Usefulness of Selected Methods of Colour Change Measurement for Pork Quality Assessment

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Abstract

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A few selected methods of the meat colour change determination were compared with regard to their usefulness in the assessment of the quality of minced pork. The study was carried out on 128 samples of the muscle *longissimus lumborum*, taken from 128 carcasses weighing 70–105 kg (equal number of both sexes – 64), obtained from pigs slaughtered in an industrial process line. The relationships were determined between the meat quality traits (concentrations of basic chemical components in the meat, colour, sensory analysis of wateriness and firmness, WHC and pH_u), and the changes in colour parameters measured in CIELAB and CIELCh scales, total colour change (ΔE^*), and the changes determined by Karamucki using the modified Kortz method. It was found that the most useful method for the quality assessment was the Kortz method modified by Karamucki, used to determine the stability of the meat colour (expressed as % colour change) and based on the measurements of absorbance at wavelengths 580 nm and 630 nm, before and after the change of colour. Out of the meat colour parameters, the most useful for assessing the meat quality were the changes in redness (a^*) – CIELAB scale, and hue angle $h°$ – CIELCh scale. The changes in colour determined by the aforementioned methods were a better indicator of the pork quality than the total colour change (ΔE^*).

Keywords: colour of pork; sensory analysis; WHC; pork quality

Meat colour is one of the most important traits defining the quality of meat (Lindahl 2005; Lindahl *et al*. 2001). The measurement of colour, depending on the scale used, is usually presented as the resultant of three different components – such as L^*, a^*, b^* on the CIELAB scale or L^*, C^*, $h°$ on the CIELCh scale (CIE 1976, 1978). Each colour parameter has a certain relationship with quality traits, such as the contents of basic chemical components in the meat, pH, and water holding capacity (WHC). The changes in the meat colour, for example during storage, are also related to the remaining quality traits. Therefore, according to some researchers (Kortz 1970) the determination of the colour change may be a good indicator of the meat quality. These changes can be determined using different methods – for example, by identifying the differences in the values of the individual colour parameters, determining the total colour change (ΔE^*) – (CIE 1978), or measuring colour stability (Kortz 1966). However, the choice of an appropriate method for the determination of the colour changes in order to evaluate the quality of meat is not easy without knowing the dependencies between different parameters of the colour and meat quality traits such as pH and WHC.

The aim of this study was to compare the suitability of the selected methods of the determination of the colour change of minced pork for the assessment of its quality.

MATERIAL AND METHODS

The material studied consisted of 128 samples of the *longissimus lumborum* muscle taken from 128 carcasses weighing between 70–105 kg (64 gilts and 64 castrates) obtained from pigs slaughtered in an industrial process line. Meat samples weighing about 1 kg (meat and bone) were collected during cutting after approximately 24 h of cooling from the section between 1st and 4th lumbar vertebra on the right half-carcass. The samples were wrapped in a plastic film, transported to the laboratory and stored at 0–4°C. About 48 h after slaughter, the meat was separated from the bone and external fat and epimysium were removed. Sensory and physico-chemical analyses were then performed, and some samples were prepared and frozen for chemical evaluation. Sensory evaluation was performed on meat slices with a thickness of 10 mm. The meat used in physico-chemical and chemical analyses was crushed using a meat mincer with a 4 mm mesh.

Sensory analysis of meat. Sensory analysis was carried out by 5 persons about 48 h after slaughter on raw meat slices about 10 mm thick. The team rated the colour, firmness, and wateriness of meat on a 5-point scale: 1 point – serious PSE (pale soft exudative), 2 points – slight PSE, 3 points – normal meat, 4 points – slight DFD (dark firm dry), 5 points – serious DFD.

Physico-chemical assessment of meat. Physicochemical assessment of the meat was carried out about 48 h after slaughter. It involved colour measurements and the determination of WHC and pH_u (pH ultimate). All the determinations were performed on freshly minced meat.

Measurements of meat colour. Meat colour measurements were performed using a Mini Scan XE Plus 45/0, with a port diameter 31.8 mm, adapted for the measurement of the colour of minced meat. Standardisation of the apparatus was made in respect of the standard black and white pattern coordinates, X = 78.5, Y = 83.3, and Z = 87.8 (for standard light D65 and 10° standard observer). The colour parameters of the individual meat samples were determined on both scales, CIELCh and CIELAB (CIE 1976, 1978), iluminant D65 and 10° Standard Observer (Honikel 1998). The measurements of the meat absorbance were performed at wavelengths 580 nm and 630 nm.

Colour measurements were carried out after placing the meat in the measurement vessels, levelling the surface, and storing at 4°C for 20 min for the oxygenation of myoglobin in the surface layer of the meat.

Changes in colour were induced according to the Kortz (1966) method, by 4-h illumination of samples with a fluorescent tube light at an intensity of 1250 lux in an atmosphere saturated with water vapor, at room temperature (22–24°C). After the illumination, the colour measurements were performed again using CIELAB and CIELCh scales, illuminant D65, Standard Observer 10°, along with repeated measurements of the meat absorbance at wavelengths 580 nm and 630 nm.

Based on the results of the measurements obtained before and after illumination, true and absolute differences in the values of the colour parameters were calculated: ΔL^*, Δa^*, Δb^*, ΔC^*, $\Delta h°$, total colour change – ΔE^* (CIE 1978), and colour stability (CS) – according to Kortz (1966) as modified by Karamucki (2008). The differences were expressed as % change of colour – $\%CC$ (Różyczka & Michalski 1978). Total colour change and % colour change were calculated according to the following formulas:

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

$$\%CC = 50 \times (2 - CS)$$

where:

$$CS = 2 - \left(\frac{A_{580}}{A_{630}} - \frac{A'_{580}}{A'_{630}}\right)$$

where:

CS – colour stability

A_{580}, A_{630} – values of absorbance at wavelengths 580 nm and 630 nm before the illumination of the samples

A'_{580} A'_{630} – values of absorbance at wavelengths 580 nm and 630 nm after the illumination of the samples

Measurements of WHC and pH_u. Water holding capacity (WHC) of meat was determined by Grau and Hamm (1953) method modified by Pohja and Niinivaara (1957), expressed as % of the bound water in relation to total water content.

The value of pH_u was measured, using a combined ESAgP.302W electrode and a CyberScan 10 pH meter (Eutech Cybernetics PTE LTD., Singapore), in the aqueous extract of meat prepared at a 1:1 ratio, after 1 h of extraction.

Chemical analysis of meat. Chemical analysis was carried out on meat samples stored frozen for 1 moth to 2 months. The samples of meat, wrapped in a double layer of foil, had been frozen at –18°C. Defrosting was carried out at 0–4°C. The meat samples were then placed in plastic containers and thoroughly mixed before the assay, in order to avoid the loss of meat juice. Chemical analysis involved the determination of dry matter, protein, fat, and ash (AOAC 2003).

Statistical methods. Calculations and statistical analyses were performed using Statistica 8.0. PL software. The means and standard deviations were calculated for the examined meat quality traits and the means and standard deviations of the changes induced by the illumination of meat samples with regard to various colour parameters (ΔL^*, Δa^*, Δb^*, ΔC^*, Δh^o), total change colour (ΔE^*) and the percentage of colour change (%*CC*) in meat samples from different groups in terms of pH_u levels. Simple correlation coefficients were calculated between the changes in colour and the contents of basic chemical components in the meat and the selected quality traits. Their significance was estimated at probability levels of $P \leq 0.01$ and $P \leq 0.001$. The calculations of simple correlation coefficients adopted absolute values of differences in colour parameters.

RESULTS AND DISCUSSION

Table 1 presents the means, minimums, maximums, and standard deviations of the meat traits

Table 1. Means ($\bar{x}$), minimums, maximums and standard deviations (SD) of pork quality traits

Trait	$\bar{x}$	Min.	Max.	SD
L^* – lightness	55.37	48.55	67.00	3.37
$L^{*\prime}$ – lightness after illumination	55.08	47.40	68.44	3.80
a^* – redness	8.00	4.89	11.61	1.19
$a^{*\prime}$ – redness after illumination	6.91	4.82	10.02	1.01
b^* – yellowness	16.59	13.50	19.09	1.18
$b^{*\prime}$– yellowness after illumination	15.25	12.87	17.70	1.00
C^* – chroma	18.44	15.10	21.72	1.41
$C^{*\prime}$– chroma after illumination	16.77	14.40	19.33	1.05
h^o – hue angle	64.28	57.50	71.08	2.87
$h^{o\prime}$ – hue angle after illumination	65.62	57.72	74.07	3.26
ΔL^*	0.29	–1.30	1.97	0.66
Δa^*	1.10	0.10	4.55	0.78
Δb^*	1.34	0.11	2.50	0.46
ΔC^*	1.67	0.11	3.88	0.68
Δh^o	–1.34	1.90	–9.50	1.71
ΔE^*	1.95	0.86	5.18	0.73
%*CC* – % change of colour	13.19	3.61	40.37	7.19
Dry matter (%)	25.91	23.60	28.08	0.83
Protein (%)	22.30	20.80	23.61	0.56
Fat (%)	2.47	1.06	4.60	0.75
Ash (%)	1.12	0.80	1.25	0.06
Colour (pkt)	3.06	1.00	5.00	0.95
Wateriness (pkt)	3.06	1.00	5.00	0.97
Firmness (pkt)	3.08	1.00	5.00	0.94
WHC (%) – water holding capacity	75.99	46.79	92.44	9.15
pH_u – pH ultimate	5.58	5.09	6.15	0.21

tested. Table 2 shows the coefficients of simple correlation between (*i*) the differences in colour parameters induced by the illumination of the meat samples (ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$), total colour change (ΔE^*), percentage of colour change (%*CC*), and (*ii*) the values of colour parameters before illumination, the percentage contents of the basic chemical components, the results of sensory evaluation, WHC, and pH_u. Table 3 shows the mean values and standard deviations of differences in colour parameters (ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$) induced by illumination and total colour change and % colour change in successive groups of meat samples with different pH_u.

We found significant positive coefficients of simple correlation between the values of colour parameters L^*, a^*, b^*, and C^* before illumination and the differences induced by illumination in various colour parameters (ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$), total colour change (ΔE^*), and the percentage of colour change (%*CC*).

There were no significant correlation coefficients between the hue angle ($h°$) and ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$ and ΔE^*, and %*CC*. The higher were the lightness (L^*), redness (a^*), yellowness (b^*), and chroma (C^*) of meat samples before illumination, the greater were the changes in colour that occurred during the illumination of the samples (Table 2).

The coefficients of simple correlation between the differences in the values of all parameters of colour (ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$), and also ΔE^*, and %*CC*, vs. the contents of dry matter, protein, fat, and ash, were low and insignificant, which indicates that the proportions of basic chemical components in the test meat samples did not have any significant impact on the changes in colour. These changes depended on other quality traits (Table 2).

The coefficients of simple correlation between the differences in the values of various parameters of colour (ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$) and ΔE^*, and %*CC*, and the notes obtained during the sensory evaluation of colour, wateriness and firmness of meat, WHC and pH_u proved to be significant.

Simple correlation coefficients for Δa^*, and %*CC* were mostly high. The lower were the notes obtained in the sensory evaluation of colour, firmness, and wateriness of meat, the smaller were WHC and pH_u, and the greater were the adverse changes in the colour of meat during illumination. The highest correlation coefficients were found for % colour change, and slightly lower for redness (Δa^*) and hue angle ($\Delta h°$). Simple correlation coefficients between the meat quality traits and

Table 2. Coefficients of simple correlation between the differences in parameters of meat colour, the total colour change (ΔE^*), the percentage of colour change (%*CC*), and the meat quality traits

Trait	ΔL^*	Δa^*	Δb^*	ΔC^*	$\Delta h°$	ΔE^*	%*CC*
L^* – lightness	–0.005	0.607**	0.311**	0.455**	0.637**	0.518**	0.790**
a^* – redness	–0.128	0.549**	0.322**	0.481**	0.342**	0.479**	0.383**
b^* – yellowness	–0.174	0.743**	0.561**	0.691**	0.595**	0.668**	0.724**
C^* – chroma	–0.177	0.767**	0.546**	0.703**	0.579**	0.689**	0.691**
$h°$ – hue angle	0.040	–0.208	–0.046	–0.149	–0.094	–0.161	–0.041
Dry matter (%)	–0.127	0.214	0.207	0.250*	0.055	0.183	0.159
Protein (%)	–0.082	0.144	0.062	0.106	0.146	0.130	0.184
Fat (%)	–0.127	0.086	0.188	0.160	–0.079	0.079	0.011
Ash (%)	–0.015	0.016	–0.042	–0.009	–0.055	–0.015	0.000
Colour (pkt)	0.108	–0.701**	–0.379**	–0.554**	–0.673**	–0.590**	–0.761**
Wateriness (pkt)	0.145	–0,708**	–0.363**	–0.548**	–0.674**	–0.578**	–0.777**
Firmness (pkt)	0.192	–0.704**	–0.364**	–0.551**	–0.665**	–0.566**	–0.758**
WHC (%) – water holding capacity	0.021	–0.701**	–0.286*	–0.494**	–0.701**	–0.577**	–0.792**
pH_u – pH ultimate	0.249*	–0.721**	–0.513**	–0.650**	–0.610**	–0.583**	–0.740**

*$P \leq 0.01$; **$P \leq 0.001$

Table 3. Effect of pH_u on the changes in meat colour

Trait	Group 1 (n = 3) $5.0 < pH_u \leq 5.2$		Group 2 (n = 13) $5.2 < pH_u \leq 5.4$		Group 3 (n = 70) $5.4 < pH_u \leq 5.6$		Group 4 (n = 24) $5.6 < pH_u \leq 5.8$		Group 5 (n = 12) $5.8 < pH_u \leq 6.0$		Group 6 (n = 6) $6.0 < pH_u \leq 6.2$	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
pH_u	5.12	0.06	5.33	0.06	5.50	0.06	5.69	0.05	5.91	0.07	6.11	0.07
ΔL^*	– 1.27	0.04	– 0.45	0.81	0.21	0.41	0.60	0.52	0.95	0.47	1.07	0.35
Δa^*	3.70	0.72	2.07	0.91	1.15	0.44	0.67	0.36	0.33	0.23	0.25	0.18
Δb^*	1.97	0.49	1.43	0.48	1.46	0.40	1.24	0.41	0.88	0.36	0.75	0.26
ΔC^*	3.20	0.72	2.16	0.71	1.81	0.54	1.40	0.49	0.93	0.45	0.78	0.31
$\Delta h°$	– 8.09	0.77	– 3.88	2.12	– 1.36	1.01	– 0.32	0.87	0.35	0.74	0.29	0.41
ΔE^*	4.40	0.77	2.72	0.88	1.94	0.51	1.65	0.45	1.46	0.31	1.39	0.14
$\%CC$	35.24	3.53	25.63	6.53	12.87	3.53	10.14	2.09	6.53	1.33	4.54	1.03

ΔL^*, Δa^*, Δb^*, ΔC^*, and $\Delta h°$ were calculated by subtracting the value of a given parameter after illumination from the value before illumination

chroma (ΔC^*), and total colour change (ΔE^*) were at a medium level. By contrast, the lowest correlation coefficients were reported for yellowness (Δb^*) (Table 2).

To sum up, the most useful method for the evaluation of the quality of minced pork was the method for the determination of colour stability by Kortz (1966), modified by Karamucki (2008), which can be presented as a percentage of colour change (%*CC*) (Różyczka & Michalski 1978). It consists of the determination of colour stability based on the measurements of absorbance (before and after illumination of the meat samples) at a wavelength of 580 nm, i.e. in one of two absorption peaks of oxymyoglobin, and at a wavelength of 630 nm, i.e. in the region of one of the peaks of metmyoglobin absorption. In contrast, the total colour change (ΔE^*), used by some authors to assess the overall change in meat colour (Kłossowska & Olkiewicz 2000; Karwowska 2008) proved to be significantly less useful in the assessment of meat quality.

One of the most important traits that determines the quality of meat is pH_u (Boler *et al.* 2010), which affects WHC, the structure of meat, and the oxidation and reduction processes, which in turn affect the relative contents of the chemical forms of myoglobin in the surface layer of meat (O'Keeffe & Hood 1982; Lindahl 2005). Therefore, all the factors responsible for the rate and range of pH decrease after slaughter affect colour changes during storage of meat. During storage, the change in colour is also affected by other factors such as temperature and humidity (Feldhusen & Reinhard 1994), the pressure of oxygen (Livingston & Brown 1982; O'Keeffe & Hood 1982), light (Bertelsen & Skibsted 1987; Zhu & Brewer 1998) and the manner and duration of storage (Rosenvold & Andersen 2003; Lindahl *et al.* 2006).

Table 3 presents the effect of the impact of pH_u on the change in colour. The results indicate that the adverse changes in various parameters of colour did not occur in parallel. The values of parameters a^*, b^*, and C^*, similarly to the values of ΔE^*, and %*CC*, decreased in all the pH_u groups, from group 1 to group 6. In contrast, lightness (L^*) after the illumination of the samples increased in groups 1 and 2, while in groups 3–6 it decreased. The hue angle $h°$, as has already been mentioned, increased in groups 1–4 (hue angle shifted toward shorter waves) and decreased in groups 5 and 6 (Table 3).

It is known that the changes in the surface colour of fresh meat exposed to oxygen are among other things caused by the changes in the contents of the chemical forms of myoglobin, e.g. oxygenated myoglobin (oxymyoglobin), oxidised myoglobin (metmyoglobin), and reduced myoglobin (deoxymyoglobin). The changing ratio of these three chemical forms of myoglobin present in raw meat has a significant impact on the chromatic parameters of colour (*a**, *b**, *C**, and *h*°) because each of them has a different colour.

The highest redness (*a**) is observed for oxymyoglobin, a lower one for deoxymyoglobin, and the lowest one for metmyoglobin. At the same time, the highest yellowness (*b**) was observed for oxymyoglobin, a lower – metmyoglobin, and the lowest – deoxymyoglobin. Therefore, the greatest impact on chroma (*C**) was exerted by the oxygenated form, and the deterioration of hue angle (*h*°) was most related to the oxidised form (Karamucki 2008).

The knowledge of the effects of the relative contents of the chemical forms of myoglobin on the meat colour can help understand the relationship between the changes in the values of colour and meat quality traits. When examining these relationships, the highest correlation coefficients are generally observed for the changes in *a**. In case of a decrease, the most common cause is a decline in the relative content of oxymyoglobin and a simultaneous increase in the relative content of metmyoglobin, which also causes a deterioration of both chroma (*C**) and hue angle (*h*°). At the same time, the changes in yellowness (Δ*b**) are smaller than those for redness (Δ*a**), due to smaller differences in yellowness in both chemical forms of myoglobin. The changes in lightness (Δ*L**) – usually smaller than those in chromatic values – depend only to a small degree on the effect of changes in the relative contents of chemical forms of myoglobin (Karamucki 2008).

In summary, the parameters *L**, *a**, and *b** do not change in parallel, and are correlated to varying extent with the traits of meat quality. Therefore, the total colour change (Δ*E**), which consists of the changes in lightness (Δ*L**), redness (Δ*a**), and yellowness (Δ*b**), is less useful in assessing the quality of pork in comparison with the method by Kortz (1966) modified by Karamucki (2008), and compared with changes in redness (Δ*a**), and hue angle (Δ*h*°).

CONCLUSIONS

The determination of changes in the colour of minced pork may be an indicator of its quality, but it is important to choose an appropriate method to identify these changes. The results of this paper show that, among the selected methods, the most useful for the evaluation of pork quality is the method by Kortz (1966) modified by Karamucki (2008). It is used to determine the stability of meat based on the measurements of the absorbance at wavelengths 580 nm and 630 nm before and after the change of the meat colour. It can be expressed as the percentage of colour change (%*CC*) – Różyczka and Michalski (1978). At the same time, out of all the parameters of meat colour measured in CIELCh and CIELAB scales, the most useful for assessing the meat quality were *a** and *h*°. The coefficients of simple correlation between the changes in the redness (Δ*a**) and hue angle (Δ*h*°), and the traits of pork quality such as pH_u, and WHC, proved to be the highest out of all the colour parameters. The changes in colour defined as: %*CC*, Δ*a**, and Δ*h*° o are a better indicator of the ground pork quality than the determination of the total colour change (Δ*E**).

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