PE3.04 Estimating Meat Color From Near Infrared Spectral Measurements 259.00

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***Abstract*—Color and color changes are important in quality assessment of meat products being observable consequences of the physical and chemical properties of this product. As suggested by a local meat industry, color estimation using near infrared (NIR) measurements could be useful in the case of small or not specialized laboratories since this instrumentation is ubiquitous in food research and quality control laboratories. In order to study this possibility we have conducted an experiment to determine the presence of such relationship in meat. We have measured the visible (VIS) reflectance, CIELAB L*, a* and b* color coordinates and the near infrared reflectance of a set of meat samples. Principal component analysis of spectral data shows that 99% of the sample variance can be explained by just four principal components for both VIS and NIR spectral bands. High correlation has been found between VIS spectral data and color coordinates. Mean CIELAB □E* color differences of 0.68 units have been found between measured and predicted color using a linear regression analysis with VIS spectral data. NIR data is not highly correlated with VIS or color data. However color estimation with a linear regression model with NIR data gives average □E* color differences of 3.32 units, which is only slightly above human discrimination thresholds. Hence the possibility of using NIR spectral data to estimate meat color depends on the precision requirements.**

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***Index Terms*— NIR, meat color, meat oxygenation, VIS**

I. INTRODUCTION

COLOR is one of the most important sensory attributes of meat products. Color depends on the sample reflectance in the visible range and can be measured with the required precision using the appropriate instrumentation (colorimeters, spectrocolorimeters, spectroradiometers, etc). In the food industry measurements are also performed in the near infrared (NIR) to obtain quantitative estimations of certain parameters.

As suggested by a local industry, it would be interesting to estimate the color of a food product like meat using NIR instrumentation solely. This possibility requires meat optical properties in the VIS and NIR to be related. This is a point of general interest that has not been studied in the past.

Meat color depends on several factors like breed, sex, animal age or pH but once they are fixed, the main factor responsible of colour and colour changes is the evolution of the surface concentrations of haeminic pigments, particularly of myoglobin and its chemical state [1, 2].

For a given breed, sex, age, pH and muscle, meat color and meat reflectance in the visible (VIS) range, mainly depend on the amount of myoglobin and its chemical state and the relative proportions of reduced myoglobin, oxymyoglobin and metmyoglobin. From reflectance values at the isobestic points (474 nm, 525 nm, 572 nm and 610 nm) the K/S ratios, where K and S are the absorption and scattering coefficients respectively, can be calculated and the relative proportions of the three forms of myoglobin obtained [3]. In fact any three wavelengths, not necessarily isobestic, can be used [4-6].

NIR spectra also depend on the physical and chemical properties of the sample. However it is not known if NIR and VIS and color data are related in some way. In this work we present the results of a study to determine the possible relationships between both spectral ranges and, in particular, about the possibility of predicting meat color from NIR measurements alone.

II. MATERIALS AND METHODS

A. Meat samples and measurement procedure.

If we want to find a relationship between VIS and NIR measurement we require variability in the optical properties of the studied samples. However samples must be comparable in basic aspects like breed, sex, muscle, etc.

In this experiment meat samples were obtained from beef longissimus dorsi muscle, purchased in local butcher shops belonging to the Appellation of Origin “Ternera de Navarra”. This guarantees homogeneity respect to muscle, breed, sex and age. On the other hand each meat sample was obtained from a different butcher shop and different animal, providing some initial variability. Color variations were further obtained by measuring the samples at different oxygenation times during the first 48 h after the first measurement. In total our data set consist in 30 different measurements obtained from six meat samples measured at five different oxygenation times (0, 2, 6, 24 and 48 h).

Samples were wrapped with oxygen permeable film and kept at 4 ºC in the refrigerator between measurements.

B. VIS measurements

Measurements in the visible range were made with a Dr. Lange Spectra-color spectrocolorimeter. The instrument uses diffuse/8º (d/8º) illumination/measurement geometry and provides the spectral reflectance in the visible range between 400 nm and 700 nm at 10 nm intervals. Instrument calibration was performed before each measurement session using the calibration white and black tiles supplied with the instrument. Calibration and measurements were made with the specular component included. Each measurement consisted in the average of ten different readings at different locations in the sample.

The instrument also provides the color coordinates in several color coordinate systems. In this experiment CIELAB color coordinates were calculated for the D65 standard illuminant and the 10º standard observer. In particular L*, a* and b* coordinates have been used. Color differences between two color stimuli have been calculated according the CIELAB ΔE* color difference formula [7]:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

C. NIR Measurements.

Measurements in the near infrared were made with a Polychromix Digichrom DX fiber optic NIR spectrometer. An Ocean Optics HL 200 halogen light source was used to illuminate the sample through the contact fiber optic illumination/measurement accessory. The instrument provides the spectral reflectance in the NIR region between 937.8 nm and 1694 nm at intervals of 7.7 nm. The instrument was calibrated with a white diffuse reflectance. Each measurement consisted in the average of ten different readings at different locations in the sample.

III. RESULTS AND DISCUSSION

A. VIS and NIR reflectance spectra and color.

Figure 1 shows and example of the VIS and NIR spectra of one sample. In this case it is a measurement after 2 h of oxygenation. The two depressions corresponding to oxymyoglobin are clearly visible around 550 nm. Oxygenation time is too short to observe the characteristic depression around 630 nm due to the metmyoglobin. In the

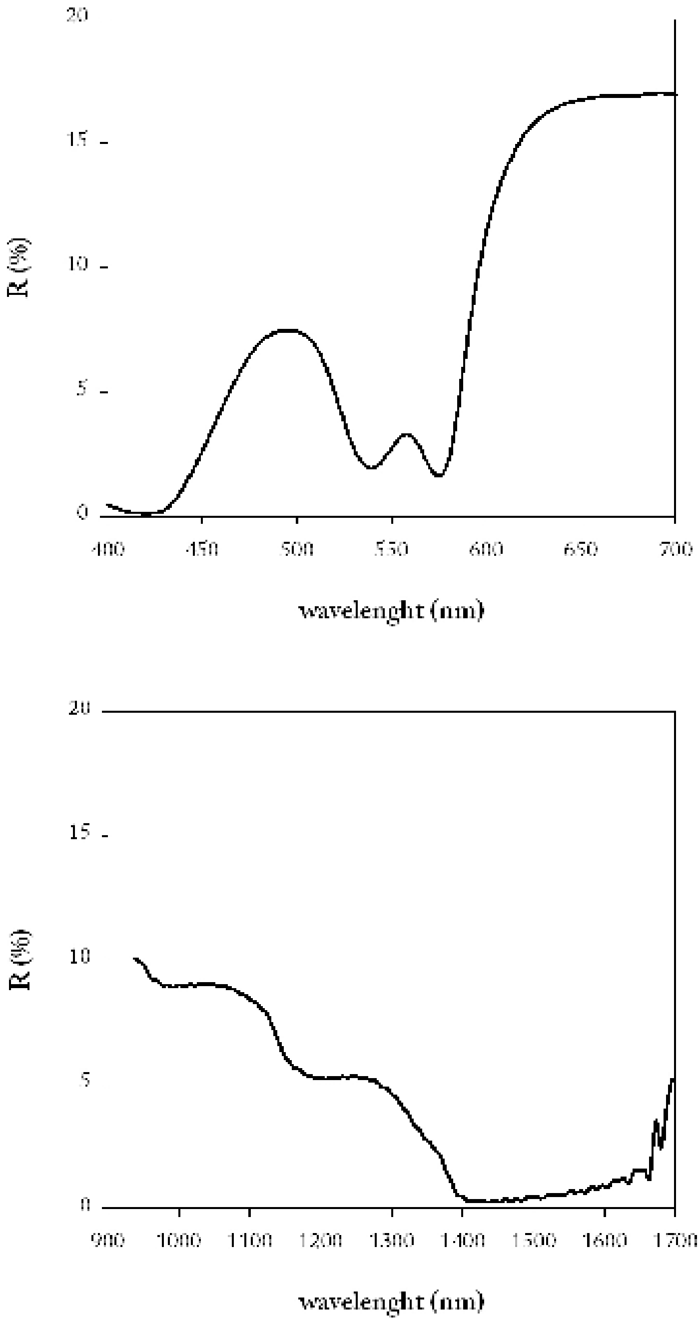

Figure 1. The reflectance spectrum of one sample of beef *longissimus dorsi* in the VIS (top) and NIR (bottom).

NIR region reflectance decreases to very small values for wavelengths greater than 1400 nm. In fact reflectance remains very small up to 2500 nm [8] (in our example some measurement noise can be seen at the end of the NIR spectrum). In all subsequent analysis only NIR data up to 1400 nm have been used. The basic spectral characteristics of our samples in both VIS and NIR coincide with published results [4, 8].

As expected from the measurement strategy, color coordinates vary within our sample set. In particular CIALB L* varies between 22 and 34 units, a* between 17 and 29 and finally, b* between 10 and 15 units. These values are in accordance with values reported in the literature [6, 9, 10]

B. Principal component analysis.

Once we have checked that our data is within the expected values, we can search for a relationship between VIS and NIR. Fist we have used a standard principal component analysis to reduce the number of variables in VIS and NIR data. In Table 1 we show the percentage of variance explained by the first four principal components denoted VIS 1 to VIS 4 and NIR 1 to NIR 4 for VIS and NIR data respectively.

In figure 2 we also show the first four principal components in both spectral regions. Four principal components explain 99% of the total variance for both visible and near infrared data. This is what we should expect in the VIS range, since reflectance and color depends on the three chemical states of the myoglobin and on the substrate. Our data show that the same situation is found in the NIR region. However differences between NIR spectra are smaller. In consequence the variance explained by the first principal component NIR 1 (92.82%) is higher than for the VIS 1 component (75.04%). Since the first component is weighting the spectral average, this fact means that spectral differences are more important in the VIS region than in the NIR region. The different distribution of explained variance between principal components also suggests that the relationship between both data sets is not simple.

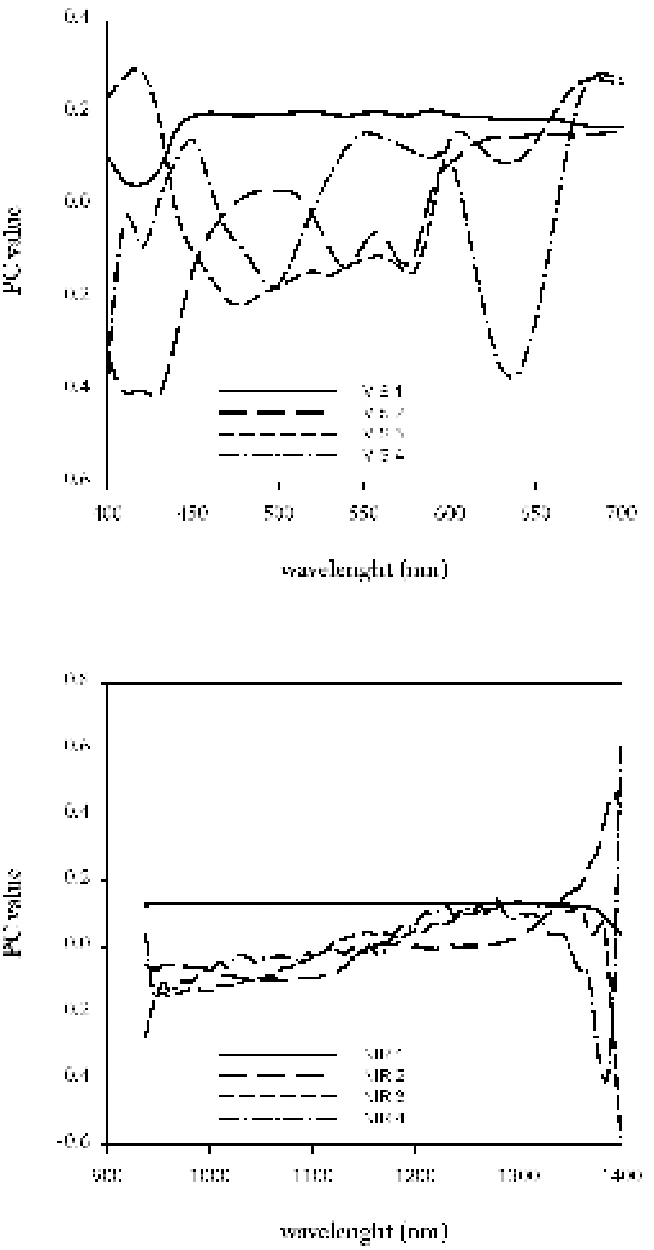

Figure 2. The first four principal components in the visible range (top) and near infrared (bottom).

Table 1. Percentage of total variance explained by the first four principal components in the visible (VIS 1 to VIS 4) and infrared (NIR 1 to NIR 4) ranges.

Principal Component	Visible		Near Infrared	
	Name	% variance	Name	% variance
1	VIS 1	75.04	NIR 1	92.82
2	VIS 2	14.65	NIR 2	5.25
3	VIS 3	7.27	NIR 3	1.17
4	VIS 4	2.03	NIR 4	0.09
Total		98.99		99.33

Table 2. Pearson correlation coefficients between sample loadings of the first four principal components in the visible and infrared ranges.

	VIS 1	VIS 2	VIS 3	VIS 4
NIR 1	ns	0.492**	ns	ns
NIR 2	ns	-0.541**	ns	0.491**
NIR 3	ns	-0.684**	-0.383*	0.635**
NIR 4	-0.476**	-0.789**	-0.448	0.642**

ns: not significant, * p<0.05, ** p<0.01

Table 3. Pearson correlation coefficients between sample CIELAB L*, a* and b* coordinates and the loadings of the first four principal components in the visible and infrared ranges.

		L*	a*	b*
Near infrared				
	NIR 1	ns	ns	0.511**
	NIR 2	ns	ns	-0.424*
	NIR 3	ns	ns	-0.433*
	NIR 4	-0.395*	ns	-0.433*
Visible				
	VIS 1	0.985**	-0.677**	ns
	VIS 2	0.631**	ns	0.558**
	VIS 3	ns	0.462*	0.744**
	VIS 4	-0.498**	ns	ns

ns: not significant, * $p<0.05$, ** $p<0.01$

For each sample the spectral data can be accurately recovered as a linear combination of just four principal components, with some particular loadings or coefficients. Principal components are by construction orthogonal (uncorrelated) but sample loadings are not. The correlation between sample loadings in the VIS and NIR inform us about the strength of the relationship between both spectral ranges. In Table 2 we show the Pearson correlation coefficients between sample loadings in VIS and NIR. NIR components are correlated with VIS 2 but not correlated with VIS 1. Although correlations are significant between the third and fourth components, their influence in explaining the observed variability in the data is small.

Correlation between CIELAB color coordinates and NIR components is weaker than in the VIS case (Table 3). In particular a* is not linearly correlated ($p>0.05$) with any of the NIR components. On the other hand, each color coordinate is significantly correlated with several VIS components, an expected result since color coordinates directly depend on the reflectance spectra in the visible range.

C. Color differences

Four principal components explain 99% of reflectance data in the visible range. Color coordinates are obtained from the reflectance data and we expect that color coordinates can be also reproduced with the VIS 1 to VIS 4 principal components. Using a multiple linear regression model we have obtained predicted values for L*, a* and b* coordinates from the sample loadings on the four principal components. As expected from the observed correlation between color coordinates and VIS components (Table 3) the linear model accurately predicts the observed values. The adjusted R^2 values obtained are $R^2=0.993$ (L*), $R^2=0.973$ (a*) and $R^2=0.851$ (b*). Good correlations however may not be sufficient since color differences between samples depend on absolute values. We have also computed the absolute color difference ΔE* between model predictions and measured values. It has been found that ΔE* is between 0.23 units and 1.69 units, being on average 0.68 units with a standard deviation of 0.29 units.

We repeated the same analysis for the NIR region, fitting the CIELAB color coordinates using the NIR 1 to NIR 4 principal components. In this case the adjusted R^2 values were $R^2=0.413$ (L*), $R^2=0.156$ (a*, statistically not significant) and $R^2=0.239$ (b*). Mean CIELAB color differences ΔE* between original and fitted data were 3.32 (standard deviation is 1.7) with a minimum value of 0.95 and a maximum value of 6.4.

On average color differences obtained from NIR data are 4.9 times greater than those obtained from VIS data. In fact, if we consider ΔE*=3 units as an estimation of acceptable color differences [11] then color differences estimated from VIS data are well below the human discrimination thresholds. Color differences obtained from NIR data are slightly above the discrimination threshold but may be nevertheless small enough if high precision is not required.

IV. CONCLUSION

It has been found that both VIS and NIR spectral reflectance data of *longissimus dorsi* muscle of beef samples can be accurately described using the first four principal components (99% of explained variance). Using those principal components and the measured CIELAB L*, a* and b* color coordinates we have analyzed the relationship between VIS, NIR and color data obtaining the following main results.

As expected, VIS spectral data is correlated with color data. In fact color can be accurately predicted using a linear model and the VIS principal components. The mean CIELAB ΔE* color difference between measured and predicted color is 0.68 units and therefore below the human color discrimination threshold. This result is even more noticeable if we consider that CIELAB color coordinates are not linear functions of the reflectance.

Color and VIS spectral data are not highly correlated with NIR spectral data. Color coordinate predictions with a linear model based in NIR components give average CIELAB ΔE* color differences slightly higher than human discrimination thresholds. However, NIR spectral data may be used to predict meat color if the required precision is not that severe. Furthermore, results may improve if the spectral region 700-900 nm (not studied in this work) is included.

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