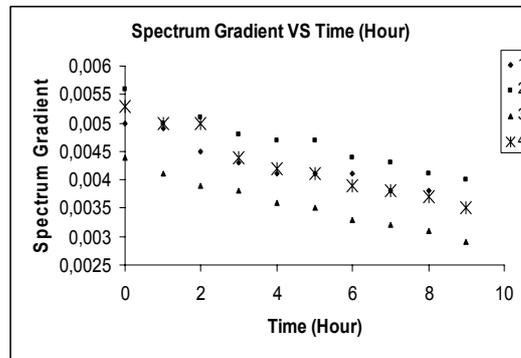**Figure 12.** NIR spectral response for green pear measurement of green pear decay.

Figure 13. Spectrum gradient shift for 9 hours between 920nm and 980nm.
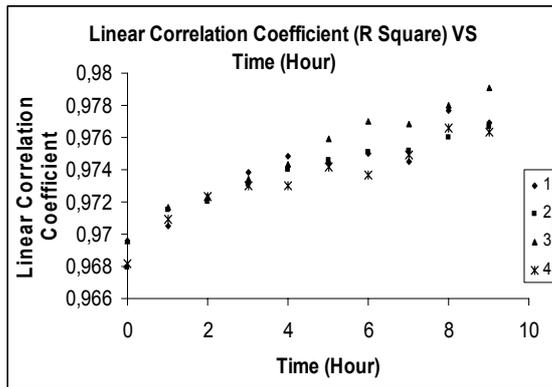
Figure 14. Spectrum linearity for 9 hours measurement of green pear decay.

Table 4. Parameters of graphs based on the results shown in Figures 13 and 14.

	Part 1	Part 2	Part 3	Part 4
R^2 (Gradient vs Time)	0.9319	0.9407	0.9851	0.951
R^2 (Linear Correlation Coefficient vs Time)	0.8787	0.882	0.9775	0.896

Similar to red and green apple, as well as yellow pear, green pear also shows the same pattern of response for spectrum gradient shift and linearization, as shown in Figure 13 and Figure 14. However, there is less significant change in the NIR gradient when compared to the other fruit examined in this study. This can be observed in Figure 12. The entire analysis is written in Table 4. There is a very good linear correlation between NIR gradient shift and linearization with time in measuring green pear decay.

Conclusions

This research has shown that the analysis conducted on a spectrum of wavelengths can result in a higher correlation coefficient if compared to the analysis committed upon a single wavelength as conducted by Omar and MatJafri [1]. When the analysis is computed on a range of NIR spectra between 920nm and 980nm, it is observed and quantified that the gradient of the spectrum decreases throughout the 9 hour duration of the experiment. Furthermore, the spectrum has shown improvement in its linearity. Further study can be conducted to examine the chemical or physical composition of apples and pears that leads to these responses when decaying through time.

Acknowledgement

References

1. Omar, A. F. and MatJafri, M. Z. (2008). The Monitoring of Spectrum Responsivity on Apples and Pears Decay through VIS-NIR Reflectance Spectroscopy, presented at ISSASS International Congress 2008, Bangkok, Thailand, 15-19 December.

2. Woodcock, T., Fagan, C. C., O'Donnell, C. P. and Downey G. (2008). Application of Near and Mid-Infrared Spectroscopy to Determine Cheese Quality and Authenticity, **Food and Bioprocess Technology**, 1, pp. 117–129.

3. Suehara, K. and Yano, T (2004). Bioprocess Monitoring Using Near-Infrared Spectroscopy, **Advances in Biochemical Engineering and Biotechnology**, 90, pp. 173–198.

4. Abu-Khalaf, N., Bennedsen, B. and Bjørn, G. (2004). Distinguishing Carrot's Characteristics by Near Infrared (NIR) Reflectance and Multivariate Data Analysis, **CIGR EJournal**, 6, Manuscript FP 03 012.

5. Dåbakk, E., Nilsson, M., Geladi, P., Wold, S. and Renberg, I. (1999). Sampling Reproducibility and Error Estimation in Near Infrared Calibration of Lake Sediments for Water Quality Monitoring, **Journal of Near Infrared Spectroscopy**, 7: 241–250.

6. Temma, T., Hanamatsu, K. and Shinoki, F. (2002). Measuring the Sugar Content of Apples and Apple Juice by Near Infrared Spectroscopy, **Optical Review***, Vol. 9, No. 2. 40~44.