Rapid, non-destructive quality assessment of fresh produce

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Introduction

Producers, wholesalers and retailers of fresh produce, world-wide, need to be able to supply their customers with an appropriate stated quality of product and, since the work of Norris and Birth[1] in the 1950s, NIR researchers have been investigating ways in which the technology could be used to provide fresh produce quality information, rapidly and non-destructively. In subsequent years, workers in Japan,[2] America,[3] Belgium[4] and France,[5] for example, have been addressing this important food industry requirement. In the UK, CCFRA have been addressing this NIR application since 1994, when a CCFRA Member's Research Club funded work to examine the potential of near infrared (NIR) spectrometry to measure maturity factors in vining peas. The Research Club continued with the theme up to the present, developing working calibrations for Tenderometer, Alcohol Insoluble Solids (AIS) and sensory attributes for whole vining peas scanned in reflectance. In 1995, an EU funded COPERNICUS project, led by CCFRA, carried the CCFRA Research Club theme into a European context, including maturity, quality and sensory assessment, by NIR, of peas and sweetcorn. The large database of spectra derived from European samples provided useful calibrations for a range of quality factors.[6]

Current research on non-destructive NIR analysis at CCFRA

Approaches

In 1997, member companies at CCFRA voted funding for a two-year research project to examine the application of NIR to the rapid, non-destructive quality assessment of fresh produce. Four main objectives have been pursued in the project:
a) to decide upon the optimum method of presentation;
b) to scan samples of fruit and vegetables exhibiting a wide range of a number of quality factors;
c) to carry out experiments to determine the depth of penetration of NIR and visible radiation;
d) to select, on the basis of the preliminary results from the previous objectives, four or five fresh produce types upon which to carry out a fuller calibration and discriminant analysis of relevant (to industry) quality factors.

Methods

Figure 1 illustrates the overall approach to presenting samples to the Foss NIRSystems 6500 monochromator. The reflectance mode was chosen, since many of the fruit types, of interest to the food industry, have large stones within them, for example, avocado, mango, peach. As far as possible, the samples were boxed-in to exclude external light from the instrument detectors. The full wavelength range from 400 to 2500 nm was employed to scan the samples. Three well-separated sites on the sam-

ples were scanned. Table 1 records the fresh produce types that were scanned and which quality attributes were used in the calibration and discriminant analysis.

A radiation depth of penetration experiment was carried out for all the larger fruit and vegetable types. A cube of tissue, approximately 10×10 cm was cut from the sample, taking the maximum depth to the stone or through to the other side of the sample. The cube was screened from external light and for each successive scan a measured thickness of tissue was removed, until only the skin remained.

Figure 1. Overall approach to presenting samples to the Foss NIR Systems 6500 monochromator.

Table 1. Record of fresh produce scanned in the project.

Fruit/vegetable	Variety–Origin	Samples	Comments
Apples	Cox–U Egremont Russet–UK Granny Smith–France	8 7 6	Scanned at intervals up to 54 days Scanned at intervals up to 54 days Scanned at intervals up to 54 days
Potatoes	Charlotte–UK King Edward–UK Maris Piper–UK Maris Peer–UK	17 14 11 16	A waxy potato A floury potatao A floury potatao A waxy potato
Strawberry	UK	141	Visual quality- MAP trials[a]
Raspberry	UK	52	Brix–MAP trials[a]
Lettuce	Little Gem–UK	49	Visual quality–MAP trials[a]
Mushrooms	UK	84	Visual quality–MAP trials[a]
Mangoes	Puerto Rico South Africa Ivory Coast	4 2 120	Brix, ripeness Brix, ripeness Brix, ripeness
Avocados	Spain South Africa	6 7	Firmness, softness Firmness, softness
Tomatoes	Spain	12	Firmness, softness
Peaches	not known Cinderella–South Africa	2 6	Firmness, softness Firmness, softness
Nectarines	Spain Israel	2 6	Firmness, softness Firmness, softness
Sharon fruit	not known	16	Brix, ripeness

[a] denotes samples scanned, that had been included in a Modified Atmosphere Packaging trial at CCFRA

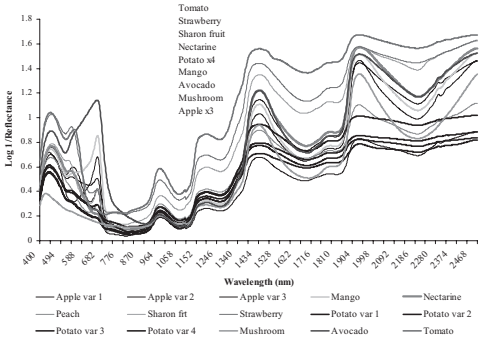

Figure 2. Log 1/*R* spectra of nine types of fresh produce.

Results and discussion

Figure 2 shows a series of spectra (six samples averaged) obtained from the fresh produce types scanned. It can be seen that the different types show substantial spectral differences, and varieties of one type show a high degree of similarity.

Figures 3(a) and (b) illustrate the spectra obtained for the radiation depth experiment carried out on mango tissue.

Several observations can be made concerning the pattern of spectra obtained from the tissue thickness experiment. First, the relative positions of the spectra change across the wavelength range. From 400 to about 900 nm, the spectra are only roughly ordered in a way that reflects the tissue depth. Above 900 nm to approximately 1300 nm the spectra are quite well ordered with an approximation of proportionality between peak height and tissue depth, particularly in the 900–1100 region. For the remaining part of the NIR spectrum only the 0.5 mm sample reflects the depth order having the lowest absorbance throughout both spectral regions (except between 780 and 900 nm). The key conclusion that can be deduced from this experiment is that for a typical depth of mango tissue, to the stone from

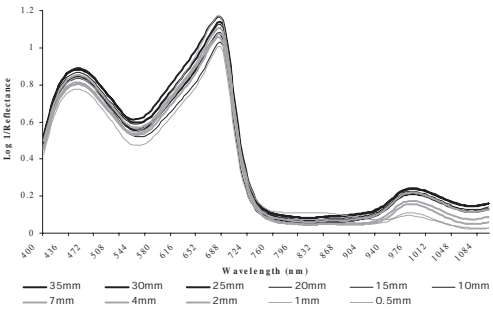

Figure 3(a). A series of spectra from different thicknesses of mango tissue, visible region.

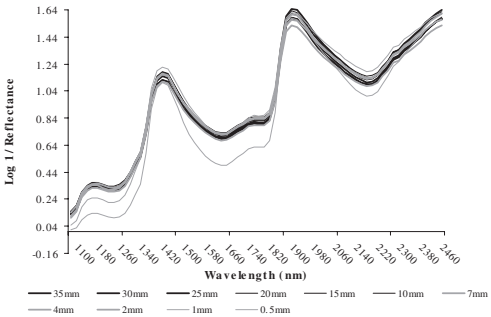

Figure 3(b). A series of spectra from different thicknesses of mango tissue, NIR region.

Table 2. Calibration and prediction statistics for mango Brix measurments.

Stepwise multiple linear regression (SMLR) equations						
Brix range 9.35–17.6 Calibration set = 96 samples, validation set = 48 samples						
Wavelength range (nm)	Maths treatment	No. of terms	R^2	*SEC*	*SEP*	Wavelengths(first four)
400–100	2,8,6,1 (2)	5	0.666	0.89	1.02	516,682,712,904
1100–2500	2,8,6,1 (2)	4	0.638	0.93	1.12	1188,2192,2004,2270
900–1300	1,4,4,1 (2)	7	0.709	0.83	1.14	954,1074,1078,998
Modified partial least squares equations						
Brix range 9.35–17.6 Calibration set = 96 samples, validation set = 48 samples						
Wavelength range (nm)	Maths treatment	No. of terms	R^2	*SEC*	*SEP*	Wavelengths (first four)
400–1100	2,8,6,1 (2)	4	0.683	0.86	1.049	NA
1100–2500	2,8,6,1 (2)	6	0.720	0.79	0.980	NA
900–1300	2,8,6,1 (2)	4	0.508	1.08	1.14	NA

the skin, the spectral region between 900 nm and 1300 nm is most likely to provide chemical and physical information for the whole depth of the tissue. The remaining parts of the spectrum may well, however, contain useful information. The visible will contain colour information, probably related to both the skin surface and the fruit tissue. The higher wavelength regions of NIR will also, probably, contain information concerning skin properties, which may correlate directly with overall fruit quality factors.

Calibration analysis has been applied to Brix data from mangoes and melons. Table 2 gives the statistics and wavelengths, where applicable. A range of mathematical treatments were applied to the data, but only the calibration analyses with the lowest corrected Standard Error of Prediction [*SEP(C)*] have been reported in the tables below.

The best overall predictive equation is that which is derived from a PLS analysis using NIR region data, with a second derivative treatment, but there is no substantial difference between any of the recorded regression statistics.

Table 3 records the calibration statistics for the Brix values of melon pieces.

The PLS loadings plots from the NIR region mango Brix calibration were also examined (see Figure 4).

Table 3. Calibration statistics for melon pieces Brix measurements.

Stepwise multiple linear regression (SMLR) equation						
Brix range 6.80–10.4 Calibration set = 42 samples						
Wavelength range (nm)	Maths treatment	No. of terms	R^2	*SEC*	*SEP*	Wavelengths (first four)
400–1100	1,4,4,1 (2)	3	0.838	0.37	NA	688, 616 ,428
1100–2500	2,8,6,1 (2)	6	0.832	0.38	NA	1914, 1792, 1894, 1460

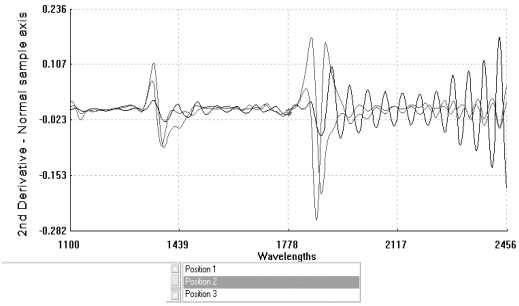

Figure 4. PLS mango Brix calibration loading plots—NIR region.

The plot for the second loading, in particular, shows in Figure 4, a very regular waveform. This was attributed to fluorescent strip lighting reaching the detectors via the fruit surface. Since the plot peak heights in the upper regions of the NIR region indicate that they are important in accounting for the variation in the data and thus contributing to the measurement of Brix, it could be deduced that, although the light is extraneous to the instrument, it is interacting with the sample and thus providing useful data to the regression.

Although not of the highest order of accuracy and precision, these regression equations would enable a user to divide the range of predicted Brix into about three or four segments, enabling a broad band prediction of sugar concentration. To be able to achieve such a measurement rapidly and non-invasively would be most useful to the fresh produce industry.

A further approach was used to examine relationships between NIR data and some quality attributes of fruit and vegetable types. Figure 5 shows a PC scores plot for potato varieties which have been classified either as "floury" or "waxy" when cooked. The plot represents the three PCs that explain the greatest amount of variation in the spectral data with respect to the coded "waxy" and "floury" charac-

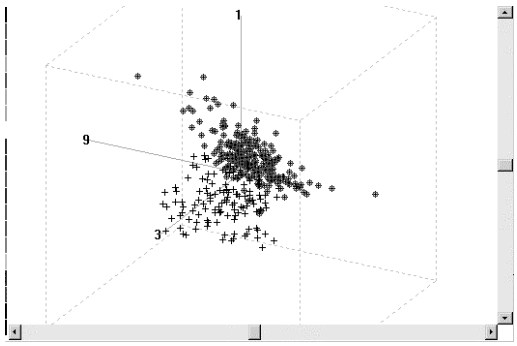

Figure 5. 3D PC scores plot for waxy and floury characteristics for four varieties of potato, two waxy and two floury.
The symbol + denotes spectra from waxy potatoes and ⊕ denotes the spectra from floury potatoes.

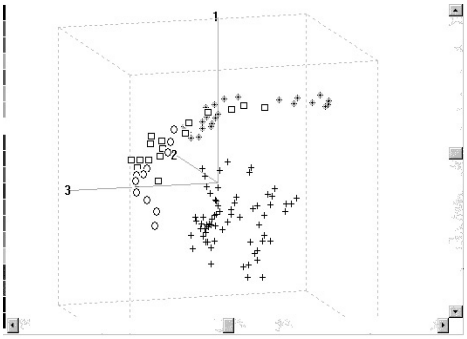

Figure 6. PC scores plot showing the distribution of spectra (visible) in relation to the storage times of apples.
+ represents spectra from two other varieties that were included in the storage experiment. The cross overlaid with a grey circle represents spectra from 0 to 14 days, the rectangle 21 to 35 days storage and the circle 41 to 54 days storage (at ambient).

ters. The PC regression that is derived from this plot gives an R^2 of 0.603. The R^2 and the distribution of the samples on the 3D plot show a useful discrimination of the two types of potato attribute.

Figure 6, using PC score plots demonstrates how storage time relates to apple spectra obtained during the storage period. It shows a clear pattern of distribution along a "horseshoe" for spectra from Granny Smith apples stored up to 54 days and scanned several times during the storage period.

Conclusion

The results obtained from the projects described demonstrate that useful measurements or discrimination of quality attributes can be obtained from whole fresh produce scanned in reflectance.

Reference

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