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Changes in the color and pH of rabbit meat in the aging process*)

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Summary

Rabbit meat in the course of aging was examined for color and pH to determine the changes occurring in both parameters with time. The study used New Zealand White × Belgian Giant Grey rabbit crosses. The animals were fed pellets ad libitum. Color was investigated on the basis of lightness (L*), redness (a*), yellowness (b*), chroma (C*), and hue-angle (H*). The L*, a*, and b* color components of meat were measured on the surface and while the pH value were measured with an electrode that was placed into the loin and thigh muscles (m. longissimus dorsi and m. biceps femoris) 45 min, 3 h, 7 h, and 24 h after slaughter. The C* and H* values were calculated on the basis of a* and b*. In addition, the absolute and relative pH changes (ΔpH_{abs} and ΔpH_{rel}, respectively) were computed using the pH measurements. The a* and b* values of the loin muscle (m. longissimus dorsi) increased with time. The b* component displayed a shift from blue towards yellow, which resulted in the fluctuations of the values of L*, C*, and H*. The values of all color components (L*, a*, b*, C* and H*) of the thigh muscle (m. biceps femoris) increased with time, with the differences between the measurements made 45 min and 3 h after slaughter being insignificant. This suggests that the changes in meat color began not earlier than 3 h after slaughter and continued until 24 h. These changes, however, were not as dynamic as in the loin. The results show that the color of rabbit meat becomes stabilized 24 h after slaughter; therefore this is the minimum post-mortem time at which color evaluation should be performed. Rabbit meat had pH in the range corresponding with good quality meat. For both muscles, the pH value of meat did not differ significantly between the 7th and 24th hour after slaughter, indicating that the acidity of meat in this period of time was stable. The thigh muscle and the loin muscle exhibited similar absolute and relative changes in pH, which shows that the ageing of meat in various parts of the carcass was uniform.

Keywords: aging process, color, meat, pH, rabbit

Rabbit meat is highly valued for its taste and nutritional and dietary qualities. The main traits that determine the quality of meat include color, pH, tenderness, marbling, and flavor. These traits depend on many factors, among them breed, age, sex, feeding system, body weight before slaughter, and slaughtering methods (6). For a potential buyer, color is one of the characteristics that determine his decision whether to buy meat or not. The most important pigments responsible for meat color are myoglobin and haemoglobin. Meat changes its color as a result of chemical reactions involving myoglobin, such as oxygenation, oxidation or the addition of a carbon monoxide molecule, and reduction, which plays a central part in maintaining the color of meat after slaughter (18).

The acidity (pH) of meat, measured 45 minutes and 24 hours after slaughter, constitutes another important indicator of meat quality (3). It is also an essential parameter taken into account when assessing the shelf life and technological usability of meat. The functional quality of meat is associated with its appearance, color, and water absorption, whereas culinary quality is connected with taste, flavor, tenderness, and juiciness. Acidity is the one of the main factors inhibiting the development of bacterial microflora, which prevents spoilage. In rabbits, the acidity of aged meat (stored at least 24 h), pH_{24}, ranges between 5.6 and 5.85, indicating that rabbit meat has an inferior shelf life compared to the meat of other animal species. This final acidity (pH_{24}) depends on many factors, among them the management system, extent of debleeding after slaughter, type of muscle, individual differences, and level of stress.

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The aim of the present is determine the changes caused by ageing to the color and pH of rabbit meat.

Material and methods

Animals and feeding. The study was conducted on the meat of rabbit crosses of the New Zealand White and Belgian Giant Grey breeds (n = 24). Rabbits were housed in the same environment in closed rabbitry in wire cages (2 rabbits/cage). The animals were fed *ad libitum* with pellets containing min. 16.5% crude protein, max. 14% crude fiber, and min. 10.2 MJ metabolizable energy. The rabbits were slaughtered at the age of 12 weeks at a body weight of around 3 kg, after a 24-h fasting period in compliance with the Polish national regulations for commercial slaughtering. The slaughterhouse was close to the farm, so stress due to transport was minimal. Hot carcasses were suspended in a ventilated area for 45 min and then they were chilled at 4°C until 24 h post-mortem.

Measurement methods. Meat color (L* – lightness, a* – redness, b* – yellowness) was measured 45 min, 3 h, 7 h, and 24 h after slaughter on the surface of *m. longissimus dorsi* (LD) and *m. biceps femoris* (BF) using a Minolta CR-410 Chromameter (Minolta Co., Ltd., Osaka, Japan), which gives the average of three measurements at each point, according to the CIELab standards (7) using light source D65 and 8 mm Ø measuring area. The redness and yellowness components were used to calculate chroma – C* ($C^* = \sqrt{a^{*2} + b^{*2}}$) and hue-angle – H* ($H^* = \arctan \frac{b^*}{a^*}$).

The post-mortem acidity of the muscular tissue of *longissimus dorsi* and *biceps femoris* was measured using a microprocessor-based pH-meter HI-9024 (with an accuracy of 0.01 units), equipped with electrode that was placed into the muscles 45 min (pH_{45}), 3 h (pH_3), 7 h (pH_7), and 24 h after slaughter (pH_{24}). Also the absolute drop ($\Delta pH_{abs} = pH_{45} - pH_{24}$) and relative drop ($\Delta pH_{rel} = \frac{\Delta pH_{abs}}{pH_{45}}$) in the pH value was calculated according to Blasco and Piles (4).

Statistical analysis. The results were analyzed using the SAS statistical software (21). Analysis of variance with repeated measurements was performed. The significance of differences was determined at the probability level $P \leq 0.05$. The data were presented as the least squares means and the standard error of the mean.

Results and discussion

Musculus longissimus dorsi (LD)

Meat color. The L* parameter describes the degree of meat lightness: the higher its value, the lighter the color of meat. Meat color was lightest 45 min after slaughter. The L* value varied with time, decreasing in the first part of the measuring period (down to at the 7th hour after slaughter), and increasing later on (Tab. 1). Significant differences in meat lightness occurred between the measurement made at the first time point (45 min after slaughter) and the measurements at the other three time points, and between 7 h and 24 h after slaughter; the other differences were insignificant.

Since the available literature on the color of meat lacks information on the measurements of L* made 3 h and 7 h after slaughter, some of the results obtained in this study cannot be compared with other findings. The values of L* measured in this experiment were comparable with the results of Maj et al. (17) and Bieniek et al. (3). The L^*_{24} values were higher than those found by Virág et al. (24), probably due to the addition of vitamin E to the diet they fed to rabbits, but lower than the L^*_{24} value reported by D'Agata et al. (10), which may be attributed to different climatic conditions (central Italy) and a different breed of rabbits (local breed).

In the course of the meat ageing process, changes occur in the proportions of myoglobin varieties, depending on oxygen availability during cold storage. This contributes to a change in the color of meat which is a resultant of the red color derived from myoglobin, bright red color derived from oxymyoglobin, and brown color derived from metmyoglobin. The red component (a*) measured on the surface of LD had a negative value 45 min after slaughter, and tended to increase with time. The values measured 3 h, 7 h and 24 h after slaughter were positive (Tab. 1). The differences between individual measurements were significant.

A similar pattern can be seen in the case of the b* parameter describing the proportion of the yellow color. Its value was lowest 45 min after slaughter, and later on it steadily increased up to 24 hours after slaughter (Tab. 1). This means a shift from the bluish color of meat towards yellow. Significant differences occurred between the measurements at the time points 45 min and both 7 h and 24 h, between 3 h and both 7 h and 24 h, as well as between 7 h and 24 h after slaughter. The measurements at times 45 min and 3 h after slaughter did not differ significantly.

Compared to the results of this study, lower values of the a* parameter were observed by Virág et al. (24) and D'Agata et al. (10), whereas Gondret et al. (14) obtained similar values. Considerably higher values of a* were noted by Maj et al. (17), which may be

Tab. 1. Color parameters and pH value of *Longissimus dorsi* muscle in rabbits

Trait	Time			
	45 min	3 h	7 h	24 h
N	24	12	24	24
L*	59.30 ± 1.61^b	52.29 ± 1.54^{ac}	50.71 ± 0.84^a	55.43 ± 1.20^c
a*	–0.67 ± 0.51^a	1.54 ± 0.69^b	3.15 ± 0.92^c	5.16 ± 1.00^d
b*	–5.06 ± 0.97^a	–3.84 ± 0.78^a	–1.98 ± 0.71^b	3.48 ± 0.85^c
C*	5.28 ± 0.95^a	4.64 ± 0.75^a	4.34 ± 0.59^a	6.36 ± 1.18^b
H*	1.07 ± 0.31^b	–0.03 ± 0.57^a	–0.41 ± 0.33^a	0.58 ± 0.11^b
pH	6.64 ± 0.10^c	6.25 ± 0.12^b	5.83 ± 0.03^a	5.90 ± 0.14^a

Explanation: a, b, c, d – mean values marked with different letters differ significantly at $P \leq 0.05$

due to the use of different breeds of rabbits and other measuring instruments. For the b* component, the differences between the results obtained by various authors were less pronounced, except for the b^*_{24} value reported by Daszkiewicz et al. (13), which was much higher. The results received by Bieniek et al. (3) were similar to those of the present study, while the b^*_{24} value obtained by D'Agata et al. (10) was lower. The differences between the data reported by various authors may be attributed to different rearing systems, rabbit breeds, transport stresses, and the life activity of individual muscles (11). They might also have resulted from the use of different measuring instruments (Minolta CR-300, CR-410, HunterLab MiniScan XE Plus). The latter factor was found by Brewer et al. (5) to cause significant differences between measurements.

Chroma (C*) and hue-angle (H*) depend directly on the red and yellow components. In this experiment, the value of C* parameter was 5.28 forty-five minutes after slaughter. Later on it decreased down to seven hours after slaughter, and then it increased (Tab. 1). Similarly, the value of H*, being 1.07 when measured 45 min after slaughter, first steadily decreased (down to -0.41, recorded 7 h after slaughter), and later on it rose at the end of measurements (Tab. 1). There is a correlation between the lightness (L*), chroma (C*) and hue-angle (H*) parameters: when the value of L* decreases or increases, the values of C* and H* decrease or increase accordingly. Compared with the results of the present study, the values of chroma calculated by Trocino et al. (23) and Virág et al. (24) were lower. Maria et al. (19) received similar results, while Maj et al. (17) reported higher values of C*. Lower values of the H* parameter than those obtained in this study were reported by Trocino et al. (23).

Meat pH. Glycogen contained in muscles serves as the main energy storage in a living animal. After slaughter, glycogen becomes converted to lactic acid, which leads to the acidification of meat. Acidification hampers microbial growth; on the other hand, it is also an indicator of faulty (PSE, DFD) meat. The pH value of meat can be affected by stresses connected to transport or slaughter (through a rapid drop in the glycogen content of muscles, adversely influencing glycolytic metabolism) (23). The concentration of hydrogen ions in muscles is also associated with meat color. As shown by Strzyżewski et al. (22), the pH value of meat 24 h after slaughter is negatively correlated with the color parameters L*, b*, and C*, but not with the parameter a*. The results of the present study support the latter findings.

The pH value of rabbit meat was highest 45 min after slaughter; after which it gradually decreased, down to at the 7th hour (Tab. 1). Twenty-four hours after slaughter the pH value was slightly increased. No statistically significant differences were found between the measurements made 7 h and 24 h after slaughter, which may indicate that the hydrogen ion concentration in muscles stabilized as early as 7 h after post-mortem. The differences between 45 min and three other time-points, as well as between 3 h and both 7 and 24 h were significant. Barron et al. (2) reported slightly higher pH values of meat 3 h after slaughter, and after 24 h. The differences compared to the present study may be due to the use of different breeds of rabbits and different climatic conditions (Mexico). Other authors, referred to hereinafter, performed pH measurements 45 min after slaughter, and after storage at +4°C for 24 h. Lower values than those measured in this study were noted by Bieniek et al. (3), and by Daszkiewicz et al. (12). In this case, the lower pH values may be associated with an extensive rearing system used by the latter. Higher pH_{45} values and lower pH_{24} values were obtained by Blasco and Piles (4). Again, the differences with the present research may be attributed to the use of different rabbit breeds.

The absolute and relative fall in the pH value provides information about the rate of change in the acidity of meat after slaughter. The pH of meat decreases faster in animals with a greater stress resistance, in which the course of glycolytic processes is optimal. In the present experiment, the results of the absolute drop in pH (ΔpH_{abs}) and the relative drop in pH were shown in Table 2. Similar results on ΔpH_{abs} were obtained by Maj et al. (17). Higher values were noted by Blasco and Piles (4), and by Bieniek et al. (3). The ΔpH_{rel} values reported by these authors were similar to those obtained in the present study, ranging from 0.12 (17) to 0.18 (3). The differences in ΔpH_{abs} may have indirectly resulted from the higher initial values of pH (pH_{45}), noted by the latter authors.

Tab. 2. Absolute and relative drop of pH in *Longissimus dorsi* and *Biceps femoris* muscles

Trait	Muscle	
	Longissimus dorsi	*Biceps femoris*
ΔpH_{abs}	0.84 ± 0.11	0.96 ± 0.15
ΔpH_{rel}	0.14 ± 0.01	0.14 ± 0.02

Musculus biceps femoris (BF)

Meat color. Forty-five minutes after slaughter, the thigh had a darker color than the loin. This was due to the fact that the muscles of the legs are larger, perform harder work, and have higher myoglobin content than the muscles of the back. In the process of ageing, however, the meat gets lighter, and 24 h after slaughter the L* value of the BF muscle becomes close to the one for the LD muscle.

In this experiment, the L* value of BF measured 45 min after slaughter was 49.09, and it decreased to 3 h after slaughter (Tab. 3). At later hours, pH started to increase up to twenty-four hours post-mortem. The results on meat lightness (L*) did not differ significantly between 45 min and 3 h after slaughter. Significant dif-

Tab. 3. Color parameters and pH value of *Biceps femoris* muscle in rabbits

Trait	Time			
	45 min	3 h	7 h	24 h
n	24	12	24	24
L*	49.03 ± 1.29^{a}	48.77 ± 0.69^{a}	50.64 ± 0.95^{b}	55.65 ± 0.67^{c}
a*	2.92 ± 0.51^{a}	3.20 ± 0.44^{a}	3.63 ± 0.54^{b}	4.26 ± 1.29^{c}
b*	3.03 ± 0.98^{a}	3.63 ± 0.93^{ab}	4.30 ± 0.40^{b}	6.28 ± 1.29^{c}
C*	4.29 ± 0.60^{a}	4.82 ± 0.46^{a}	5.69 ± 0.56^{b}	7.62 ± 0.85^{c}
H*	0.78 ± 0.10^{a}	0.88 ± 0.10^{ab}	0.89 ± 0.07^{ab}	0.99 ± 0.05^{b}
pH	6.92 ± 0.11^{c}	6.37 ± 0.11^{b}	5.98 ± 0.04^{a}	6.07 ± 0.18^{a}

Explanation: a, b, c, d – mean values marked with different letters differ significantly at $P \leq 0.05$

ferences occurred between the two first measurements (L^*_{45}, L^*_{3}) and two last measurements (L^*_{7}, L^*_{24}), as well as between L^*_{7} and L^*_{24}.

As for the LD muscle, the available literature does not contain information on measurements made 3 h and 7 h after slaughter; therefore only data for 45 min and 24 h can be compared. In the case of L^*_{24}, the results received by D'Agata et al. (10), Gondret et al. (14), and Maj et al. (17) were similar to those of the present study, while the values recorded by Virág et al. (24) were lower. In the case of L^*_{45}, Maj et al. (17) reported higher values compared to those from the present research.

The changes in the values of the red (a*) and yellow (b*) components of the BF muscle color were not as marked and dynamic as for LD. Higher values of a* and b* are associated with a darker color of meat (lower L*), which is indirectly related to a higher myoglobin content of the leg muscles compared with the back muscles.

The value of the a* parameter was 2.92 forty-five minutes after slaughter, and increased with time (Tab. 3). No statistically significant differences were found between the a* values measured 45 min and 3 h after slaughter, whereas the two measurements differed significantly from those made 7 h and 24 h after slaughter.

A similar trend was observed for the b* parameter: its value was lowest 45 min after slaughter (3.03), and steadily increased in the process of meat ageing, to reach 6.28 twenty-four hours after slaughter (Tab. 3). Significant differences existed between b^*_{45} and both b^*_{7} and b^*_{24}, as well as between b^*_{7} and b^*_{24}; the differences between the other measurements were insignificant.

Compared to this study, similar values of a^*_{24} were found by Virág et al. (24) and by Gondret et al. (14), while D'Agata et al. (10) reported lower values. The a^*_{24} value obtained by Daszkiewicz et al. (12) was higher than the one noted in this study, which may be due to the use of a different measuring instrument and a different method (measurement on minced meat).

The b^*_{24} values found in this experiment were similar to the values recorded by Hernandez et al. (15). D'Agata et al. (10) obtained lower values, whereas Virág et al. (24) reported slightly higher values.

Chroma (C*) and hue-angle (H*) are directly derived from the color parameter a* and b*. In this experiment, the C* value was lowest 45 min after slaughter, tended to increase with time to 7.62 twenty-four hours after slaughter (Tab. 3). There were no statistically significant differences between C^*_{45} and C^*_{3}. The differences between the values of C^*_{45} and C^*_{3} and the values of C^*_{7} and C^*_{24}, as well as between C^*_{7} and C^*_{24} were significant. Similar color saturation 24 h after slaughter was reported by Hernández et al. (15). Slightly higher C^*_{24} values were obtained by Virág et al. (24).

In the present study, the hue-angle values (H*) increased with time (Tab. 3). Significant differences were observed only between H^*_{45} and H^*_{24}. The H^*_{24} values found by Trocino et al. (23) were lower than those obtained in our study, which may have resulted from transport stresses experienced by the animals investigated by those authors.

Meat pH. The hydrogen ion concentration in the thigh exceeds that in the loin, which may be attributed to the amount of residual blood that remains in the tissues after debleeding, probably larger in the thigh muscles because of their harder work during life.

The pH value of the BF muscle followed the pattern observed earlier for LD. Namely, it was highest 45 min after slaughter; the values recorded 3 h and 7 h post-mortem were lower, and the final value, measured 24 h after slaughter, was increased (Tab. 3). As for LD, the measurements made 7 h and 24 h after slaughter did not differ from each other, while the differences between the other measurements were statistically significant. Barron et al. (2), investigating the influence of genotype and sex on the pH of rabbit meat, recorded higher values than those measured in the present research. The factor responsible for these differences may include the location of experiments (Mexico vs. Poland), and the breed of rabbits. Maj et al. (17), who studied the effect of age and sex of New Zealand White rabbits on meat quality, reported lower values than those measured in the present study.

The rate at which the pH value of muscles after slaughter becomes lower depends on the level of adrenaline before slaughter, the latter being influenced by many factors (mainly stress). The absolute and relative drops in the pH value of the BF muscle were similar to those found for LD (Tab. 2). The higher ΔpH_{abs} value of the thigh may result from higher pH_{45} values than for the loin. The results obtained by Blasco and Piles (4) and Maj et al. (17) were closer to our results.

Meat color in other animal species. Rabbit meat, together with veal and poultry meat, is classified as white meat. It is lighter in color than red meat (mainly pork and beef) due to a lower myoglobin content of muscle fibers. In nutritional terms, however, there are no signif-

icant differences between the two groups of meat: both have similar protein composition and energy value.

In the case of poultry, breasts form the most valued part of their carcass. According to Qiao et al. (20), the lightness of the breast muscles in chicken broilers were darker immediately after slaughter and revealed higher values of redness and yellowness than rabbit meat, while after 24 h chilling values of lightness and color components (L*, a* and b*) were similar to those observed in this paper. In the studies Alvarado et al. (1), concerning the breast muscles of turkey broilers, the L* values were lower than our results. Lagoda et al. (16), who investigated the changes occurring in veal in the ageing process, found the color of meat to be darkest just after slaughter, and lightest after 24 hours of storage under refrigerated conditions. Comparison of the above data shows that rabbit meat is the lightest in the group of white meats. Compared to poultry, rabbit meat has a somewhat higher proportion of the red component (a*) and a slightly lower share of the yellow component (b*). Compared to veal it has a higher proportion of red and a similar share of yellow in the overall color composition.

The lightness (L^*_{48}) and yellowness of beef (b^*_{48}), measured by Węglarz (25) on the surface of the loin, were lower, and the values of the red component (a^*_{48}) were higher than the data presented in this work. Characterizing the color of pork loin, Czarniecka-Skubina et al. (9) found higher values of the L*, a*, and b* parameters 48 h after slaughter while comparing the same components in the rabbit meat. These results show that beef is much darker than rabbit meat, and contains a greater proportion of red. Pork has a similar lightness to rabbit meat but a much larger proportion of the red and yellow components in the overall color, which makes it appear darker than the rabbit meat.

Conclusions

The results of the study indicate that the color of rabbit meat is stabilized 24 h after slaughter. At this time, the values of the color parameters of meat in various parts of the carcass even out, i.e. the differences between the parts are not as significant as they were shortly after slaughter. This suggests that the evaluation of meat color (and thus the assessment of its quality) should be carried out not earlier than 24 h after slaughter because only then it would be possible to relatively objectively compare both the carcasses with each other and the individual parts of a carcass. The pH indicators of rabbit meat were within the standards set for good quality meat. The pH value of meat (*m. longissimus dorsi* and *m. biceps femoris*) did not differ significantly between the 7th and 24th hour after slaughter, indicating that the acidity of meat in this period of time was stable. The thigh muscle and the loin muscle exhibited similar absolute and relative changes in the pH value, which demonstrates that the ageing of meat in these two parts of the carcass was uniform.

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