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RELATIONSHIP BETWEEN CIE *L*a*b** AND CIE *L*C*h* SCALE COLOUR PARAMETERS DETERMINED WHEN APPLYING ILLUMINANT C AND OBSERVER 2° AND ILLUMINANT D65 AND OBSERVER 10° AND PROXIMATE CHEMICAL COMPOSITION AND QUALITY TRAITS OF PORCINE *LONGISSIMUS LUMBORUM* MUSCLE

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Meat samples, numbering 72 in total, differentiated in respect of quality and collected from *longissimus lumborum* muscle of 72 carcasses of porkers (36 gilts and 36 hogs) approximating in their exterior Polish Large White and Polish Landrace crossbreeds originated from a large-scale farm at Kolbacz and slaughtered on an industrial processing line, were examined. Approximately 45 min after slaughter, pH_1 value was determined between the 4th and the 5th lumbar vertebra. Meat samples were collected after approximately 24-h cooling and stored for *ca*. 24 h at 0° to 4° C. Approximately 48 h from the slaughter, sensory examination of colour, wateriness and springiness of raw meat was performed, followed by determination of water-binding capacity, pH_u and dry matter, total protein and fat percentages, as well as that of water-soluble protein, after double mincing the meat. Using Mini Scan XE Plus 45/0 apparatus, meat colour parameters were determined in CIE *L*a*b** and CIE *L*C*h* scales applying two illuminant/observer combinations used most frequently in meat colour measurements, *i.e.* illuminant C and standard observer 2° as well as illuminant D65 and standard observer 10°. Colour measurements were made after 20-min storage of the samples at 0° do 4° C.

Colour parameters closely connected with meat quality proved to be lightness (*L**) and yellowness (*b**), and slightly less chroma (*C**), whereas *a** (redness) and *h°* (hue) parameters were linked with meat quality to the least extent, which in general showed medium and low correlation with meat quality traits.

The application of illuminant D65 and observer 10° for measurements of meat colour proved to be more suitable in the case of parameter *a** and *C**, whereas the use of illuminant C and observer 2° in the case of parameter *h°*.

INTRODUCTION

The colour of pork, apart from water-binding capacity, is the most important trait determining its quality. According to consumer evaluation, it is the main trait of meat that affects the willingness of purchasing it [Risvik, 1994; Brewer & McKeith, 1999]. In case of lean raw pork, it is determined by the concentration of haem pigments, in particular of myoglobin and reciprocal relation of its forms, but also to a great extent by the status of other muscle proteins that influence transparency degree of meat [Feldhusen, 1994]. Meat with PSE traits is characterised by low pH, no or inconsiderable transparency, high colour lightness as well as by decreased solubility of proteins and low water-binding capacity. On the other hand, DFD pork is characterised by higher transparency of tissue, lower lightness and high water-binding capacity, maintaining not reduced solubility of proteins [Garrido *et al.*, 1994; Joo *et al.*, 1999; Lindahl *et al.*, 2001, 2004; Lopez-Bote *et al.*, 1989; O'Keeffe & Hood, 1982; Warris *et al.*, 1990]. However, in meat colour measurements the values of its parameters also depend, among others, on light source and standard observer used for measuring, the type of spectrophotometer used [Brewer *et al.*, 2001], and even on the method of sample preparation (measurement on meat slices or measurement of colour of the minced meat) It is known, based on own studies, that grinding meat by mincing affects to some extent, due to larger damage of tissue structure, the increase of colour lightness and the values of parameters *a** (redness), *b** (yellowness) and *C** (chroma). However, taking measurements on the minced meat increases their accuracy when compared to measurements made on meat slices, which are frequently not much unified in respect of colour [Drewniak, 2000]. The light source used for measuring, as well as standard observer, not only affect the values of colour parameters (mostly chromatic ones), but can also influence the correlation degree between these parameters and meat quality traits and indices. In turn, expression of colour in CIE *L*C*h* scale in the form of lightness (*L**), chroma (*C**) and hue (*h°*) allows presenting it more readably than it is allowed by CIE *L*a*b** scale recommended in meat colour description [Honikel, 1998].

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The aim of the study was to examine the relationship between basic chemical composition and quality traits (sensory and physicochemical) and quality indices (pH_1 and pH_u) of porcine *longissimus lumborum* muscle and the values of colour parameters in CIE *L*a*b** and CIE *L*C*h* scales obtained when applying two illuminant/observer combinations commonly used in meat colour measurements, *i.e.* C/2° and D65/10°.

MATERIAL AND METHODS

Studies included 72 meat samples, well differentiated in respect of quality and collected from *longissimus lumborum* muscle of 72 carcasses of porkers (36 gilts and 36 hogs) approximating in their exterior Polish Large White and Polish Landrace crossbreeds originated from a large-scale farm at Kolbacz and slaughtered on an industrial processing line. Approximately 45 min after the slaughter, pH1 was measured in *longissimus lumborum* muscle between lumbar vertebrae 4 and 5 of the right-hand half-carcass. Meat samples for further laboratory assessments were collected from *longissimus lumborum* muscle after approximately 24-h cooling. Meat samples were packed into plastic bags and transported to a laboratory, where they were placed at 0–4°C. Next, approximately 48 h after the slaughter, sensory evaluation was carried out for raw meat colour, water-binding capacity and springiness [Różyczka *et al.*, 1975] The evaluation was performed by a team of five persons with verified sensory sensitiveness. The evaluation was made based on a 5-point scale, scoring: 1 point – PSE meat, 2 points – slightly PSE meat, 3 points – normal meat, 4 points – slightly DFD meat, and 5 points – DFD meat. To carry on further assessments, after epimysium/perimysium and fat trimming, meat samples were minced twice using a mesh of 4-mm diameter. Water-binding capacity [Pohja & Niinivaara, 1957], volume of thermal drip [Walczak, 1959] and percentage of dry matter, total protein and fat in meat [A.O.A.C., 1990], as well as of water-soluble protein [Kotik, 1974] were determined in the meat samples prepared this way. Determination of meat pH_u value was carried out after 1 h in meat aqueous extracts applying 1:1 water:meat ratio. Using Mini Scan XE Plus 45/0 apparatus, adapted for measuring the colour of minced meat, with 31.8 mm measuring port opening, colour parameters of respective meat samples were determined in CIE *L*a*b** and CIE *L*C*h* scales [CIE, 1976; 1978], applying two illuminant/observer combinations, *i.e.* illuminant C (average day light) and standard observer 2° as well as illuminant D65 (day light) and standard observer 10°, recommended for measurements of meat colour [Honikel, 1998] and most common. Measurements with the use of the aforementioned scales, illuminants and observers were made using the so-called "double standard" which enabled obtaining values of all parameters for each sample after taking one measurement and the same allowed excluding possible inaccuracies resulting from the repetition of measurements. Colour measurements were made after placing meat samples onto measuring dishes, careful surface smoothing and storing them for 20 min at 0–4°C to oxygenate myoglobin in the surface layer.

The collected data were analysed statistically by means of Statistica 6.0 computer software package.

RESULTS AND DISCUSSION

Mean values, minimum and maximum values, standard deviations and coefficients of variation for respective parameters of meat colour in CIE *L*a*b** and CIE *L*C*h* scales obtained when using illuminant C and observer 2° and illuminant D65 and observer 10° in the examined material are given in Table 1. As it could be expected, the value of parameter *L** (colour lightness) proved to be almost identical when using both illuminant/observer combinations. Differences, however, referred to chromatic parameters, *i.e. a** (redness) and *b** (yellowness) and calculated on their basis parameters *C** (chroma) and *h*° (hue), describing colour tone. The largest variation was a characteristic of parameter *a**, intermediate one of parameters *b** and *C**, and the lowest of parameters *L** and *h*°.

The results presented in Table 2 show that material under examination was differentiated in respect of quality. The largest variation was characteristic of colour, wateriness and springiness sensory examination results as well as of fat content, intermediate one of water-soluble protein content,

TABLE 1. Mean values ($\bar{x}$), minimum and maximum values, standard deviations (s) and coefficients of variation (v) for CIE *L*a*b** and CIE *L*C*h* scale meat colour parameters obtained when applying illuminant C and observer 2° as well as illuminant D65 and observer 10° in the material examined (*n=72*).

Trait	$\bar{x}$	Minimum	Maximum	s	v
Using illuminant C and observer 2°					
*L**	55.03	48.46	63.23	2.93	5.32
*a**	10.71	8.15	13.61	1.25	11.67
*b**	15.45	12.28	18.02	1.21	7.83
*C**	18.83	15.79	22.14	1.36	7.22
h°	55.29	48.09	63.59	3.34	6.04
Using illuminant D65 and observer 10°					
*L**	54.97	48.53	63.07	2.88	5.24
*a**	8.35	5.89	11.68	1.19	14.25
*b**	16.68	13.71	19.07	1.12	6.71
*C**	18.68	15.36	21.80	1.34	7.17
h°	63.49	57.58	70.30	2.84	4.47

TABLE 2. Mean values ($\bar{x}$), minimum and maximum values, standard deviations (s) and coefficients of variation (v) for meat chemical composition, sensory examination results, physicochemical traits and quality indices in the material examined (*n=72*).

Trait	$\bar{x}$	Minimum	Maximum	s	v
Chemical composition (%)					
Dry matter	26.24	24.30	28.01	0.69	2.63
Total protein	22.39	21.23	23.29	0.47	2.10
Fat	2.69	1.14	4.55	0.75	27.88
Water-soluble protein	9.25	7.08	11.01	0.85	9.19
Sensory examination (points)					
Colour	3.05	1.00	5.00	0.95	31.15
Wateriness	3.06	1.00	5.00	0.97	31.70
Springiness	3.06	1.00	5.00	0.97	31.70
Physicochemical traits					
Water-binding capacity bound water (as % total water)	75.99	57.03	92.09	7.46	9.82
Thermal drip (%)	27.61	20.50	37.33	3.55	12.86
Meat quality indices					
pH_1	6.39	5.51	6.92	0.33	5.16
pH_u	5.59	5.34	6,18	0.17	3.04

water-binding capacity and thermal drip values, whereas the lowest of dry matter and protein contents and pH_1 and pH_u values.

In Tables 3 and 4 there are presented coefficients of correlation between colour parameters in the applied scales and sensory examination results, physicochemical traits and quality indices when using, respectively illuminant C and observer 2° (Table 3) and illuminant D65 and observer 10° (Table 4).

Proximate chemical composition of meat proved to be very low connected with the values of meat colour parameters. No significant relationship was found between their magnitude and the percentage of total protein in meat, and coefficients of simple correlation proved here to approximate zero. These results, as well as those discussed below, show that in the material examined the meat differed mainly in protein state rather than in its total content. Also other authors [Florowski, 2004] did not state any significant relationship between total protein content, as well as fat and dry matter contents in porcine *longissimus lumborum* muscle, and the magnitude of CIE $L^*a^*b^*$ scale colour parameters. In the material discussed, few significant coefficients of correlation were found solely between the values of b^*, C^* and $h°$ parameters and the percentage of fat and dry matter in meat. However, these coefficients proved to be very low in each case (from r=0.236* to r=0.266*), thus the percentage of fat and dry matter in meat was of little significance to its colour.

TABLE 3. Coefficients of simple correlation between CIE $L^*a^*b^*$ and CIE L^*C^*h scale meat colour parameters obtained when applying illuminant C and observer 2° and meat chemical composition, sensory examination results, physicochemical traits and quality indices in the material examined (*n=72*).

Trait	L^*	a^*	b^*	C^*	$h°$
Chemical composition (%)					
Dry matter	0.005	0.177	0.239*	0.266*	-0.031
Total protein	-0.023	-0.029	0.020	-0.001	0.044
Fat	0.010	0.210	0.194	0.010	0.252*
Water-soluble protein	-0.856**	-0.098	-0.776**	-0.620**	-0.410**
Sensory examination (points)					
Colour	-0.899**	0.015	-0.767**	-0.556**	-0.512**
Wateriness	-0.830**	-0.028	-0.731**	-0.551**	-0.449**
Springiness	-0.830**	-0.028	-0.731**	-0.551**	-0.449**
Physicochemical traits					
Water-binding capacity, bound water (as % total water)	-0.794**	-0.117	-0.730**	-0.597**	-0.367**
Thermal drip (%)	0.498**	0.154	0.404**	0.372**	0.113
Quality indices					
pH_1	-0.532**	-0.133	-0.478**	-0.417**	-0.179
pH_u	-0.736**	-0.167	-0.821**	-0.686**	-0.384**

** – significant at p≤0.01; * – significant at p≤0.05

TABLE 4. Coefficients of simple correlation between CIE $L^*a^*b^*$ and CIE L^*C^*h scale meat colour parameters obtained when applying illuminant D65 and observer 10° and meat chemical composition, sensory examination results, physicochemical traits and quality indices in the material examined ($n=72$).

Trait	L^*	a^*	b^*	C^*	$h°$
Chemical composition (%)					
Dry matter	0.001	0.207	0.240*	0.257*	-0.119
Total protein	-0.026	0.011	0.002	0.006	-0.002
Fat	0.008	0.205	0.208	0.234*	-0.137
Water-soluble protein	-0.854**	-0.324**	-0.759**	-0.696**	-0.049
Sensory examination (points)					
Colour	-0.898**	-0.209	-0.758**	-0.651**	-0.179
Wateriness	-0.828**	-0.249*	-0.714**	-0.634**	-0.111
Springiness	-0.828**	-0.249*	-0.714**	-0.634**	-0.111
Physicochemical traits					
Water-binding capacity, bound water as % total water	-0.791**	-0.326**	-0.715**	-0.665**	-0.027
Thermal drip (%)	0.499**	0.254*	0.401**	0.397**	-0.077
Quality indices					
pH_1	-0.529**	-0.284*	-0.456**	-0.453**	0.067
pH_u	-0.731**	-0.374**	-0.813**	-0.756**	-0.022

** – significant at $p \leq 0.01$; * – significant at $p \leq 0.05$

Along with an increase in the values of all analysed colour parameters, the results of colour sensory examination, meat wateriness and springiness, meat water-soluble protein content, water-binding capacity and pH_1 and pH_u values decreased significantly, whereas those of thermal drip increased. The highest coefficients of correlation were stated in the case of sensory traits evaluated, meat water-soluble protein content, water-binding capacity and pH_u, while lower ones in the case of pH_1 and thermal drip. A lower degree of correlation for colour parameters and pH_1 values in relation to pH_u results from the fact that pH_u value was determined in the same time when meat colour parameters were measured, *i.e.* 48 h after slaughter, whereas pH_1 value is a measure of metabolism rate in the muscle tissue during the first hour after slaughter.

Of the meat colour parameters, the colour lightness (L^*) and yellowness (b^*) proved to be correlated the most with the traits that determine meat quality, whereas chroma (C^*) showed slightly lower correlation, which points to the largest suitability of these parameters for meat quality evaluation. Out of two chromatic parameters of CIE $L^*a^*b^*$ scale, the value of parameter a^* (redness), contrary to that of parameter b^* (yellowness), proved to be little connected with meat quality traits, while none of the obtained coefficients of correlation proved to be significant when use was made of illuminant C and observer 2°. The lack of significant coefficients of simple correlation was also stated between meat quality traits and parameter $h°$ value upon the application of illuminant D65 and observer 10°, whereas significant coefficients of correlation were found between parameter $h°$ value and meat quality traits when use was made of illuminant C and observer 2°. Simultaneously, colour sensory evaluation results, meat wateriness and springiness, meat water-soluble protein content, water-binding capacity and pH_u value were observed to decrease significantly along with the increase in hue value (shifting of colour tone towards shorter waves). Thus, the applied illuminant/observer combination affected mainly the values of coefficients of correlation between meat quality traits and indices and parameters a^* and $h°$, with coefficients of correlation being higher in the case of parameter a^* when using combination D65/10° and higher for parameter $h°$ when using combination C/2°.

Worth emphasising is the fact that when the value of parameter L^*, irrespective of the applied illuminant/observer combination, proved to be more connected with meat quality traits than that of parameter b^*, parameter b^* value showed more close connection with pHu value. On the basis of own studies and available references [Lindahl *et al.*, 2001], the reason of that fact in meat with small concentration of pigments, which is porcine *longissimus lumborum* muscle, should be sought mainly in differences in the content of myoglobin forms in meat surface layer penetrated by light, as pH value is closely connected with oxidation and oxygenation processes of muscle pigments [Rosenvold & Andersen, 2003].

The coefficients of simple correlation between colour parameters of CIE $L^*a^*b^*$ and CIE L^*C^*h scales, obtained upon the use of both illuminant/observer combinations (Table 5), show that in both cases parameter a^* value proved to be correlated the most with colour hue ($h°$) and chroma (C^*) values and parameter b^* value to be correlated the most with meat colour chroma (C^*) and lightness (L^*). At he same time closer connections were found of parameter a^* with parameters b^*, C^* and $h°$, parameter b^* with parameter C^* and parameter C^* with parameter $h°$ when using a combination of illuminant D65 and observer 10° than that of illuminant C and observer 2°°.

When applying the D65/10° combination, no connection was stated between parameter b^* value and that of parameter $h°$, which is confirmed by studies of Van Oeckel *et al.* [1999], whereas highly significant correlation was reported between these parameters (r=0.408**) when using the C/2° combination, which was not without effect on the correlation between parameter $h°$ value and meat quality traits (Tables 3 and 4).

As the value of coefficients of correlation between param-

TABLE 5. Coefficients of simple correlation between CIE $L^*a^*b^*$ and CIE L^*C^*h scale meat colour parameters obtained when applying illuminants C/2° and D65/10° in the material examined ($n=72$).

Trait	L^*	a^*	b^*	C^*	$h°$
Using illuminant C and observer 2°					
L^*	1.000	-0.154*	0.812**	0.518**	0.666**
a^*		1.000	0.257*	0.705**	-0.776**
b^*			1.000	0.866**	0.408**
C^*				1.000	-0.102
$h°$					1.000
Using illuminant D65 and observer 10°					
L^*	1.000	-0.083	0.799**	0.632**	0.340**
a^*		1.000	0.485**	0.756**	-0.874**
b^*			1.000	0.939**	-0.003
C^*				1.000	-0.340**
$h°$					1.000

** – significant at $p \leq 0.01$; * – significant at $p \leq 0.05$

eter b^* value and parameter L^* value was similar when applying combinations C/2° and D65/10° (r=0.812** and r=0.799**, respectively), whereas correlation degree between parameter a^* value and parameter b^* value proved to be higher in the case of combination D65/10° (r=0.485**) than in case of combination C/2° (r=0.257*), this influenced an increase in correlation degree between lightness (L^*) and chroma (C^*) of meat colour (r=0.518** with combination C/2° and r=0.632** with combination D65/10°, respectively). Similarly, very low and non-significant correlation degree between lightness (L^*) and redness (a^*) when applying combination D65/10° (r=-0.083), as compared to a higher correlation degree between the values of these parameters when applying combination C/2° (r=-0.154*), affected a decrease in the values of coefficients of correlation between lightness (L^*) and colour tone ($h°$) (r=0.340** when using combination D65/10° and r=0.666** when using combination C/2°).

The results obtained show that of the colour parameters discussed, lightness (L^*) and yellowness (b^*) demonstrated the closest connection with meat quality, with the value of the latter being connected more with pH_u value of meat. However, parameter a^* value, contrary to that of parameter b^*, proved to be little connected with meat quality traits, while being closely correlated with hue ($h°$) that characterises colour tone, which also proved to be low (Table 3) or non-significantly (Table 4) correlated with the values of meat quality traits. On the other hand, the correlation degree of chroma (C^*) with meat quality traits was determined by a low correlation degree of parameter a^* and a high correlation degree of parameter b^* with these traits (Tables 3 and 4). Therefore, the lower degree of the connection of parameter C^* with meat quality traits was stated when applying both illuminant/observer combinations, as compared with parameters b^* and L^*, *i.e.* with colour lightness, whose value was highly positively correlated with parameter b^*, as already mentioned above (Table 5).

Summing up, colour parameters closely connected with meat quality proved to be parameters L^* (colour lightness) and b^* (yellowness) and slightly less C^* (chroma), whereas parameters a^* (redness) and $h°$ (colour tone) demonstrated, in general, a low correlation degree with meat quality traits.

The application of illuminant D65 and observer 10° for measurements of meat colour proved to be more suitable in the case of parameter a^* and C^*, whereas the use of illuminant C and observer 2° – in the case of parameter $h°$.

CONCLUSIONS

1. When using both combinations of illuminant/observer, *i.e.* C/2° and D65/10°, the largest variation was characteristic of parameter a^*, intermediate one of parameters b^* and C^*, and the lowest of parameters L^* and $h°$.
2. Proximate chemical composition of meat proved to be very little connected with the values of meat colour parameters, but significant coefficients of correlation were stated only in some cases between the values of parameters b^*, C^* and $h°$ and the percentage of fat and dry matter in meat.
3. In the case of both applied combinations of illuminant/observer, the meat water-soluble protein content, water-binding capacity and pH1 and pHu values decreased significantly along with the increase of lightness (L^*), yellowness (b^*) and chroma (C^*), whereas thermal drip value increased.
4. The magnitude of parameter a^* proved to be significantly correlated with meat quality traits only upon the application of illuminant D65 and observer 10°, whereas that of parameter $h°$ only when using illuminant C and observer 2°.
5. When using illuminant C and observer 2° as well as illuminant D65 and 10°, parameter b^* showed more close relation to meat pHu value than parameter L^*.
6. The colour parameters highly correlated with meat quality proved to be L^* (colour lightness) and b^* (yellowness), slightly less chroma (C^*), whereas parameters a^* (redness) and $h°$ (hue) showed low correlation.
7. The application of illuminant D65 and observer 10° for measurements of meat colour proved to be more suitable in the case of parameter a^* and C^*, whereas the use of illuminant C and observer 2° – in the case of parameter $h°$.

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ZALEŻNOŚĆ MIĘDZY PARAMETRAMI BARWY SKALI CIE *L*a*b** I CIE *L*C*h* OKREŚLONYMI PRZY ZASTOSOWANIU ILUMINANTA C I OBSERWATORA 2° ORAZ ILUMINANTA D65 I OBSERWATORA 10° A PODSTAWOWYM SKŁADEM CHEMICZNYM I CECHAMI JAKOŚCI WIEPRZOWEGO MIĘŚNIA *LONGISSIMUS LUMBORUM*

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Badaniami objęto 72 próby, zróżnicowane pod względem jakości, pobrane z mięśnia *longissimus lumborum* 72 tusz tuczników (36 tusz loszek i 36 tusz wieprzków), zbliżonych pokrojem do mieszańców ras wbp i pbz, pochodzących z fermy wielkostadnej w Kołbaczu, ubijanych na przemysłowej linii technologicznej. Około 45 min. po uboju określono pH_1 mięsa w odcinku między 4 a 5 kręgiem lędźwiowym. Próby mięsa pobrano po około 24 godzinnym chłodzeniu i przetrzymywano przez około 24 godziny w temperaturze 0° do 4° C. Około 48 godzin od momentu uboju, przeprowadzono ocenę sensoryczną barwy, wodnistości i sprężystości mięsa surowego, a następnie po dwukrotnym zmieleniu mięsa określono: wodochłonność, pH_u, procentową zawartość suchej masy, białka ogólnego i tłuszczu, a także białka rozpuszczalnego w wodzie. Przy zastosowaniu aparatu Mini Scan XE Plus 45/0 określono parametry barwy mięsa w skalach: CIE *L*a*b** i CIE *L*C*h*, przy dwóch najczęściej stosowanych w pomiarach barwy mięsa kombinacjach iluminant/obserwator, tj.: iluminant C i standardowy obserwator 2° oraz iluminant D65 i standardowy obserwator 10°. Pomiarów barwy dokonywano po 20 minutach przetrzymywania prób w temperaturze 0° do 4° C.

Parametrami barwy ściśle powiązanymi z jakością mięsa okazały się jasność (*L**) i żółtość (*b**), w nieco mniejszym stopniu nasycenie (*C**), a najmniej parametry *a** (czerwoność) i *h*° (ton barwy), które wykazały ogólnie średni i niski stopień zależności z cechami jakości mięsa.

Zastosowanie do pomiarów barwy mięsa iluminanta D65 i obserwatora 10° okazało się bardziej przydatne w przypadku parametru *a** oraz *C**, natomiast iluminanta C i obserwatora 2° w przypadku parametru *h*°.