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COMPARISON OF D65/10° AND TL84/10° ILLUMINANT/OBSERVER SYSTEMS IN MEASUREMENTS OF COLOUR IN RAW PORCINE *LONGISSIMUS* MUSCLE

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ABSTRACT

This study involved 240 samples of *longissimus lumborum* muscle taken from 240 carcasses (with an average weight of 90.3 ±7.6 kg) of pigs slaughtered on an industrial production line. The moisture content, crude protein, intramuscular fat content, water holding capacity (WHC), and pH_{48} were determined. Colour measurements were taken using the CIELAB and CIELCh colour scales, using the D65/10° and TL84/10° illuminant/observer systems. Reflectance measurements were taken in the 400–700 nm range (at intervals of 10 nm). The chromatic absorbance at a wavelength of 525 nm (A_{525p}) and the relative quantities of MbO_2, MetMb, and Mb were calculated, before and after illuminated, and differences (Δ) were calculated. Hue difference (ΔH) and total colour difference (ΔE) were also calculated. The use of the TL84/10° illuminant/observer system for measuring the colour of raw pork *longissimus* muscle, as compared to the D65/10° system, changed the observed effect of the amount of pigments and relative quantities of myoglobin chemical forms on colour parameters, mainly a^* and $h°$ as well as C^* and in the effect result in higher correlation coefficients between WHC and pH_{48} and changes in redness (Δa^*) and hue angle ($\Delta h°$) as well as chroma (ΔC^*) of colour. The TL84/10° system, as compared to the D65/10° system, may be more useful for measuring changes in the colour of raw pork, especially for determining Δa^* and $\Delta h°$ as well as ΔH and ΔE.

Key words: colour of meat, illuminant, pork quality, CIELAB, CIELCh

INTRODUCTION

Colour is one of the most important quality characteristics of meat that is readily accessible to consumers [Ngapo et al. 2007], and thus greatly influences their decision to purchase [Brewer and McKeith 1999, Ngapo et al. 2018]. It is a key indicator of freshness and consumption and technological quality – consumers can discriminate a total colour difference (ΔE) of approximately 1 [Altmann et al. 2022]. The CIELAB system [CIE 1976] and CIELCh system [CIE 1978] are commonly used to measure the colour of meat, in which the colour is described by three component parameters. In the CIELAB system, these are lightness (L^*), redness (a^*), and yellowness (b^*), while in the CIELCh system, these are lightness (L^*), chroma (C^*), and hue angle ($h°$). The colour component parameters are correlated with other quality characteristics of meat, such as pH and WHC, especially in the case of pork. These parameters depend not only on the chemical composition and physicochemical properties of meat but also on the type of spectrophotometer used [Wei et al. 2021], as well as the illuminant and standard observer. The illuminant D65 (daylight) is the most commonly used and recommended for measuring meat colour, in combination with the 10° standard observer [Honikel 1998]. Illuminant C (mean daylight) is less commonly used, usually in combination with the 2° standard observer. Illuminant A (incandescent) is rarely used, as are fluorescent illuminants [Tapp et al. 2011], although a few of these are used to illuminate meat in retail displays [Sáenz et al. 2004].

Each illuminant has a different spectral characteristic, which affects the colour of the meat when illuminated by different light sources. These differences can be seen both

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in the visual perception of colour and in its instrumental measurements, where the same colour parameters may vary [Brewer et al. 2001]. Of particular importance is the emission of light in the red part of the visible spectrum, which affects the meat's red colouration to varying degrees. The illuminants D65 and C emit significantly less light in the red part of the spectrum than illuminants A or F11. The results of colour measurements also depend on the type of standard observer used, although this issue is not well understood [Tapp et al. 2011].

The colour of raw meat undergoes continuous changes mainly due to pigment oxygenation and oxidation in its surface layer, which is associated with changes in the relative amounts of individual chemical forms of pigments. Meat structure also plays an important role [Swatland 2004, Boler et al. 2010, Chmiel et al. 2014, Hughes et al. 2014, Purslow et al. 2020]. It determines, among other things, the thickness of the surface layer of meat penetrated by light and oxygen, thus affecting the amount of light absorbed and reflected from its surface, as well as the amount of pigments and their chemical forms available for this light.

Changes in meat colour also depend on pH and WHC. In pale, soft, exudative (PSE) pork, characterized by low pH and WHC, these changes occur faster and are greater than in normal or dark, firm, dry (DFD) meat with high pH and WHC. The highest correlation between changes in colour parameters and pH and WHC is found for redness (Δa^*) and hue angle (Δh°) [Karamucki et al. 2011]. The observed Δa^* and Δh° depend, among other things, on the illuminant used, with small differences in redness possibly not being as easily detected when using illuminants with low emission in the red part of the visible spectrum, such as D65. On the other hand, illuminants with greater emission in this part of the spectrum, such as illuminant A, are recommended for samples where the priority is to detect differences in redness [AMSA 2012]. These findings are supported by the results of Karamucki and Jakubowska [2021], who showed that the A/10° system, compared to the D65/10° system, may be more useful for measuring the colour stability of raw pork, especially for the determination of Δh° ΔH, and ΔE.

The available literature offers no publications regarding the suitability of the TL84 illuminant (similar to CIE F11) for measuring meat colour. This illuminant, often used in retail and supermarkets, is characterized by a significantly higher proportion of red spectrum wavelengths than the D65 illuminant. Therefore, it can be expected that, similarly to the A illuminant, it will prove more useful in measuring colour stability for assessing the quality of raw pork.

The aim of the study was to compare the usefulness of the D65/10° and TL84/10° illuminant/observer systems for measuring the colour of raw pork *longissimus* muscle, using the CIELAB and CIELCh systems.

MATERIAL AND METHODS

Material. The material for the study consisted of 240 *longissimus lumborum* muscle samples taken from 240 pork carcasses with an average weight of 90.3 ±7.6 kg, obtained from 240 six-month-old porkers slaughtered on an industrial technological line. The pigs represented two crosses in equal numbers (120 individuals each): German Landrace × German Large White sows × Pietrain boars and Polish Large White × Polish Landrace sows × Duroc × Pietrain boars. For each cross, the pig carcasses were equally divided into three classes according to lean meat as a percentage of recorded carcass cold weight (S, E, and U) with 40 carcasses per class. The carcasses were cooled in two stages (cooled for 60 min. at –20°C and stored for 24 hours at 4°C). After cooling, meat samples (meat with bone) were taken from the right half-carcass from the section between the 1st and 4th lumbar vertebrae for analysis.

Chemical and physicochemical assessment of the meat. The physicochemical analysis of the meat was conducted approximately 48 hours post-slaughter. The meat samples were separated from the bone, and the external fat and perimysium were removed. Subsequently, the meat was minced twice, using a 4 mm mesh, to facilitate the assessment of its moisture, crude protein, and crude fat content, as well as its colour measurements, water holding capacity (WHC), and pH at 48 hours post-slaughter. It is noteworthy that all these determinations were conducted on freshly minced meat to ensure accuracy and consistency in the obtained results.

Proximate measurements. The minced meat samples were analyzed for several chemical constituents using the official AOAC [2003] methods. The moisture content was determined by drying approximately 2 g of the sample in an oven at 102°C until a constant weight was achieved (method 950.46B, p.39.1.02). The crude protein content was determined by the classical macro-Kjeldahl method (method 981.10, p.39.1.19). The lipid (crude) content was determined by extracting with petroleum ether using a Soxhlet apparatus (method 960.39(a), p.39.1.05).

Colour measurements. The measurements were carried out using a MiniScan XE Plus 45/0 spectrophotometer, with a measurement port diameter of 31.8 mm and an attachment allowing for colour measurement of minced meat. Standardization of the device was conducted using black glass and white tile standards with the following parameters: X = 78.5, Y = 83.3, and Z = 87.8 (for D65 illuminant and 10° observer). Minced meat samples were placed into measurement containers, and their surface was smoothed and left for 20 minutes at 4°C to allow for oxidation of myoglobin in the surface layer [Krzywicki

1979]. Subsequently, the samples were placed in the spectrophotometer attachment, and colour was measured using CIELAB and CIELCh colour scales [CIE 1976, CIE 1978] and two illuminant/observer systems: D65/10° and TL84/10°. Reflectance was also measured for each meat sample in the range of 400 to 700 nm, at 10 nm intervals. The obtained reflectance values were converted into absorbance values using the formula: $A = 2 - log_{10}R$, where A represents absorbance, and R represents reflectance.

A duplicate standard was used in the measurements, allowing for the determination of all colour parameters and reflectance for each meat sample from a single measurement.

Chromatic absorbance values at a wavelength of 525 nm (A_{525p}) and the relative content of myoglobin chemical forms in the surface layer of the meat was determined based on the absorbance using the Krzywicki [1979] method. The absorbance at 473, 525, and 572 nm needed to calculate the relative amounts of myoglobin chemical forms were obtained by linear interpolation. In accordance with AMSA [2012], the absorbance at 700 nm, which is the highest wavelength measurable by the MiniScan XE Plus 45/0, was used instead of the absorbance at 730 nm as follows:

$$A_{525p} = A_{525} - A_{700}$$

$$\text{Metmyoglobin (MetMb)} = 1.395 - \frac{A_{572} - A_{700}}{A_{525} - A_{700}}$$

$$\text{Deoxymyoglobin (Mb)} = 2.375 \times \left(1 - \frac{A_{473} - A_{700}}{A_{525} - A_{700}}\right)$$

$$\text{Oxymyoglobin } (MbO_2) = 1 - (\text{Mb} - \text{MetMb})$$

where:

A_{525p} – chromatic absorbance at a wavelength of 525 nm,
A_{572} – absorbance at a wavelength of 572 nm,
A_{473} – absorbance at a wavelength of 473 nm,
A_{525} – absorbance at a wavelength of 525 nm,
A_{700} – absorbance at a wavelength of 700 nm.

To induce changes in the colour of the meat, the Kortz [1966] method was employed. The meat samples were exposed to a 1250 lux intensity incandescent lamp for 4 hours in a closed chamber at 22–24°C, saturated with water vapor to prevent drying. Colour and reflectance measurements of each sample were conducted before and after the illumination using the same procedure as before. The results were used to calculate the differences in colour parameters (ΔL^*, Δa^*, Δb^*, ΔC^*, $\Delta h°$), chromatic absorbance at a wavelength of 525 nm (ΔA_{525p}), the relative content of myoglobin chemical forms (ΔMbO_2, ΔMetMb, and ΔMb), as well as hue difference (ΔH) and total colour difference (ΔE).

Hue difference ΔH and total difference ΔE were calculated according to CIE [1976] as follows:

$$\Delta H = \sqrt{\Delta E^2 - \Delta L^2 - \Delta C^2}$$

$$\Delta E = \sqrt{\Delta L^2 - \Delta a^2 - \Delta b^2}$$

WHC. The method of Grau and Hamm [1953], as modified by Pohja and Niinivaara [1957], was employed to determine the water holding capacity (WHC) of the meat, expressed as the percentage of bound water in relation to the total water content.

pH measurement. The pH of the samples was measured using a CyberScan 10 pH meter equipped with an ERH-12–6 glass composite electrode (HYDROMET S.C.). The pH_{48} measurement was conducted by immersing the electrode in meat water extracts prepared at a ratio 1:1 of meat to distilled water after one hour of extraction. The electrode was calibrated using pH 7.0 and pH 4.0 buffers.

Statistical analysis. The statistical analyses were performed using STATISTICA 13.3 software (TIBCO Software Inc.). The means and standard deviations (SD) of the studies features and means and standard errors (SEM) of the colour parameters were calculated. The significance of the differences between the means for the colour parameters determined using the D65/10° and TL84/10° illuminant/observer systems was determined using Student's t-test. Additionally, simple correlation coefficients (Pearson's r) and corrected coefficients of determination (R^2) were calculated for the colour parameters, and their significance was estimated at probability levels of $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$. The corrected coefficients of determination (R^2) were calculated using of the model Multiple Linear Regression (MLR).

RESULTS AND DISCUSSION

The means and SDs of the features and means and SEMs of the colour parameters are presented in Table 1. The mean water content in the tested samples was 74.57%, total protein – 22.52%, intramuscular fat – 1.86%, WHC – 73.21%, and pH_{48} – 5.55. The mean chromatic absorbance at the wavelength of 525 nm (A_{525p}) was very similar before (0.358) and after (0.355) illumination. The relative amounts of MbO_2, MetMb, and Mb in the surface layer of the meat penetrated by the spectrophotometer light before and after illumination were: 0.499 (49.9%),

Table 1. Means and SD of characteristics and means and SEM of colour parameters (n = 240)

Characteristic	Mean	SD	Colour parameters	Mean	SEM	Mean	SEM	p value
				D65/10º		TL84/10º		
Moisture content, %	74.57	0.91	L^* – lightness	54.58	0.16	54.96	0.16	0.0937
Total protein, %	22.52	0.73	a^* – redness	8.24	0.07	16.52	0.07	0.0000
Intramuscular fat, %	1.86	0.77	b^* – yellowness	15.90	0.07	19.52	0.07	0.0000
WHC, %	73.21	5.35	C^* – chroma	17.93	0.08	25.59	0.09	0.0000
pH_{48}	5.55	0.19	$h°$ – hue angle	62.65	0.17	49.76	0.11	0.0000
A_{525p}	0.358	0.024	L^* – after illumination	54.38	0.17	54.80	0.17	0.0836
MbO_2	0.499	0.080	a^* – after illumination	7.13	0.06	13.40	0.08	0.0000
MetMb	0.168	0.033	b^* – after illumination	14.68	0.06	18.03	0.06	0.0000
Mb	0.333	0.101	C^* – after illumination	16.34	0.06	22.49	0.07	0.0000
A_{525p} – after illumination	0.355	0.025	$h°$ – after illumination	64.10	0.18	53.41	0.18	0.0000
MbO_2 – after illumination	0.327	0.061	ΔL^*	–0.20	0.05	–0.16	0.05	0.6345
MetMb – after illumination	0.280	0.064	Δa^*	–1.11	0.08	–3.12	0.05	0.0000
Mb – after illumination	0.393	0.109	Δb^*	–1.22	0.03	–1.49	0.04	0.0000
ΔA_{525p}	0.003	0.009	ΔC^*	–1.59	0.05	–3.10	0.08	0.0000
ΔMbO_2	–0.172	0.061	$\Delta h°$	1.45	0.11	3.65	0.12	0.0000
ΔMetMb	0.112	0.042	ΔH	0.52	0.03	1.53	0.05	0.0000
ΔMb	0.060	0.068	ΔE	1.91	0.05	3.59	0.09	0.0000

ΔA_{525p}, ΔMbO_2, ΔMetMb, ΔMb, ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$ were calculated by substracting the value of a given parameter before illumination from the value after illumination.

and 0.327 (32.7%), 0.168 (16.8%) and 0.280 (28.0%), and 0.333 (33.3%) and 0.393 (39.3%), respectively. This indicates that the relative amount of MbO_2 decreased by 17.2% during illumination, while the amount of MetMb and Mb increased by 11.2% and 6.0%, respectively. When the TL84/10° illuminant/observer system was used for colour measurement, significantly higher a^*, b^*, and C^* and significantly lower $h°$ were observed both before and after illumination than when the D65/10° illuminant/observer system was used. However, very small differences in lightness (L^*) and ΔL^* were observed. The differences in all chromatic parameters during illumination were significantly greater when the TL84/10° illuminant/observer system was used, with the largest differences observed for Δa^*, ΔC^*, and $\Delta h°$ as well as Δh and ΔE.

Table 2 presents the correlation coefficients (Pearson's r) between the moisture content, crude protein, intramuscular fat, WHC, and pH_{48} and the colour parameters determined before and after illumination using both illuminant/observer systems, as well as the differences in these parameters that occurred during illumination. With an increase in moisture content, lightness (L^*), yellowness (b^*), and chroma (C^*) decreased significantly, both before and after illumination, using both illuminant/observer systems. In addition, the redness of the colour (a^*) decreased significantly before illumination using the D65/10° system and after illumination using the TL84/10° system, as well as hue angle ($h°$), both before and after illumination using the TL84/10° system. With an increase in crude protein content, lightness (L^*) and yellowness (b^*) measured using both illuminant/observer systems increased significantly, both before and after illumination. In addition, the chroma (C^*) was determined using both illuminant/observer systems, and the hue angle ($h°$) measured using the TL84/10° system before illumination increased significantly. Chroma (C^*) also increased after illumination, but only when using the D65/10° system. At the same time, hue angle ($h°$) increased significantly after illumination, as determined using both illuminant/observer systems and the redness (a^*) of the colour measured using the TL84/10° system decreased significantly. No significant correlation coefficients were found between colour parameters and intramuscular fat content, both before and after illumination.

As the moisture content increased, the differences in the chromatic parameters (Δa^*, Δb^*, ΔC^*, and $\Delta h°$) that arose during illumination decreased significantly. With an increase in crude protein content, there was a significant increase in the differences observed in the redness (Δa^*) and hue angle ($\Delta h°$) of the meat colour. However, this increase was observed only when the TL84/10° system was used. Moreover, an increase in intramuscular fat content led to a significant increase in the differences observed in redness (Δa^*) when the TL84/10° system was used. Furthermore, there was a significant increase in the differences observed in yellowness (Δb^*) and chroma (ΔC^*) when both illuminant/observer systems were used.

The correlation coefficients between moisture content, crude protein, and intramuscular fat and colour parameters and their differences (Δ) were low and often statistically insignificant. This suggests that these chemi-

Table 2. Correlation coefficients (r) for the basic chemical components, WHC, and pH_{48} of the meat (n = 240)

Characteristic	Illuminant/ observer	L*	a*	b*	C*	h^o
		Before illumination				
Moisture content, %	D65/10°	–0.293***	–0.157*	–0.326***	–0.311***	–0.022
	TL84/10°	–0.301***	–0.049	–0.276***	–0.195**	–0.197**
Crude protein, %	D65/10°	0.203**	0.083	0.324***	0.280***	0.103
	TL84/10°	0.210**	–0.040	0.272***	0.145*	0.291***
Intramuscular fat, %	D65/10°	0.125	0.116	0.074	0.101	–0.088
	TL84/10°	0.124	0.109	0.067	0.099	–0.060
WHC	D65/10°	–0.522***	–0.204**	–0.552***	–0.499***	–0.109
	TL84/10°	–0.529***	–0.207**	–0.533***	–0.437***	–0.249***
pH_{48}	D65/10°	–0.600***	–0.258***	–0.664***	–0.604***	–0.121
	TL8410°	–0.610***	–0.196**	–0.606***	–0.473***	–0.334***
		After illumination				
Moisture content, %	D65/10°	–0.260***	–0.013	–0.250***	–0.216***	–0.111
	TL84/10°	–0.271***	–0.275***	–0.147*	0.079	–0.335***
Crude protein, %	D65/10°	0.170**	0.020	0.344***	0.299***	0.153*
	TL84/10°	0.181*	–0.251***	0.253***	0.010	0.366***
Intramuscular fat, %	D65/10°	0.122	0.028	–0.022	–0.009	–0.041
	TL84/10°	0.125	–0.042	–0.046	–0.059	0.016
WHC	D65/10°	–0.560***	0.066	–0.576***	–0.467***	–0.346***
	TL84/10°	–0.569***	0.273***	–0.497***	–0.172**	–0.517***
pH_{48}	D65/10°	–0.650***	0.053	–0.604***	–0.489***	–0.366*
	TL8410°	–0.662***	0.394***	–0.480***	–0.066	–0.625***
		ΔL^*	Δa^*	Δb^*	ΔC^*	Δh^o
Moisture content, %	D65/10°	–0.058	–0.194**	–0.204***	–0.215***	–0.154*
	TL84/10°	–0.046	–0.305***	–0.253***	–0.299***	–0.298***
Crude protein, %	D65/10°	0.074	0.089	0.029	0.056	0.099
	TL84/10°	0.060	0.204**	0.084	0.010	0.257***
Intramuscular fat, %	D65/10°	0.029	0.122	0.188**	0.174**	0.067
	TL84/10°	0.030	0.134*	0.185**	0.169*	0.078
WHC	D65/10°	0.217***	–0.346***	–0.066	–0.187**	–0.415**
	TL84/10°	0.229***	–0.439***	–0.165*	–0.334***	–0.511***
pH_{48}	D65/10°	0.269***	–0.403***	–0.239**	–0.326***	–0.431***
	TL8410°	0.285***	–0.545***	–0.317***	–0.477***	–0.586***

*P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.

cal components had little influence on meat colour in the samples.

Clearly higher and mostly statistically significant correlation coefficients were observed for WHC and pH_{48}. As WHC and pH_{48} increased, the colour parameters L^*, b^*, C^*, and h° determined using both illuminant/observer systems, significantly decreased (except for three cases), both before and after illumination, as well as the parameter a^* before illumination. However, after illumination, redness (a^*) increased with the increase of WHC and pH_{48}, with correlation coefficients being significant only when the TL84/10° system was used. Regarding yellowness (b^*) and chroma (C^*), the correlation coefficients were higher when the D65/10° system was used, while for hue angle (h°), they were higher when the TL84/10° system was used.

Moreover, as the WHC and pH_{48} increased, the differences in lightness (ΔL^*) significantly increased, while the differences (Δ) in the chromatic parameters measured using both illuminant/observer systems significantly (except for one case) decreased, with higher correlation coefficients observed when the TL84/10° system was used.

Individual colour parameters depend not only on the chemical composition of the meat, its WHC, and pHu, but also on the type of spectrophotometer and illuminant/observer system used in colour measurements. Pork often does not show large differences in the content of basic chemical components. Therefore, the correlation coefficients (r) between moisture content, crude protein, intramuscular fat, and colour parameters are often not high and not always statistically significant.The greatest variability is usually observed in the intramuscular fat con-

tent, but its amount in the *longissimus* muscle of young porkers is not high. Other qualitative characteristics, often significantly correlated with each other, such as WHC and pH, have a greater impact on the colour parameters.

The results obtained suggest that the correlation coefficients between pH and WHC and the colour parameters were the highest, particularly for lightness (L^*), yellowness (b^*), and hue angle ($h°$). This is because the pH of raw meat has a significant impact on the WHC and the formation of its structure, which in turn affects achromatic reflectance/absorbance that mainly determines the lightness (L^*) of the colour and the chromatic reflectance/absorbance of pigments that influences all colour parameters [Karamucki et al. 2013].

The pH of meat plays a crucial role in the oxygenation and deoxygenation processes in meat, as well as in the oxidation and reduction of muscle pigments. These processes have a significant impact on the colour parameters, especially the chromatic ones, and are determined by the differences in the colour of each of these chemical forms of pigments and their relative amounts. Among the various forms of pigments, the bright red oxygenated form of myoglobin, oxymyoglobin (MbO_2), has the highest redness (a^*) and yellowness (b^*), as well as the highest chroma (C^*). On the other hand, the dark red reduced form of myoglobin, deoxymyoglobin (Mb), has the lowest yellowness (b^*), while the brownish oxidized form, metmyoglobin (MetMb), has the lowest redness (a^*).

An increase in the relative amount of MetMb, at the expense of the other myoglobin forms, leads to a deterioration in meat colour [Hernández et al. 2016] by reducing redness (a^*), lowering chroma (C^*), and shifting hue angle ($h°$) towards shorter wavelengths [Luciano et al. 2011, Karamucki et al. 2013]. The lowering of the meat pH contributes to this effect by increasing the susceptibility of myoglobin to oxidation and reduction [Lindahl 2005]. Elevated temperature and light exposure also favor these changes [Zhu and Brewer 1998, Mikkelsen et al. 1999, Bekhit and Faustman 2005, Mancini and Hunt 2005].

Changes in redness (Δa^*) and hue angle ($\Delta h°$) are crucial factors in determining meat colour changes and measuring its stability.

Colour parameters also depend on the amount of pigments in the meat layer penetrated by light. This amount is directly proportional to the chromatic absorbance at a wavelength of 525 nm (A_{525p}), i.e., at the isosbestic point of the three chemical forms of myoglobin. As the amount of pigments (A_{525p}) affecting colour increases, lightness (L^*) and hue angle ($h°$) decrease, while redness (a^*) and chroma (C^*) increase. However, the amount of pigments usually does not have a significant effect on yellowness (b^*), as confirmed by the obtained results. The level of b^* mainly depends on the relative amount of myoglobin chemical forms [Lindahl et al. 2001, Karamucki et al. 2013].

The illuminant used to measure colour significantly affects its parameters, especially the chromatic ones, which is related to its spectral characteristics. The participation of red waves is particularly important. In the study by Karamucki and Jakubowska [2021], it was reported that the incandescent illuminant (A) allowed a better explanation of changes in the redness (Δa^*) and hue angle ($\Delta h°$) of meat colour caused by changes in the relative amount of myoglobin chemical forms, especially MetMb, compared to the D65 illuminant. In the case of illuminant A, higher correlation coefficients were noted between WHC and pH_{48} and Δa^* and $\Delta h°$ as well as ΔC^*. The results presented in this study indicate that the use of TL84 illuminant also results in an increase in correlation coefficients between WHC and pH_{48} and differences (Δ) in colour parameters, especially Δa^*, ΔC^*, and $\Delta h°$ [Table 2].

Table 3 presents the corrected coefficients of determination (R^2) indicating the effect of pigment absorbance (A_{525p}) and relative amounts of myoglobin forms on the variability of colour parameters, as well as the effect of changes in pigment absorbance (ΔA_{525p}) and relative myoglobin content on changes (Δ) in colour parameters, using both illuminant/observer systems.

The determination coefficients (R^2) for lightness (L^*) were similar for both illuminants. Larger differences in R^2 were found for chromatic parameters. The influence of the amount of pigments (A_{525p}) on redness (a^*) and hue angle ($h°$) was greater with the illuminant/observer system D65/10° both before and after illumination, and was also clearly greater than the influence of the relative amount of myoglobin forms. On the other hand, in the case of the TL84/10° illuminant/observer system, the influence of the amount of pigments (A_{525p}) on redness (a^*) and hue angle ($h°$) was greater than the influence of myoglobin forms only before illumination.

The relative amount of different chemical forms of myoglobin (each separately and in combination) primarily affected the chromatic parameters and depended on the illuminant/observer system used. This effect was significant in almost every case. When using the D65/10° illuminant/observer system before illumination, there was no significant effect of the relative amount of different forms of myoglobin (each separately and in combination) on hue angle ($h°$), and after illumination, it was not observed only for the relative amount of MbO_2. Moreover, after illumination, when using the TL84/10° system, no significant effect of the relative amount of MbO_2 on redness (a^*) and of the relative amount of MetMb on chroma (C^*) was observed, and when using the D65/10° system, no significant effect of the relative amount of MetMb on redness (a^*) was observed.

When using the TL84/10° illuminant/observer system, the relative amount of each form of myoglobin significantly influenced hue angle ($h°$), particularly in the

Table 3. The corrected coefficient of determination R^2 for colour parameters (n = 240)

Characteristic	Illuminant/ observer	L*	a*	b*	C*	$h°$
				R^2		
		Before illumination				
A_{525p}	D65/10°	0.2665***	0.6494***	0.0000	0.1253***	0.7716***
	TL84/10°	0.2394***	0.4483***	0.0104	0.1875***	0.4102***
MbO_2	D65/10°	0.3202***	0.2551***	0.6761***	0.6712***	0.0003
	TL84/10°	0.3479***	0.2600***	0.5939***	0.5532***	0.0121*
MetMb	D65/10°	0.1673***	0.1437***	0.4234***	0.4124***	0.0000
	TL84/10°	0.1838***	0.0154*	0.3590***	0.1924***	0.1409***
Mb	D65/10°	0.3429***	0.2783***	0.7535***	0.7456***	0.0004
	TL84/10°	0.3735***	0.2028***	0.6573***	0.5430***	0.0472***
MbO_2 + MetMb + Mb	D65/10°	0.3404***	0.2753***	0.7537***	0.7453***	0.0000
	TL8410°	0.3711***	0.2743***	0.6563***	0.5585***	0.1422***
A_{525p} + MbO_2 + MetMb + Mb	D65/10°	0.7287***	0.8795***	0.7566***	0.8076***	0.8414***
	TL84/10°	0.7298***	0.7993***	0.6549***	0.7153***	0.7822***
		After illumination				
A_{525p}	D65/10°	0.3416***	0.8086***	0.0021	0.1623***	0.7138***
	TL84/10°	0.3154***	0.4017***	0.0258**	0.2795***	0.2500***
MbO_2	D65/10°	0.2059***	0.1302***	0.6424***	0.6713***	0.0000
	TL84/10°	0.2274***	0.0019	0.4918***	0.2835***	0.0872***
MetMb	D65/10°	0.2993***	0.0000	0.3353***	0.2523***	0.0596***
	TL84/10°	0.3279***	0.3491***	0.1363***	0.0094	0.5664***
Mb	D65/10°	0.3344***	0.0453***	0.6271***	0.5727***	0.0263**
	TL84/10°	0.3675***	0.0899***	0.3752***	0.0500***	0.3739***
MbO_2 + MetMb + Mb	D65/10°	0.3389***	0.1607***	0.6811***	0.6801***	0.0650***
	TL8410°	0.3725***	0.5444***	0.4900***	0.4878***	0.5741***
A_{525p} + MbO_2 + MetMb + Mb	D65/10°	0.7381***	0.9187***	0.6797***	0.7900***	0.7953***
	TL84/10°	0.7458***	0.9376***	0.4993***	0.7177***	0.8547***
		ΔL^*	Δa^*	Δb^*	ΔC^*	$\Delta h°$
ΔA_{525p}	D65/10°	0.4187***	0.5514***	0.5284***	0.6146***	0.4577***
	TL84/10°	0.3632***	0.3495***	0.5062***	0.4778***	0.1882***
ΔMbO_2	D65/10°	0.0812***	0.4990***	0.5562***	0.6079***	0.3613***
	TL84/10°	0.0575***	0.3728***	0.3953***	0.4467***	0.2283***
ΔMetMb	D65/10°	0.0291**	0.1207***	0.0234**	0.0594***	0.1336***
	TL84/10°	0.0494***	0.5196***	0.1440***	0.3664***	0.6508***
ΔMb	D65/10°	0.0184*	0.1721***	0.3221***	0.2965***	0.0948***
	TL84/10°	0.0022	0.0068	0.1052***	0.0476***	0.0003
ΔMbO_2 + ΔMetMb + ΔMb	D65/10°	0.0952***	0.5514***	0.5556***	0.6201***	0.4317***
	TL8410°	0.0902***	0.7639***	0.4708***	0.6946***	0.7697***
ΔA_{525p} + ΔMbO_2 + ΔMetMb + ΔMb	D65/10°	0.4341***	0.7457***	0.7148***	0.8186***	0.6137***
	TL84/10°	0.4000***	0.8673***	0.6743***	0.8576***	0.8170***

*P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.

case of MetMb, especially after illumination, when its quantity increased at the expense of MbO_2.

When using the TL84/10° illuminant/observer system, the relative amount of each form of myoglobin (MbO_2 + MetMb + Mb) had a significant impact on hue angle ($h°$), particularly for MetMb, especially after illumination when its amount increased at the expense of MbO_2. The combined effect of the relative amounts of myoglobin forms on hue angle ($h°$) before illumination was significant only for the TL84/10° system, with R^2 = 0.1422 (14.22%), and the effect was significantly greater after illumination for the TL84/10° system than for the D65/10° system, for both hue angle ($h°$) (57.41% and 6.50%, respectively) and redness (a^*) (54.44% and 16.07%, respectively). Additionally, before illumination, the combined effect of the amount of pigments and myoglobin forms (A_{525p} + MbO_2 + MetMb + Mb) on all chromatic parameters was smaller for the TL84/10° system

than for the D65/10° system, while after illumination, the effect was smaller only for yellowness (b^*) and chroma (C^*), but larger for redness (a^*) and hue angle ($h°$).

When using both illuminant/observer setups, the amount of pigments (A_{525p}) did not significantly affect the variability of b^* before illumination, and significant effects were only observed for the TL84/10° setup after illumination, with a small effect size of $R^2 = 0.0258$ (2.58%). On the other hand, the effect of pigment absorbance (A_{525p}) on chroma (C^*) was greater when the TL84/10° setup was used, both before and after illumination. Meanwhile, the effect of the relative amounts of each individual and combined form of myoglobin (MbO_2 + MetMb + Mb) on b^* and C^* was greater, both before and after illumination, when the D65/10° setup was used.

The changes in the amount of pigments affecting the colour (ΔA_{525p}) that occurred during illumination had a significant impact on the differences in all colour parameters, with a greater effect observed for the D65/10° illuminant, especially in the case of differences in hue angle ($\Delta h°$) and redness (Δa^*). Among the three forms of myoglobin, changes in the relative amount of metmyoglobin (ΔMetMb) and oxymyoglobin (ΔMbO_2) mainly caused differences in redness (Δa^*) and hue angle ($\Delta h°$), with changes in the amount of metmyoglobin (ΔMetMb) having a greater impact in the case of the TL84/10° illuminant, and changes in the amount of oxymyoglobin (ΔMbO_2) in the case of the D65/10° illuminant. However, since the greatest effect on changes in chromatic parameters, especially Δa^* and $\Delta h°$ was observed in the case of ΔMetMb and the TL84/10° system, the combined effect of changes in the relative amounts of myoglobin forms ($\Delta MbO_2 + \Delta M$etMb + ΔMb) on differences in redness (Δa^*) and hue angle ($\Delta h°$), as well as in chroma (ΔC^*), was significantly greater for the TL84/10° system. Similarly, the combined effect of changes in the amount of pigments affecting colour and changes in the relative amounts of myoglobin forms ($\Delta A_{525p} + \Delta MbO_2 + \Delta M$etMb + ΔMb) on changes in redness (Δa^*) and hue angle ($\Delta h°$) and chroma (ΔC^*) was greater when using the TL84/10° system [Table 3].

In summary, the presented results indicate greater usefulness of the TL84/10° illuminant/observer system for measuring changes in meat colour parameters in assessing its stability.

In the assessment of the raw quality of pork, both redness (a^*) and hue angle ($h°$) show lower correlation coefficients with other quality traits (e.g. pH, WHC) than lightness (L^*) or yellowness (b^*), as the variability of redness (a^*) and hue angle ($h°$) determined using the D65/10° illuminant/observer system is mainly influenced by the amount of pigments, and to a lesser extent by the proportions of their chemical forms [Lindahl et al. 2001, Karamucki et al. 2013]. However, in the case of measuring colour changes (Δ) and assessing their stability, changes in redness and hue angle (Δa^* and $\Delta h°$) show the highest correlation coefficients with sensory evaluation results for colour, wateriness, firmness, pHu, and WHC [Karamucki et al. 2011]. Under conditions where the meat surface does not dry out, these changes are mainly due to variations in the relative amounts of myoglobin chemical forms, especially MetMb, whose increase leads to a decrease in redness. When using an illuminant with higher red spectrum emission than D65, such as illuminant A [Karamucki and Jakubowska 2021], or as shown by the results presented in this study – the TL84 illuminant, these changes are even more visible.

Table 4 presents the corrected coefficients of determination (R^2) showing the effect of changes in the absorbance of pigments (ΔA_{525p}) and the relative amounts of myoglobin forms on the hue difference (ΔH) and total difference (ΔE), using both illuminant/observer systems.

Table 4. The corrected coefficient of determination R^2 for ΔE and ΔH (n = 240).

Characteristic	Illuminant/ Observer	ΔH	ΔE
		R^2	
ΔA_{525p}	D65/10°	0.2623***	0.3912***
	TL84/10°	0.1656***	0.3658***
ΔMbO_2	D65/10°	0.2411***	0.4812***
	TL84/10°	0.2229***	0.3892***
ΔMetMb	D65/10°	0.1825***	0.0898***
	TL84/10°	0.6332***	0.4621***
ΔMb	D65/10°	0.0277**	0.1872***
	TL84/10°	0.0001	0.0159*
ΔMbO_2 + ΔMetMb + ΔMb	D65/10°	0.3616***	0.5144***
	TL8410°	0.7494***	0.7271***
ΔA_{525p} + ΔMbO_2 + ΔMetMb + ΔMb	D65/10°	0.4512***	0.6109***
	TL84/10°	0.7852***	0.8355***

*P ≤ 0.05, **P ≤ 0.01, ***P ≤ 0.001.

In the case of the TL84/10° system, the effect of ΔA_{525p} on the variability of ΔH and ΔE was lower than in the D65/10° system (respectively: 16.56% and 36.58% for ΔH, and 26.23% and 39.12% for D65/10°). Meanwhile, the combined effect of changes in the relative amounts of myoglobin forms ($\Delta M\text{bO}_2$ + ΔMetMb + ΔMb) using the TL84/10° system was significantly greater than that using the D65/10° system for both ΔH (74.94% vs. 36.16%) and ΔE (72.71% vs. 51.44%). Analysis of the influence of changes in the relative amounts of each myoglobin form indicated that, in both ΔH and ΔE, the effect was primarily due to changes in the relative amount of metmyoglobin (ΔMetMb). The effect of changes in the relative amount of oxymyoglobin ($\Delta M\text{bO}_2$) and deoxymyoglobin (ΔMb) using the TL84/10° system was markedly lower, and in the case of the effect of ΔMb on ΔH, it was not significant.

The use of the TL84/10° illuminant/observer system allowed for explaining 78.52% of the variability of ΔH and 83.55% of the variability of ΔE with the combined effect of changes in pigment absorbance and relative amounts of myoglobin forms (ΔA_{525p} + $\Delta M\text{bO}_2$ + ΔMetMb + ΔMb), while the D65/10° system the numbers were 45.12% and 61.09%, respectively. These results indicate that the TL84/10° illuminant/observer system is more useful for determining ΔH and ΔE.

CONCLUSIONS

The use of the illuminant/observer TL84/10° for measuring the colour of *longissimus* muscle compared to the use of D65/10° resulted in a change in the influence of the amount of pigments and the relative proportion of myoglobin forms on colour parameters, particularly a^*, $h°$ and C^*. The use of TL84/10° allowed for a better explanation of changes (Δ) mainly in redness (Δa^*) and hue angle ($\Delta h°$) and also in hue difference (ΔH) and total colour difference (ΔE) caused by changes in the relative proportion of myoglobin forms, with the largest impact on changes in these parameters due to changes in the amount of metmyoglobin (ΔMetMb) for TL84/10° and changes in the amount of oxymyoglobin ($\Delta M\text{bO}_2$) for D65/10°. Measurements using TL84/10° led to an increase in correlation coefficients between WHC and pH_{48} and changes in redness (Δa^*), hue angle ($\Delta h°$), and chroma (ΔC^*). In conclusion, compared to D65/10° TL84/10° may be more useful for measuring changes in the colour of raw pork, particularly for determining Δa^* and $\Delta h°$ as well as ΔH and ΔE.

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REFERENCES

Altmann, B.A, Gertheiss, J., Tomasevic, I., Engelkes, Ch., Glaesner, T., Meyer, J., Schäfer, A., Wiesen, R., Möllein, D. (2022). Human perception of color differences using computer vision system measurements of raw pork loin. Meat Sci., 188, 108766. DOI: 10.1016/j.meatsci.2022.108766.

AMSA (2012). Meat colour measurement guidelines. American Meat Science Association.

AOAC (2003). Official Methods of Analysis of AOAC International (17th ed.). Gaithersburg, MD, USA: Association of the Official Analytical Chemists (AOAC) International.

Brewer, M.S., McKeith, F.K. (1999). Consumer-rated quality characteristics as related to purchase intent of fresh pork. J. Food Sci. 64(1), 171–174. DOI: 10.1111/j.1365-2621.1999.tb09885.x.

Brewer, M.S., Zhu, L.G., Bidner, B., Meisinger, D.J., McKeith, F.K. (2001). Measuring pork colour: effect of bloom time, muscle, pH, and relationship to instrumental parameters. Meat Sci., 57(2), 169–176. DOI: 10.1016/S0309-1740(00)00089-9.

Bekhit, A.E.D., Faustman, C. (2005). Metmyoglobin reducing activity. Review. Meat Sci. 71(3), 407–439. DOI: 10.1016/j.meatsci.2005.04.032.

Boler, D.D., Dilger, A.C., Bidner, B.S., Carr, S.N., Eggert, J.M., Day, J.W., Ellis, M., McKeith, F.K., Killefer, J. (2010). Ultimate pH explains variation in pork quality traits. J. Muscle Foods, 21(1), 119–130. DOI: 10.1111/j.1745-4573.2009.00171.x.

CIE (1976). Colorimetry: Official Recommendations of the International Commission on Illumination. Publication CIE No. 15 (E-1.3.1). Bureau Central de la CIE, Paris, France.

CIE (1978). Recommendation on uniform colour spaces, colour difference equations, psychometric colour terms. Supplement No. 2 to publication CIE no. 15 (e-1.3.1). Commission Internationale De L'Eclairage, Paris.

Chmiel, M., Słowiński, M., Janakowski, S. (2014). The quality evaluation of RFN and PSE pork *longissimus lumborum* muscle considering its microstructure. Ann. Anim. Sci., 14(3), 737–747. DOI: 10.2478/aoas-2014-0035.

Grau, R., Hamm, R. (1953). A simple method for the determination of water binding in muscle. Natural Sci., 40, 29–30. DOI: 10.1007/BF00595734.

Hernández, B., Sáenz, C., Alberdi, C., Dineiro, J.M. (2016). CIELAB colour coordinates versus relative proportions of myoglobin redox forms in the description of fresh meat appearance. J. Food Sci. Technol., 53(12), 4159–4167. DOI: 10.1007/s13197-016-2394-6.

Hughes, J.M., Oiseth, S.K., Purslow, P.P., Warner, R.D. (2014). A structural approach to understanding the interactions between colour, water-holding capacity and tenderness. Meat Sci., 98(3), 520–532. DOI: 10.1016/j.meatsci.2014.05.022.

Honikel, K.O. (1998). Reference methods for the assessment of physical characteristics of meat. Meat Sci., 49(4), 447–457. DOI: 10.1016/S0309-1740(98)00034-5.

Karamucki, T., Gardzielewska, J., Rybarczyk, A., Jakubowska, M., Natalczyk-Szymkowska, W. (2011). Usefulness of

selected methods of colour change measurement for pork quality assessment. Czech J. Food Sci., 3, 212–218. DOI: 10.17221/191/2010-CJFS..

Karamucki, T., Jakubowska, M. (2021). Comparison of D65/10° and A/10° illuminant/observer systems for colour measurement of raw pork. Acta Sci. Technol. Aliment. 20(4), 485–496. DOI: 10.17306/J.AFS.2021.0971.

Karamucki, T., Jakubowska, M., Rybarczyk, A., Gardzielewska, J. (2013). The influence of myoglobin on the colour of minced pork loin. Meat Sci., 94(2), 234–238. DOI: 10.1016/j.meatsci.2013.01.014.

Kortz, J. (1966). The effect of free sulfhydryl groups on the colour stability of raw meat (pork). [PhD. Thesis]. Technical University of Gdańsk, Gdańsk, Poland [In Polish].

Krzywicki, K. (1979). Assessment of relative content of myoglobin, oxymyoglobin and metmyoglobin at the surface of beef. Meat Sci., 3(1), 1–10. DOI: 10.1016/0309-1740(79)90019-6.

Lindahl, G. (2005). Colour characteristics of fresh pork. Doctoral thesis. Swedish University of Agricultural Sciences, Uppsala 2005.

Lindahl, G., Lundström, K., Tornberg, E. (2001). Contribution of pigment content, mioglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. Meat Sci., 59(2), 141–151. DOI: 10.1016/S0309-1740(01)00064-X.

Luciano, G., Vata, V., Monahan, F.J., Lopez-Andres, P., Biondi, L., Lanza, M., Priolo, A. (2011). Antioxydant status, colour stability and myoglobin resistance to oxidation of *longissimus* dorsi muscle from lams fed a tannin-containing diet. Food Chem., 124(3), 1036–1042. DOI: 10.1016/j.foodchem.2010.07.070.

Mancini, R.A., Hunt, M.C. (2005). Review: Current research in meat colour. Meat Sci., 71(1), 100–121. DOI: 10.1016/j.meatsci.2005.03.003.

Mikkelsen, A., Juncher, D., Skibsted, L.H. (1999). Metmyoglobin reductase activity in porcine m. *longissimus* dorsi muscle. Meat Sci., 51(2), 155–161. DOI: 10.1016/S0309-17 40(98)00114-4.

Ngapo, T.M., Martin, J.F., Dransfield, E. (2007). International preferences for pork appearance: II. Factors influencing consumer choice. Food Quality and Preference, 18, 139–151. DOI: 10.1016/j.foodqual.2005.09.007.

Ngapo, T.M., Rubio Lozano, M.S., Braña Varela, D. (2018). Mexican consumers at the point of meat purchase. Pork choice. Meat Sci., 135, 27–35. DOI: 10.1016/j.meatsci.2017.08.005.

Purslow, P.P., Warner, R.D., Clarke, F.M., Hughes, J.M. (2020). Variations in meat colour due to factors other than myoglobin chemistry; a synthesis of recent findings (invited review). Meat Sci., 159, 107941. DOI: 10.1016/j.meatsci.2019.107941.

Pohja, N.S., Niinivaara, F.P.. (1957). The determination of water binding of meat by the constant pressure method. Fleischwirtschaft, 9, 193–193.

Sáenz, C., Hernández, B., Beriain, M.J., Lizaso, G. (2004). Meat colour in Retail Display with Fluorescent Illumnation. Colour Res. Appl., 30(4), 304–311. DOI: 10.1002/col.20123.

Swatland, H.J. (2004). Progress in understanding the paleness of meat with a low pH. S. Afr. J. Anim. Sci., 2004, 34 (Suppl. 2), 1–7. DOI: 10.4314/sajas.v34i6.3816.

Tapp III, W.N., Yencey, J.W.S., Apple, J.K. (2011). How is the instrumental colour of meat measured? Meat Sci., 89(1), 1–5. DOI: 10.1016/ j.meatsci.2010.11.021.

Wei, X., Lam, S., Bohrer, B.M., Uttaro, B., López-Campos, O., Prieto, N., Larsen, I.L., Juárez, M. (2021). A comparison of fresh pork colour measurements by using four commercial handheld devices. Foods, 10(11), 2515. DOI: 10.3390/foods10112515.

Zhu, L.G., Brewer, M.S. (1998). Metmyoglobin reducing capacity of fresh normal, PSE and DFD pork during retail display. J. Food Sci., 63(3), 390–393. DOI: 10.1111/j.1365-2621.1998.tb15749.x.

Karamucki, T. (2023). Comparison of D65/10° and TL84/10° illuminant/observer systems in measurements of colour in raw porcine *longissimus* muscle. Acta Sci. Pol. Zootechnica, 22(3), 47–58. DOI: 10.21005/asp.2023.22.3.06

PORÓWNANIE UKŁADÓW ILUMINANT/OBSERWATOR D65/10° I TL84/10° W POMIARACH BARWY SUROWEGO WIEPRZOWEGO MIĘŚNIA *LONGISSIMUS*

STRESZCZENIE

Badaniami objęto 240 próbek mięśnia *longissimus lumborum* pobranych z 240 tusz (o średniej masie 90.3 ±7.6 kg) tuczników ubijanych na przemysłowej linii technologicznej. Określono zawartość wody całkowitej, białka ogólnego tłuszczu śródmięśniowego oraz WHC i pH_{48}. Przeprowadzono pomiary barwy w skalach CIELAB i CIELCh przy zastosowaniu układów illuminant/obserwator D65/10° i TL84/10° oraz reflektancji w zakresie od 400–700 nm (co 10 nm). Obliczono wartość absorbancji chromatycznej przy długości fali 525 nm (A_{525p}) oraz względną ilość MbO_2, MetMb i Mb, przed i po naświetlaniu próbek, oraz określono różnice (Δ). Obliczono ponadto ΔH i ΔE [CIE 1976]. Zastosowanie układu illuminant/observer TL84/10° do pomiarów barwy surowego wieprzowego mięśnia *longissimus* w porównaniu z użyciem układu D65/10° powoduje, że zmienia się wpływ ilości barwników i względnej ilości form chemicznych mioglobiny na wartości parametrów barwy, przede wszystkim a^* i $h°$ oraz C^*, co w efekcie powoduje podwyższenie wartości współczynników korelacji między WHC i pH_{48} a zmianami w czerwoności (Δa^*) i tonie ($\Delta h°$) oraz nasyceniu (ΔC^*) barwy. Układ TL84/10° w porównaniu z D65/10° może być bardziej przydatny do pomiarów zmian barwy surowej wieprzowiny, zwłaszcza do określania Δa^* i $\Delta h°$ oraz ΔH and ΔE.

Słowa kluczowe: barwa mięsa, iluminat, jakość wieprzowiny, CIELAB, CIELCh

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