Combining Near Infrared Spectroscopy and Infrared Aerial Imagery for Assessment of Peanut Crop Maturity and Aflatoxin Risk

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Abstract

The indeterminate flowering pattern, field variability and subterranean podding habit of peanut crops all combine to make maturity assessment very difficult. Less than optimum harvest timing can lead to lower quality produce, resulting from a range of factors including harvest losses, reduced grain filling and associated lowering of kernel grades, and high aflatoxin infection in years conducive to the contamination. These quality-associated factors can substantially reduce grower returns. The research reported in this paper examined near infrared spectroscopy (NIR) and low cost infrared aerial imagery as methods for determining variations in crop maturity in field grown peanuts. Reliable and accurate methods for sampling, processing and statistical analysis of canopy biomass, kernels and shells were developed. Partial least squares regression and discriminant function analysis of pre-treated spectral data identified a number of maturity-correlated wavelengths, while infrared (IR) aerial imagery identified a relationship between canopy reflectance and pod maturity.

Media Summary

Near infrared spectroscopy (NIR) and infrared aerial imagery may provide peanut growers with the ability to remotely assess optimum harvest maturity to maximise grower returns.

Keywords

Peanut, crop maturity, aflatoxin, near infrared spectroscopy, aerial imagery.

Introduction

The use of remote sensing techniques for yield prediction and in-field stress detection within the agricultural industry is not a new concept. However, specific applications such as the use of distinct spectral bands for disease identification and crop maturity assessment from plant canopies have not been widely developed. With peanuts, there has been very little research involving the measurement of harvest maturity and the presence of aflatoxin within the near infrared spectral region, and even less on their measurement through the crop canopy. The identification of specific spectral wavelengths that correlate with maturity-dependant leaf chemical constituents may provide a solution to broad-scale maturity assessment, when applied to hyper spectral imagery. Current methods used for the identification of peanut maturity are predominantly based on physiologically related assessments of the peanut kernel and shell, without any direct assessment of the plant canopy. The main methods currently employed involve the “hull scrape” and “shell out” techniques, which are slow and limited to samples of pods collected from the field (Mackson et al. 2001). If there are significant spatial variations in maturity throughout the field, sampling issues become important and render these methods ineffective for extrapolation to the rest of the crop. The ability to rapidly assess the maturity of an entire crop based on images or field samples collected at specific wavelengths would provide the grower with an important harvest management tool that would maximise yield potential and gross returns. Similarly, in seasons where severe drought stress and high soil temperatures during pod filling prevail, aflatoxin contamination in pods following invasion by *Aspergillus flavus* is likely to occur as kernel moistures decline below about 30%. In these high risk years, research has shown that early harvesting can minimise aflatoxin contamination with only slight reductions in yield, which again emphasises the need for accurate information for growers to make timely harvesting decisions.

This paper reports research that examines the potential use of near infrared spectroscopy (NIR) and low cost infrared aerial imagery to remotely and non-destructively determine variations in crop maturity in field grown peanuts.

Methodology.

Near infrared spectroscopy.

Three field trials on peanut growers' properties were used for this study: Fresser Pivot (irrigated centre pivot) with variety 'Condor' (FP), Bird (dry land field trial) with variety 'Condor' (BC) and Bird (dry land field trial) with variety 'Streeton' (BS). FP samples were taken on April 17th 2003, with pods separated into different maturity groups at each sampling interval. BC and BS samples were taken over a three-month period***,*** with BC canopy samples taken weekly to form a maturity time series. Three, one metre, replicate samples were taken, where each bush in the sample had the central branch removed, were dried at 50?C, then ground and refrigerated until scanning. The samples were placed in a small ring cup and scanned by a NIRSystems model 6500 spectrometer (FOSS NIRSystems Inc., Silver Spring, Maryland, U.S.A.), between the diffuse reflectance range of 400 to 2500nm, at 2nm increments. Peanut pods were also removed from the bushes and divided into three maturity classes, based on the "hull scrape" method. These pods were shelled and separated into kernels and shells, with wavelengths identified for each component. Samples were dried at 50?C and then coarsely ground in a blender. Samples were also placed in a small ring cup and scanned. Initial visual assessment of spectra was made with the image analysis program ENVI (Research Systems Inc. 2004) with the statistical analysis of the raw absorbance data performed with Unscrambler v.8.0 software (Camos AS, Norway). Shells and kernels from three maturity classes were expressed as 1 for immature, 2 for yellow/ orange and 3 for the black, based on the shell pericarp colour. The maturation of peanuts is generally linear with the three above-mentioned classes representing the start, middle and finish of the maturation process. A number of pre-processing methods, including first and second derivatives, multiplicative signal correction and polynomial data smoothing were evaluated before partial least squares (PLS) regression analysis, so as to identify which method produced the result with the highest explanation of the observed spectral variance in terms of the maturity classes. Once the best method was identified, those wavelengths with the largest weighted regression coefficients and therefore the most influential on the regression model were selected.

Aerial Imagery

Aerial images of the FP site were taken on April 17th 2003, flying in a northerly direction, when the sun was close to the solar zenith and at an altitude of 6000ft. Infrared imagery was obtained through a Sony digital camcorder (model DSR-PD100) with a Hoya 58mm R72 filter mounted in the door of a Cessna 185 (G.C. Wright, unpublished data). These images enabled the peanut crop to be segregated into five regions based on IR crop reflectance. Digital images extracted from the AVI video files and saved as TIF files, were imported into ENVI v.3.6. The image data were then georeferenced to Global Positioning System (GPS) positions taken around each site, sub-setted by a region of interest and classified by unsupervised classification into five groups. This camera system does not output digital reflectance data in separate wavelengths so cannot be used to calculate ratios between bands or specific vegetation indices. It does, however, present a raster of pixel brightness values that is useful for density slicing and unsupervised classification. Samples used to ground truth the aerial images consisted of 3 x 1 m rows, taken across three replicates per colour zone. These were taken to coincide with the acquisition of aerial imagery as well as prior to harvest. Samples were processed to provide pod yield and the maturity distribution of pods. These parameters were then correlated to reflectance to determine the accuracy of this system for maturity prediction.

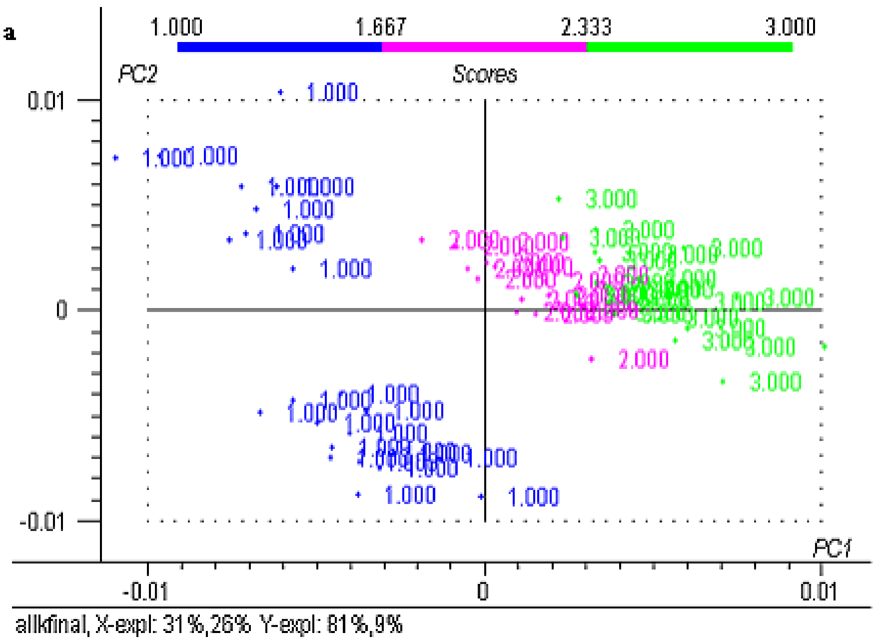
Results and Discussion

Near Infrared Spectroscopy

The distribution of samples from the three maturity classes along the first and second principal component axes is defined in Figure 1a. The first principal component explains 81% of the variance between specific wavelengths and the differentiation of maturity classes. Those wavelengths with the highest weighted regression coefficient (see figure 1b) are the most significant. The individual wavelength 454nm and the range 918- 942nm were identified as the most significant. Absorption at 454nm is attributed to peanut oil, while the 918 - 942nm range represents water. The peanut oil wavelength (454nm) shows a strong positive correlation with maturity, while the water bands have shown a strong negative correlation. Physiologically, these results are sound. As peanut kernels mature their oil content increases, and there is a corresponding reduction in water content.

A similar strong segregation of shells from pods of the three maturity classes was observed from a partial least squares regression, with 92% of the spectral variation in terms of maturity, explained by the first principal component (data not shown). Major absorption peaks were observed at 574, 1654 and 2226nm and troughs at 460, 1428, 1912 and 2274nm. The chemical constituents identified from previous research as corresponding to the significantly related wavelengths were predominantly cellulose and fatty acids.

1a



1b

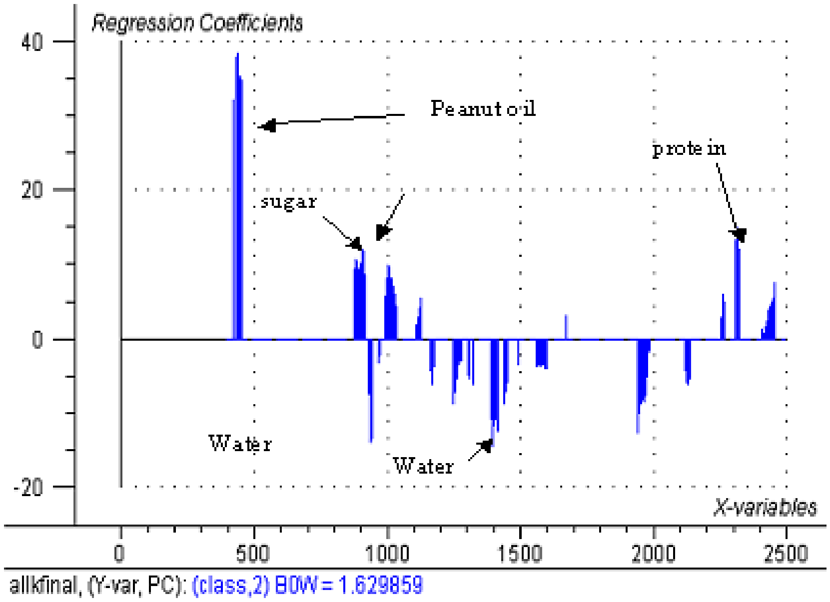
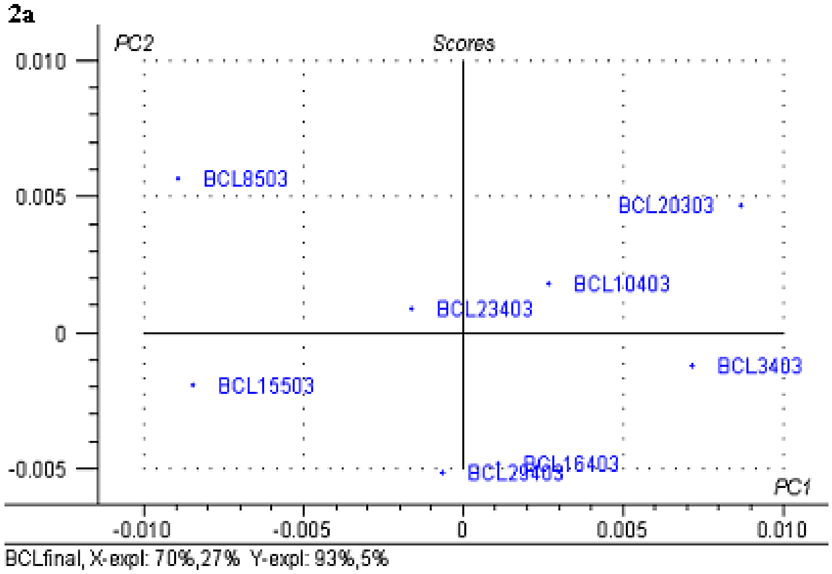


Figure 1. Kernel maturity class distribution; 1= immature, 2= yellow/orange, 3= black. identified through polynomial data smoothing and a second derivative pre-treatment (1a). Partial least squares regression analysis identified the wavelengths of interest (1b).

The distribution of leaf samples from eight sampling dates across the first and second principal component axes are identified in Figure 2a. The dates are chronologically distributed across the first principal component axis from right to left. The first principal component explains 93% of the variation in spectra in terms of maturity dates. The wavelengths defined in the top right graph are the most significant in the calibration model. The wavelengths 536, 594, 610, 1414 and 1912nm showed the highest weighted regression coefficients for a positive correlation with absorbance, while 474, 506 and 720nm exhibited the highest negative correlation.

2a



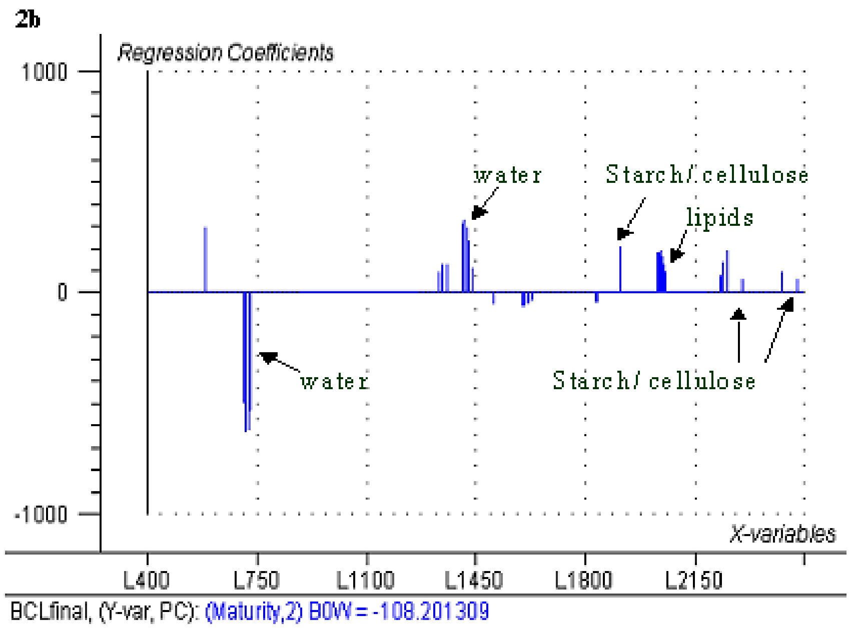
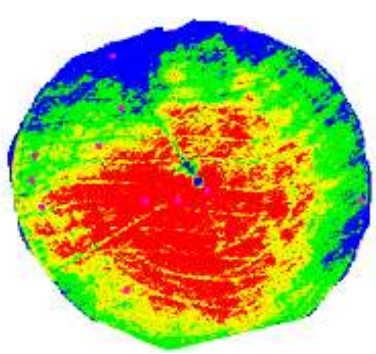
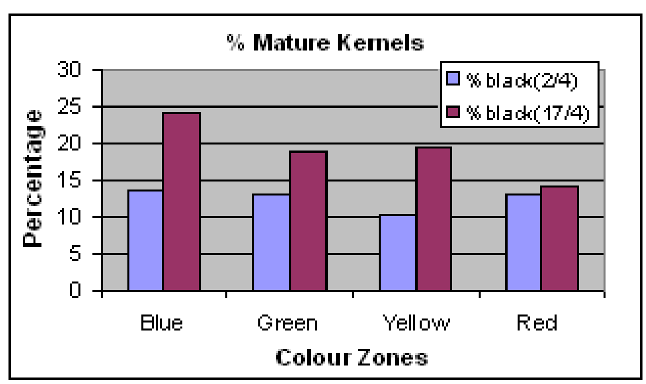


Figure 2. Distribution of leaf maturity samples (2a) and significant wavelengths (2b) from partial least squares regression of polynomial smoothed and 2nd derivative pre- treated spectral data. BCL- Bird (the grower), Condor (the variety) and Leaf.

Aerial Imagery.

Infrared aerial imagery of the centre pivot at Fressers' farm (figure 3a) identified a strong correlation between colour zones and pod maturity class distribution. These findings indicated a high probability that specific wavelengths within the NIR spectral range correlate to variations in pod maturity. Pod samples (pink dots) obtained from the various colour regions in Figure 3a were segregated into three maturity classes based on the hull scrape method. Figure 3b shows there were a higher percentage of black (mature) pods in the blue (low vigour) regions of the paddock, which decreased as crop vigour increased (i.e. in green- yellow- red regions).





3a. **3b.**

Figure 3. Aerial image of the Fresser centre pivot displaying variation in crop canopy reflectance (a) and pod maturity distribution within each colour zone on two sample dates (b).

Conclusion

The results presented here demonstrate that NIR spectroscopy is a viable method for measuring internal chemical constituents of peanut leaves, kernels and shells that correlate with harvest maturity. Spectral indices derived from sensitive wavelengths could lead to the development of non-destructive sensors that can operate with existing colour sorters for enhanced quality assurance. The IR aerial imagery has the potential to provide a useful decision support tool for peanut growers to assist them in making better-informed decisions regarding optimal harvest times, as well as the potential for segregating regions on the crop based on differing maturities (Wright et al., 2002). The technology may allow growers to formulate harvest regimes that can maximise yield, quality and reduce aflatoxin risk.

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