Spectral methods for quantifying seed colour change in maturing Canola for time of windrowing decisions

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Abstract
Windrowing canola within the optimal window for windrowing can improve yield and reduce quality penalties such as green seed being present after windrowing. However it is the subjective nature of assessing seed maturity that makes it difficult to determine the optimal time for windrowing. A quantitative alternative to the current subjective seed colour percentage assessment was sought using spectral information and colour space analysis using two different sensors. A chroma meter, a portable colorimeter that is able to measure small samples and a field spectrometer was used to measure the spectra of maturing seeds and siliques (pods). The field spectrometer was also used to measure the canopy spectra in the field. An L*a*B* colour space analysis was used and it was found that the a* and B* colour spaces axis (both colour-opponent dimensions) did relate seed colour to silique and canopy colour. This appears to be promising as a quantitative method to make informed windrowing decisions. Moisture content was also assessed and it was also found to correlate to the seed colour change and the a* and B* colour space measures.

Keywords
Remote sensing, chroma meter, colour space, hyper spectral sensing.

Introduction
Currently the colour of canola seed is used to determine optimal time to windrow and desiccate canola. It is regularly recommended that windrowing should occur when 40 – 60 % of seeds have changed colour (Hertel 2013). While this advice remains consistent across the various national grains / canola production bodies the interpretation of what 40 – 60 % seed colour change means is subjective and can cause confusion amongst growers and advisors.

A survey conducted by Hertel (2011) in NSW examined the practices and perceptions of growers, advisors and contractors highlighting the confusion of when to windrow. A number of different rules of thumb were described and at least 13 examples of different definitions of seed colour change were provided. Identification of a quantifiable measure of canola seed colour change would reduce the confusion of how to identify the correct time to windrow and could reduce the significant yield and quality losses being experienced by the industry caused by windrowing too early (Graham et al. 2016). Hertel (2013) quantified these losses with windrowing 7 days prior to the optimal seed colour resulted in a decreased yield of 800 kg.

The use of colour space analysis has previously been used throughout the food processing and production industry for performing tasks such as quantifying the colour of cereal grain and flour (Black and Panozzo 2004). L*a*B* values which were defined by the Commission Internationale de L'Eclairage (CIE) are used to describe colour in three dimensions. The L* axis represents lightness and the a* and B* are colour-opponent dimensions with the a* axis defining red to green and the B* axis defining yellow to blue. L*a*B* values can be calculated using spectral data through converting the spectral reflectance data to tristimulus XYZ values and further converting these values to L*a*B* values. Colorimeters or Chroma meters work within the visible light spectral range often using a tristimulus sensor.

The aim of this research was to identify and compare different methodologies of quantifying canola canopy, silique and seed colour change through colour space analysis in order to determine whether seed colour can be inferred from silique and canopy colour.

Methods
Location
This experiment was conducted in Hamilton at the DEDJTR Research Farm (Longitude 142.05, Latitude -

37.75), with an average rainfall of 690mm and an elevation of 175 m. The canola crop was grown on Chromosol soils.

Plant Material and Experimental Design
This project utilised plots sown within the canola phenology evaluation trial (GRDC project DAV00141). The trial consisted of 21 early, mid and late maturing varieties that had a range of 44 days in flowering time from a May 7 sowing date. The experimental design was a randomised block design with 4 replicates.

Laboratory Setup
For accurate results all surfaces within the vicinity of the spectrometer were painted matt black to avoid reflection. The ASD Field Spectrometer (Analytical Spectral Devices, Boulder, Colorado, USA) was mounted on a small tripod using a pistol grip holder. The sensor was directed straight down over the target area. Two halogen lamps were placed at a 45 degree angle above the sample area to ensure the sample was fully illuminated. The chroma meter did not require the same level of environmental control due to it having an internally calibrated light source.

Data Collection
Data was collected in both the field and the lab on December 12 when the individual varieties covered a range in seed colour from 100% green to 100% black. In the field the ASD Field spectrometer was used to collect spectral data of the canopy of standing canola plants. The spectrometer was calibrated every 20 plots using a white plate to account for change in solar illumination. For each plot three measurements were taken and a visual weed score was also recorded on a 1-10 scale (1 = no weeds present, 10 = complete ground cover of mature weeds). Within hours of the field spectrometer measurements a sample of 100 siliques were collected from each plot, the siliques where taken at random from various levels of the canopy.

In the laboratory a random sub-sample of 24 siliques were taken from each sample and the seeds of the remaining siliques were then removed to produce a seed sample for each plot. Three sub samples (15ml) of seeds from each plot were taken and placed in small matt black vessels to limit any reflectance. A chroma meter (CR400, Konica Minolta, Japan) was then used to measure colour space data including XYZ data, CIELAB L*a*B* data and CIE L*C*h data. Each of the sub samples where then placed under the spectrometer sensor and a measurement of the spectral reflectance from 350 to 2500nm wavelengths was collected.

The seed samples were then visually scored for percentage of brown seed by a minimum of three people and averaged to give a plot percentage brown seed score. The seed samples were then weighed and dried in a fan forced oven at 100º C to a consistent weight and reweighed to determine the moisture percentage of the seeds. The siliques were randomly grouped into three sub samples of eight siliques. Each group of eight siliques where placed adjacent to each other on a matt black board for analysis by the chroma meter and spectrometer. All 24 siliques were combined, weighed and dried using the same procedure as the seeds to determine percent moisture.

Data Analysis
Prior to data analysis the data for each data set was averaged for each plot. Field spectral data was corrected for the changing light conditions using the white plate calibrations and sample time data on a minute by minute basis. Spectral data was converted to CIE tristimulus XYZ values with a standard 2°Observer as described by Black and Panozzo(2004). Two methods were then used to convert the XYZ values to colour space values, the first continued the method from Black and Panozzo (2004), the second used a XYZ to L*a*B* conversion table published by Konica Minolta. Each method used a 2° Observer and a D65 illuminate level in line with the internal calculation of the chroma meter. Coefficients of determination with a linear model were used to determine relationships within the data and t-tests were performed to measure the significance of the relationships.

Results and Discussion
Baseline Maturity Measure
The reference for comparing methodologies was the visual score as it is current industry practice. Seed colour was considered to have changed to brown as soon as any portion of the seed had changed colour from green.

The percentage of moisture in the seed also provides a measure of seed maturity. Analysis of the visual seed colour score and seed moisture percentage supported this with a strong correlation ($R^2 = 0.731$). A relationship ($R^2 = 0.615$) was also seen between the silique moisture content and seed colour change. Due to the strong correlation between seed colour and seed moisture content both of these data sets were used as a baseline scale of maturity and seed colour.

Chroma Meter

The L*a*B data derived from the chroma meter was analysed on an individual axis basis against the baseline data with varying levels of relatedness to the three colour axis (see Table 1).

Table 1. Chroma meter L*a*B* data coefficients of determination (R^2) with visual assessment of seed colour change and moisture comparisons.

	Seed % Brown	Seed % Moisture	Silique % Moisture
Seed L*	0.798*** (30.98)	0.617*** (4.196)	0.530*** (4.177)
Silique L*	0.098*** (25.99)	0.180*** (1.811)	0.175*** (1.819)
Seed a*	0.413*** (32.99)	0.171*** (6.293)	0.120*** (6.272)
Silique a*	0.706*** (28.51)	0.756*** (3.761)	0.731*** (3.747)
Seed B*	0.819*** (22.83)	0.772* (5.393)	0.659** (5.423)
Silique B*	0.466*** (31.58)	0.668*** (6.016)	0.632*** (5.990)

*** = P < 0.001 ** = P < 0.005 * = P< 0.01 Standard deviation in brackets

While there were varying levels of relatedness between the baseline data and the various colour space axis the B* axis stood out as being consistently strongly correlated. The a* axis showed strong correlations at the silique level however was a lot more variable at the seed level of baseline data. Although strongly correlated to the baseline seed data the L* axis readings were not well correlated with the silique chroma meter data.

Spectral Reflectance Derived Colour Space

The two methods tested to convert spectral reflectance data to L*a*B* colour space data showed high correlations ($R^2 = 0.99$). The individual values did vary slightly however the variation was consistent across both data sets with the variation being less than 0.2. With the strong correlation between the two data sets the Black and Panozzo (2004) L*a*B* methodology was chosen to analyse individual axis.

With the addition of the field spectrometer, data was collected on three levels, seed, silique and canopy. With the extra dimension it was possible to relate in field canopy colour to seed colour derived in the laboratory (Table 2). The L* axis was accurate when correlated to the seed level of baseline data; however this relationship was poor when comparing silique and canopy data.

Table 2. Spectral reflectance derived L*a*B* colour space coefficients of determination (R^2) by sample type and colour space axis.

	Seed % Brown	Seed % Moisture	Silique % Moisture
Seed L*	0.870*** (32.91)	0.834*** (6.053)	0.733*** (6.029)
Seed a*	0.490*** (25.63)	0.165* (2.204)	0.104 (2.208)
Seed B*	0.821*** (35.51)	0.879*** (8.954)	0.776*** (8.929)
Silique L*	0.155*** (28.63)	0.260*** (3.411)	0.237*** (3.397)
Silique a*	0.786*** (23.01)	0.763 (4.822)	0.733 (4.852)
Silique B*	0.685*** (31.81)	0.808*** (5.414)	0.751*** (5.386)
Canopy L*	0.277*** (28.73)	0.338*** (2.851)	0.296*** (2.837)
Canopy a*	0.819*** (24.12)	0.660** (3.423)	0.569* (3.445)
Canopy B*	0.671*** (30.42)	0.750*** (3.858)	0.672*** (3.835)

*** = P < 0.001 ** = P < 0.005 * = P< 0.01 Standard deviation in brackets

Surprisingly the a* axis of data taken at the seed level did not correlate well with both the known colour and moisture data with the a low R^2 value for moisture related baseline data. The L* and B* axis did however show strong relationships across the baseline data set.

When comparing silique colour to seed colour previous research suggests that there is not a relationship in the colour of the silique and the seeds inside the silique. This was true for the L* axis however the a* and B* axis did show a strong correlation to the seed colour and moisture baseline data. On further analysis comparing the different sample types within the same colour axis the B* axis showed strong relationships when comparing within the spectral data (Figure 1).

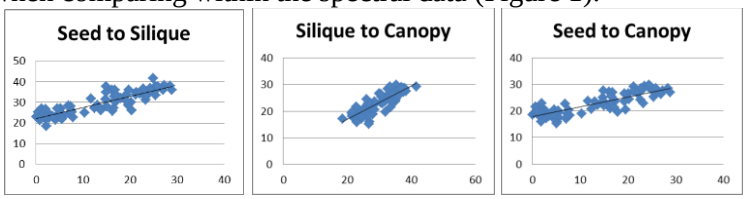

Figure 1. Relationship between spectral data between different sample types of the B* colour axis, with a linear trend line applied with R^2 values of 0.777 for seed to silique, 0.762 silique to canopy and 0.714 seed to canopy.

Comparison of Colour Space Methods

The ability of the spectrometer to assess colour change in the field with a completely non-destructive method would allow for multiple assessments with minimal effort and no crop damage on a regular basis to optimise the timing of windrowing. This would be enhanced once accurate reliable spectral sensors can be deployed on Unmanned Aerial Vehicles mounted and a whole paddock could be mapped for maturity variation. Currently the spectrometer is limited to days with clear skies, while changing light conditions can be corrected to a point it does cause a decrease in accuracy. While there were varying relationships between the quantitative method and the baseline data there was a trend of the colour opponent dimensions (a* and B* axis) to have a better correlation to the baseline data across all the sample types. In contrast the L* axis showed greater variability and this is thought to be due to its higher sensitivity to changing light sources. The Chroma meter showed promise to using the B* axis however more data and analysis is need to validate this.

Conclusion

In contrast to previous belief colour correlations were found between canopy colour, seeds and siliques within two axes of the L*a*B* colour space. This demonstrates that using colour space analysis to inform windrow timing decisions has potential to be developed with further research and refinement. Exploring the colour-opponent dimensions and exploiting the broader spectral reflectance wavelength data to examine various water indices in particular is a future direction of this research. It is hoped that this research could be developed into a spectral index that when used with UAV and remote sensing technology could give growers and consultants a measure of whole paddock maturity as well as paddock wide variability of maturity.

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