A Comparison of Meat Colour Measurements From a Colorimeter and Multispectral Images.

C H. Trinderup[a], A L. Dahl[a], K. Jensen[b], J M. Carstensen[a,c], and K. Conradsen[a]

[a] *DTU Compute, Technical University of Denmark, Matematiktorvet, Building 303B, 2800 Kgs. Lyngby, Denmark*
[b] *Danish Meat Research Institute, Maglegårdsvej 2, 4000 Roskilde, Denmark*
[c] *Videometer A/S, Lyngsø Allé 3, 2970 Hørsholm, Denmark*

Corresponding author: ctri@dtu.dk

Introduction

Consumers select products based on colour, especially with fresh products, such as fruit, vegetables, and meat (Francis, 1995). This choice is associated with their earlier experiences, and acceptance relies on these (MacDougall & Hutchings, 2002). Consistent and objective colour assessment is therefore important in the fields of research, product development, and quality control (Wu & Sun, 2013). Within food science the CIELAB colour space is often applied for colour evaluation. This colour space corresponds well with the colour perception by humans (León et al., 2006), which is advantageous when comparing with results of a sensory panel.

This study focuses on the assessment of meat colour. The standard instruments for colour measurement are colorimeters and spectrophotometers. A colorimeter is a so-called tristimulus instrument that employs filters in order to obtain colour values (Hunt et al., 1991). The colorimeter is a handheld instrument, where the operator measures a sample at a number of sites. These sites are chosen depending on the sample, e.g. to avoid meat tendons and intramuscular fat. This makes the measurements subjective and hard to reproduce (Larraín et al., 2008). Furthermore, these site measurements do not always reflect the colour variation of the entire sample (Mancini & Hunt, 2005).

To overcome some of the limitation of the colorimeter we suggest using a multispectral imaging system. We map the detailed images to the CIELAB colour space using a photometric imaging model. We compare the colour assessment of our visual system with a standard colorimeter for different meat types using the CIELAB values. Unlike the colorimeter, the imaging system measures the spatial colour variation across the entire sample.

Food colours have previously been assessed using visual systems by converting RGB images to sRGB images and then to CIELAB values (Larraín et al., 2008; Mendoza et al., 2006; Blasco et al., 2003; Chen et al., 2002; O'Sullivan et al., 2003; Yam & Spyridon, 2004). Wu & Sun (2013) emphasize that the RGB images, amongst other issues, are dependent on the sensitivity of the camera employed, and cannot be directly transformed to sRGB in a consistent manner. As a result, the reproducibility and objectivity of the colour assessment is compromised. By applying a multispectral vision system, the advantage of more spectral information is achieved, but also the robustness and consistency that is needed for colour assessment. In addition, mapping by the photometric imaging model is a direct way of obtaining the CIELAB values. We therefore chose to use multispectral images for our colour assessment.

Yagiz et al. (2009) reported a study similar to ours on differences in colour measurements from a colorimeter and a RGB vision system for fresh salmon fillet colour. The study revealed that despite the fact that similar results were obtained from calibration plates for the two assessment methods, the measured colour of fresh salmon differed. The colour recorded by the vision system closely resembled the perceived colour of the fillets, whereas the colorimeter returned grayish colours.

In this study we investigated meats from livestock animals and poultry, both fresh and processed types. Working with these two types ofproduct under the same conditions made it possible to investigate how the processing of the meat influenced the colour assessment. The basis of the analysis was a variance component analysis considering all of the possible effects influencing the colour assessment. First and foremost the analysis established that the two methods assessed the colour components differently, especially the chromatic components, a* and b*. The difference depended on the type of the sample, since the measurements of processed and fresh meat showed different behaviours. This indicated that the reflectance properties of the samples influence the colorimeter more than the multispectral vision system. The results are in accordance with the results of Yagiz et al. (2009) and support the advantages of using a vision system for colour assessment in food science.

Materials and Methods

Our investigation of meat colour employs a colorimeter, a multispectral vision system - the VideometerLab (www.videometer.com), and a range of meat samples.

Meat Samples Our choice of meat samples aimed at representing the natural colour variation occurring in meat. Samples ranging from dark red fillet steak to lighter red pork loin and turkey breast were considered, as well as different products of processed meat. In all, 12 different meat products were investigated, seven fresh and five processed. Within each type there were five samples, giving a total of 60 samples. Each sample was approximately 2 cm in height and after defrosting the sample was left for at least an hour. The samples of veal and beef were left for at least 80 minutes. Before colour assessment the samples were lightly dried with a napkin to remove surface liquids that can influence the measurements.

Figure 1: Left: Calibration procedure for the colorimeter Minolta CR-300. Right: The multispectral imaging system VideometerLab.

Colorimeter We used a Minolta CR-300 colorimeter. Each of the meat samples was measured at four circular sites, each with a diameter of 11 mm. The measurements were performed under D65 standard illumination. Besides choosing a suitable position on the sample for measurements, the operator had to be aware of the pressure of placing the instrument onto the sample, because this influences the measurements. Briggs et al. (1998) point out that the sample must have the same temperature as the instrument to obtain stable colour assessment. The instrument is seen in Figure 1.

Multispectral Imaging System The experiment employed a VideometerLab for capturing multispectral images. The instrument is seen in Figure 1(right). It has 20 spectral bands in the range 410 nm - 955 nm and the images are all 2056 × 2056 pixels. The sample of interest is illuminated by LEDs at the given wavelengths under a light-integrating sphere. This diffuse illumination ensures that specular reflectance is to a large extent avoided.

To gain colour information from the multispectral images a photometric imaging model (PIM) was employed. The model was inspired by the work of Lasarte et al. (2006) and Hardeberg (2001) and combines the spectral information of the LEDs seen in Figure 2(left) with the CIE XYZ standard colour matching functions (CMF) at illumination D65 shown in Figure 2(right). The PIM was based on a fit of the LED spectral bands to each of the CMFs. This fit was found by finding the least squares solution to

$$\min_{W} \| AW - B \|$$

Each column of *A* holds information on one of the 12 visible bands of the VideometerLab and the columns of *B* each represent a colour matching function. The resulting *W* will be the weights of each spectral band for mapping from multispectral pixel information to X, Y and Z respectively. The fit of the spectral bands to the CMFs are seen with solid lines in Figure 2(right). Three images of X, Y and Z values were obtained by applying the weights to each pixel in the series of multispectral images. The pixel-wise X, Y and Z information was mapped to the CIELAB color space by the non-linear transformation (ISO/CIE Standard, 1976)

$$L^* = 116 \cdot f\left(\frac{Y}{Y_n}\right) - 16$$

$$a^* = 500 \cdot \left(f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right)$$

$$b^* = 200 \cdot \left(f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right)$$

with

$$f(q) = \begin{cases} q^{1/3}, q < 0.008856 \\ 7.787q + 16/166, q > 0.008856 \end{cases}$$

By this conversion of the X, Y and Z images, three images with pixel values representing L*, a*, and b* values were obtained.

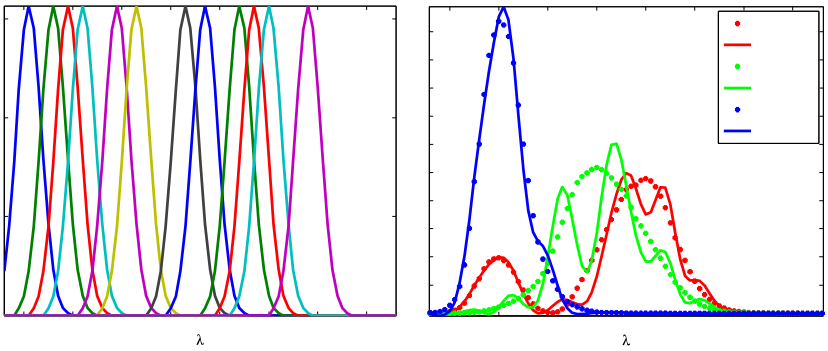

Figure 2: Left: Spectra of the LEDs of the VideometerLab. Right: CIE XYZ colour matching functions and fit of the spectral bands.

Results and Discussion

The objective of this experiment was to establish to what extent meat colour measurements by the vision system were comparable to those of the colorimeter. This section describes how the two methods related analysis of the actual meat colour measurements with respect to a known standard, and a discussion of their relationships.

Color Checker. We applied the photometric imaging model described in the previous section to a multispectral image of the Macbeth Color Checker®, resulting in the L*, a*, and b* images in Figure 3. The colour scales of the images were based on the definition of the CIELAB space - L* from black to white, a* from green to red, and b* from yellow to blue. By averaging the pixel values inside each colour square 24 different values of L*, a* and b* are found. The colorimeter was applied to seven out of the 24 squares. Mainly the reddish and brownish squares were considered.

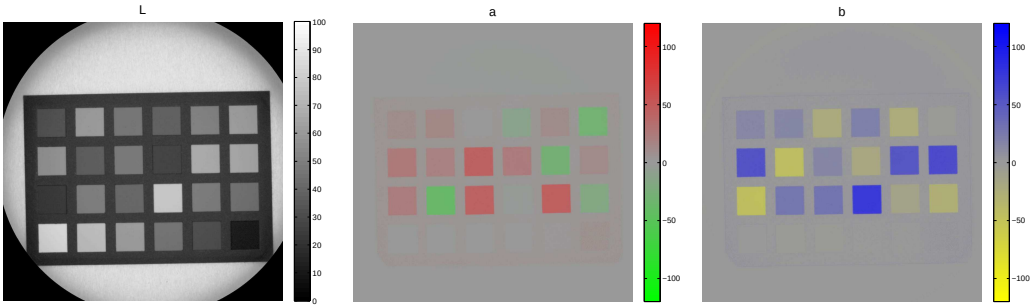

Figure 3: L*, a* and b* image of the Color Checker based on the photometric imaging model.

The measurements were compared to the ground truth values of the Color Checker and the root mean square errors (RMSE) of each colour component and the ΔE^*_{ab} values were used for evaluation of the performances of the two methods.

The RMSE for the L component is found by

$$RMSE = \frac{\sqrt{\sum_{n=1}^{i}\left(L_{CC,i} - L_{PIM,i}\right)^2}}{n}$$

and similarly, for the a* and b* components for both the colorimeter and the PIM. The ΔE^*_{ab} values are found by

$$\Delta E^*_{ab} = \sqrt{\left(L_i - L_j\right)^2 + \left(a_i - a_j\right)^2 + \left(b_i - b_j\right)^2},$$ and

express the total difference in colour. Tables 1 and 2 summarize the results. The RMSEs indicate that the two methods assessed the three colour components equally well, whereas the ΔE^*_{ab} gave an indication of the differences in the assessment of the individual colours. Despite these differences in ΔE^*_{ab} values we concluded that the two methods were both valid for measuring relative colour, which is the main concern in food applications.

Table 1: RMSE values of the Color Checker.

		L*	a*	b*
RMSE	24 colours (PIM)	6.8	2.5	3.0
	7 colours (PIM)	2.1	3.8	3.8
	7 colours (CM)	5.8	3.1	4.0

Meat Experiments. In the L*, a* and b* images of the meat samples we imitated the site measurements of the colorimeter as illustrated in Figure 4. These site measurements did not correspond directly to the sites of the colorimeter measurements. They were chosen by the same guidelines and were therefore just as subjective and random as the colorimeter sites. Within the measurements the range of the three colour components were 28.3-74.13 (L*), 2.17-29.01 (a*), and 2.66-20.28 (b*), i.e. only a small range of the chromatic components was represented in the data.

Table 2: Error values for the Color Checker for the photometric imaging model (PIM) and the colorimeter (CM).

Colour name	ΔE^*_{ab}		*Colour name*	ΔE^*_{ab}		*Colour name*	ΔE^*_{ab}	
	PIM	CM		PIM	CM		PIM	CM
Dark Skin	6.36	1.26	Light Skin	5.93	4.24	Blue Sky	4.15	
Foliage	5.7		Blue flower	5.89		Bluish green	11.47	
Orange	6.46		Purplish red	4.52		Moderate red	3.91	2.87
Purple	5.69		Yellow green	8.19	4.29	Orange yellow	8.91	4.77
Blue	9.71	11.36	Green	8.41		Red	8.20	6.11
Yellow	5.07		Magenta	4.68		Cyan	8.48	
White	14.66		Neutral 8	8.43		Neutral 5.5	5.80	
Neutral 5	5.40		Neutral 3.5	5.40		Black	11.45	

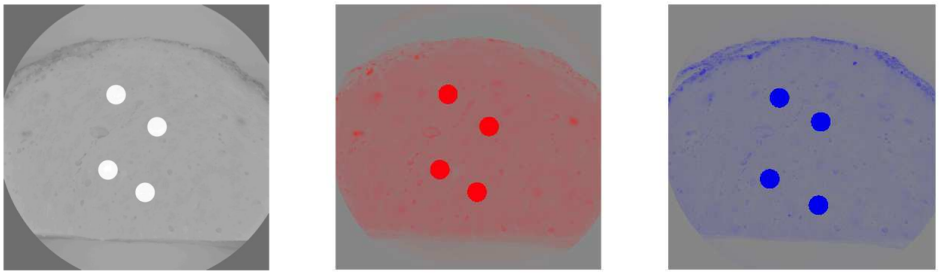

Figure 4: Point simulations in the L*, a* and b* images.

The standard way of reporting colour is by averaging over the four site measurements of the colorimeter. In order to validate the correctness of this procedure for the site measurements for both methods an ANOVA was performed. The model is formulated as

$$y_{hjkl} = \mu + p_h + t(p)_{j(h)} + S(TP)_{k(jh)} + L(TSP)_{l(jkh)} + \varepsilon_{hjkl},$$
$$h = 0,1, \quad j = 1,\ldots,7, \quad k = 1,\ldots,5, \quad l = 1,\ldots,4$$

where *p*, *t*, *S* and *L* correspond to preprocessing effects, type within preprocessing level, sample within type and preprocessing levels, and location within type, sample, and preprocessing levels. The effects relating to sample and location are considered as random, and the remaining effects as fixed. Table 3 summarizes the random effects ANOVA on each of the six cases. Without entering into a detailed discussion it follows that the variation due to the selection of measurement sites is of no relevance when comparing preprocessing level and types. The relevant variation is described by the *S(TP)* mean square, the variation between sample averages within type and preprocessing level. Thus it is reasonable to represent a sample by the average of the four site measurements and this is the procedure followed for the rest of the study.

Table 3: ANOVA table showing the mean squares for testing the averages of each color component for the two color assessment methods.

Source	DF	$MS_{L^*_{CM}}$	$MS_{a^*_{PIM}}$	$MS_{a^*_{CM}}$	$MS_{a^*_{PIM}}$	$MS_{b^*_{CM}}$	$MS_{b^*_{PIM}}$	Expected MS
p	1	35481.4	39655.7	4028	11611.8	356.9	450.6	
t(p)	10	1044.8	1578.8	798.6	406.1	177.2	111.7	$\sigma^2 + \sigma^2_{L(TSP)} + 2\sigma^2_{S(TP)} + Q(p,t(p))$
S(TP)	48	9.2	9.7	5.3	2.9	0.9	1.3	$\sigma^2 + \sigma^2_{L(TSP)} + 2\sigma^2_{S(TP)}$
L(TSP)	180	3.6	2.2	1.8	1.1	0.8	0.6	$\sigma^2 + \sigma^2_{L(TSP)}$
Cor. total	239	196.8	235.6	52.7				

Figure 5 shows the relationships between the average colour measurements of the two methods for each component. The L* component shows a clear correlation. The crude measure of correlation, $R^2_{L^*} = 0.99$ indicates that the two methods assessed the L* component equally. For the chromatic components, a* and b*, these correlations are $R^2_{a^*} = 0.90$ and $R^2_{b^*} = 0.46$. The plots of the a* and b* components indicated that there was a difference in the amount of chromatic component returned by the two methods. The value returned by the vision system was generally higher than that of the colorimeter. The difference in measurements is also illustrated by ΔE^*_{ab} values displayed in Figure 5. Processed and fresh meat were clearly separated under and above a value of 5. This difference in magnitude of the ΔE^*_{ab} values for fresh and processed meat indicated that the processing method influenced how colour was assessed by the two methods.

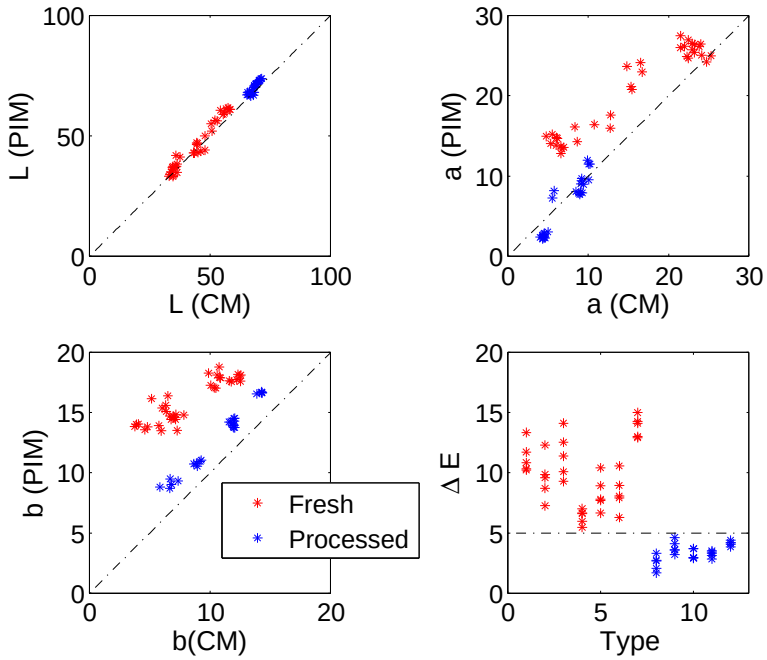

Figure 5: For each colour component the relationship between the two measurement methods are displayed.
The identity line is indicated with the dotted line. The last graph shows the error values when comparing the two methods.

Turning to the actual colours returned by the two different methods, there were some distinct differences. In the top row of Figure 6 examples of the different meat types are seen. These are pseudo RGB images and therefore not an exact representation of the colour of the sample. Underneath these examples we see the colours returned by the two different methods in sRGB colours for each of the five samples for each type of meat. For the samples of fresh meat there was especially a difference in colour of the lighter samples, such as turkey and pork loin. The colorimeter measurements of these had a tone of grey, whereas the VideometerLab measurements were closer to a light red color. For the five types of processed meat there were rather small differences for the two instruments, which is in accordance with the plots of Figure 5.

Figure 6: Top row are examples of each of the 12 types of meat considered. These are pseudo RGB images. Bottom rows: Average measurements for the colorimeter and the VideometerLab for the five samples of each type in sRGB.

The average measurements were investigated more extensively by a variance component analysis. The effects considered were:

- m_i : Method used for measurement. Determined factor.
- t_j : Type within preprocessing. Determined factor.
- p_k : Processing. Determined factor.
- S_l : Sample number within each type. Random factor.

The model describing the colour outcome y_{ijkl} - whether that is L*, a*, or b* - is given as

$$y_{ijkl} = \mu + m_i + p_k + mp_{ik} + t(p)_{j(k)} + mt(p)_{ij(k)} + S(TP)_{l(jk)} + MS(TP)_{il(jk)},$$

$$i = 1,2, \quad j = 1,\ldots 7, \quad h = 0,1,$$

$$k = 1,\ldots,5, \quad l = 1,\ldots 4.$$

Based on this model we tested each of the variance components - the results are summarized in Table 4.

Table 4: Tests of variance components for the L*, a*, and b* colour components.

Effect	*DF*	MS_{L^*}	*F value*	MS_{a^*}	*F value*	MS_{b^*}	*F value*	$F_{0.999}$
M	1	42.6	78.9	217.17	570.4	632.32	2851.1	12.29
mp	1	17.14	31.7	247.69	650.5	206.48	931.0	12.29
mt(p)	10	8.89	16.4	16.17	42.5	3.56	16.1	3.70
S(TP)	48	4.05	7.5	1.85	4.9	0.35	1.6	2.49
MS(TP)	48	0.54		0.38		0.22		
P	1	18860.58	4655.1	3674.3	1988.6	1.02	2.9	12.29
t(p)	10	654.69	161.6	287.82	155.8	66.47	187.8	3.70
S(TP)	48	4.05		1.85		0.35		

The primary goal of the analysis was to establish whether the two methods could be considered equal in their assessment of colour. The plots of Figure 5 indicated that this might not be the case for the chromatic components. For the effect of method (M) we noted an increase in F-value of the tests for the three components - 66.9 for the L* component, 570.4 for the a* component and 2851.1 for the b* component. For the F-values of the processing effect (p) the opposite trend was observed. The F-values decreased dramatically. These results, together with the correlations found earlier, suggested that the two methods measured the L* component in a similar way. The a* component was more influenced by the measurement method used but was also dependent on whether the sample was processed or fresh meat. Finally for the b* component there was a strong difference in assessment by the two methods and the processing of the meat was not as significant as for the a* component. These results supported the visual investigation of the plots in Figure 5 and the visualization in Figure 6.

The perceived colour of a sample is dependent on both the absorption and scattering properties. The scattering properties are significantly different for the fresh and processed meat samples of this experiment, where the processing had homogenized the meat. The glossiness of fresh meat can lead to specular reflectance, which will lead to a less significant contribution to the measurement of chromatic components. Figure 7 illustrates how the chromatic components, a* and b*, related to the lightness component L* for processed and fresh meat samples. In the plots of the processed meat samples little chromaticity dependency on the lightness component was observed, whereas a trend was present for both the colorimeter and the colour measurements from the L*, a*, and b* images. This tendency could be explained by the fact that a sample with a high L* value will often have less a* or b* contribution, e.g. fresh turkey or pork loin compared to beef. Despite this, a higher dependency on the L* component was observed for the colorimeter measurements. These results indicated that the diffuse illumination by the VideometerLab was less dependent on the lightness and glossiness of the sample than the simple illumination and filtration employed by the colorimeter. The results also suggested that the colour measurements of the multispectral images were more accurate and closer to the true

value. The study presented by Yagiz et al. (2009) showed the same tendencies - the colour of the calibration tiles were measured equally by the vision system and the colorimeter, but the resulting colour of the fresh salmon fillets deviated. The present study on different meat types revealed that the reflectance properties of fresh meat, whether the source is fish, poultry or livestock animals, can influence the colorimeter measurements and that diffuse illumination of the sample can be a way of overcoming this problem.

The study focused on the comparison of site measurements of the two different methods, without considering that an additional advantage of using a vision system is the ability to capture the variation in colour across the entire sample. Furthermore the photometric imaging model employed can easily be modified for transformation to other colour spaces or different illuminations without further image acquisition.

The spatial information provided by a vision system can aid measurement of factors other than colour, e.g. segmentation and classification. The vision system also offers the opportunity to measure colour in highly varying materials, e.g. salami or minced meat, where it would be hard to find a suitable site for measurement with the colorimeter.

Conclusion

This study on the measurement of meat colour of both fresh and processed meat types have shown that employing a multispectral imaging system, such as the VideometerLab in combination with a colour model based on the CIE standards is a valid alternative to the standard colorimeter. The analysis revealed differences in the assessment of colour by the two methods, especially in the case of samples of fresh meat. For these samples the analysis indicated that specular reflectance can influence the colorimeter measurements of the chromatic components, giving rise to a dependency on the lightness component L*. The use of a vision system with diffuse lightning is therefore considered to be a practicable alternative to the standard measurement method. Besides offering objective measurement and capture of colour variation across a sample, it offers other possibilities that can be of advantage in quality control or research within food science.

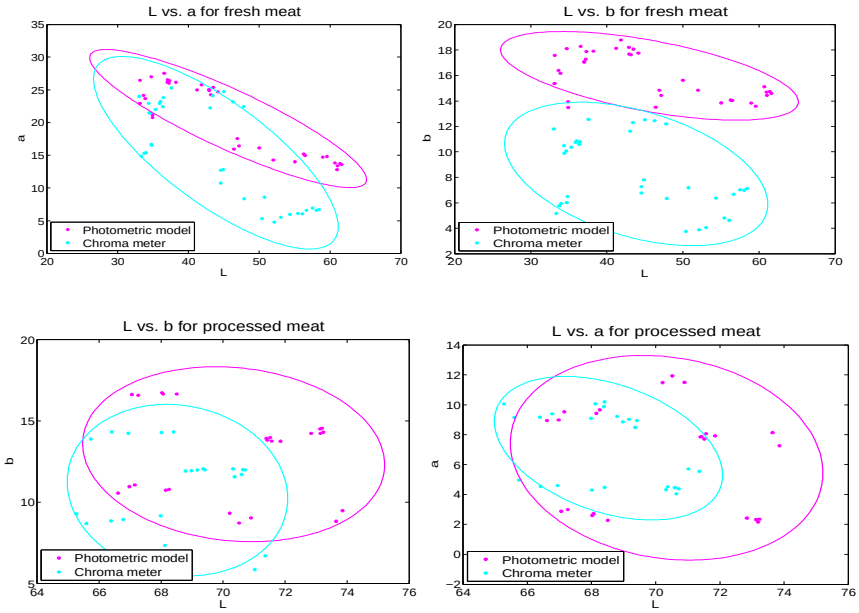

Figure 7: L* components vs. the chromatic components a* and b* respectively. Top row: Fresh meat. Bottom row: Processed meat.

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