COMPARATIVE STUDY OF THE EFFECT OF DRY AND WET AGING ON BEEF MEAT COLOUR PARAMETERS DURING MATURATION

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Abstract

Meat colour remains one of the most important quality parameters influencing consumers and attracting the attention of meat scientists around the world. The objective of this scientific article was to follow the colorimetric differences produced by two types of maturation - wet and dry, on meat from intensively reared cattle. Colorimetric tests were performed on samples of the beef round for a 20-day maturation period, the first sample being analyzed less than 24 hours after slaughter and the others on days 4, 8, 12, 16, and 20 of maturation. Colorimetric measurements were performed both on the meat surface and in sections for both types of maturation. The colour of beef outside showed non-significant differences ($p > 0,05$) between the two types of maturation studied for all three colorimetric parameters studied (L*, a*, and b*), with highly significant differences ($p < 0.001$) only between the type of maturation and advancement of maturation (TM*Days) for the same colour parameters. As regards the colour of the beef round in the section, the differences identified were highly significant ($p < 0.001$) for the parameters L* and b*, but significant ($p < 0.05$) for the parameter a*. As for the colour on the outside of the meat, highly significant differences ($p < 0.001$) were identified between the type of maturation and the advancement of the maturation period in the section of the beef round.

Keywords: beef meat colour, dry-aging, wet-aging, pH

The beef industry is a vital factor for the agricultural economy, with global production reaching approximately 73.9 million tons in 2022, a value that is 1.4% higher compared to 2021 (FAO, 2022).

The color of meat is essential for consumer acceptability. Dark or overly pale colors are associated with a decrease in consumer preference and a more pronounced rejection compared to a bright red hue (Hughes J. *et al*, 2017; Jeremiah L.E. *et al*, 1972; Viljoen H.F. *et al*, 2002). Among the quality attributes of beef, maintaining a red color is of major importance in terms of its attractiveness, being interpreted as an indicator of freshness and safety. All changes that occur inside or on the surface of the muscle are reflected in the resulting color (Gašperlin L. *et al*, 2001). Beef cuts that exhibit changes in color are often sold at reduced prices or are ground to produce lower-value products, such as ground beef, and if the color change is very pronounced, the product will be discarded. All of these practices result in economic losses. A very important factor that affects meat color is meat aging, according to numerous studies (Smith G.C. *et al*, 2000).

In general, aging can be dry aging (where beef carcasses or primary/subprime cuts are stored at a refrigerated temperature without packaging materials) or wet aging (primarily, meat cuts are vacuum-sealed). Dry aging is typically intended for higher-quality meat and occurs in well-controlled environmental conditions in terms of temperature, relative humidity, and air ventilation (Smith R.D. *et al*, 2008).

Wet aging is an aging process introduced in the 1970s, where vacuum packaging is used to protect the meat from spoilage and dehydration when it is stored for aging in a refrigerated environment for a period of 3 to 83 days. This type of aging offers several economic advantages, including significant reductions in weight and trim losses. It also requires less storage space and is suitable for an automated and efficient production process. In addition to these benefits, wet aging extends the shelf life of meat by controlling microbiological factors, without compromising palatability characteristics (Kim Y.H.B. *et al*, 2018).

The main mechanism of meat aging is attributed to the proteolysis of essential myofibrillar and cytoskeletal proteins (Koohmaraie

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M., 1996; Ouali A., 1990; Valin C., 1988). Boakye K. and Mittal G.S. (1996) argue that the duration of aging influences all CIE color parameters (the values of L*, a*, b* parameters and color attributes: hue, saturation, and intensity) of beef.

The surface color of meat is largely determined by the concentration and chemical state of myoglobin, as well as the depth of myoglobin layers (Faustman C. *et al*, 2010), and also by changes in post-mortem muscle structure. In the case of an early drop in muscle pH after slaughter, there is evidence of structural changes and the formation of drip channels (Heffron J.J.A., Hegarty P.V.J., 1974; Bertram H.C. *et al*, 2004), which could result in differences in oxygen absorption, reflection, and penetration into the muscle. As the muscle enters rigor mortis, there is a 14-16% reduction in muscle fiber diameter, leading to an increase in extracellular space (Heffron J.J.A., Hegarty P.V.J., 1974). Additionally, myofibrils can contract, creating opportunities for water formation and loss (Diesbourg L. *et al*, 1988; Bertram H.C. *et al*, 2004). The magnitude of these changes is a pH-dependent process and is a key factor in the alteration of post-mortem muscle color. A slight decrease in pH results in a higher pH (pH > 5.7) and a darker color. In contrast, a complete drop in pH to 5.4-5.5 leads to a bright red-purple color (Murray A.C., 1989).

Rapid post-mortem metabolism (rapid pH decline) can lead to the denaturation of proteins, resulting in changes in light diffusion and the loss of sarcoplasmic proteins, such as myoglobin in the muscle (Swatland H.J., 2008), and hence the appearance of a paler color of beef. For these reasons, it has been hypothesized that meat color is influenced by the drop in pH and temperature after slaughter, with these parameters being determined by factors of animal origin and processing conditions (Hughes J.M. *et al*, 2014).

MATERIAL AND METHOD

In the present study, beef sirloin from intensively raised animals was used to analyze color parameters and pH. A total of 6 sirloins were used, each of which was divided into two pieces, resulting in a total of 12 pieces (samples). Six of these were dry-aged, and six were wet-aged. The meat was acquired on the day of animal slaughter and aged for 20 days, with analyses performed on the day of slaughter and on days 4, 8, 12, 16, and 20 of aging, totaling 6 analysis periods. The first sample was dry-aged, while the second was wet-aged in vacuum-sealed bags. Both samples were stored during aging in refrigerated aging rooms with controlled microclimate parameters. For dry aging, the microclimate parameters were set in accordance with the recommendations established by Kim Y.H.B. *et al* (2016) following a consumer evaluation, which were as follows: a refrigeration temperature of 3°C, relative humidity of 49%, and air current velocity of 0.2 m/s. The refrigeration temperature for wet-aged beef sirloin was 0-2°C, as per Jaspal M.H. *et al* (2021).

For conducting instrumental meat color analyses, a portable Konica Minolta CR-410 colorimeter with a measurement diameter of 50 mm was used, previously calibrated on a white standard plate. To measure the color of the samples, Illuminant D65 with a 10° observation angle was employed. This angle is considered the most representative for reproducing colors as perceived by the human eye, in accordance with the method provided by Kim Y.H.B. *et al* (2016).

The data were analyzed in the CIELAB color space, which expresses the quantitative relationship between colors on three axes: L*, a*, and b*. L* indicates values from 0 (black) to 100 (white). The a* component indicates the presence of red colors (for positive values) and green colors (for negative values), while the b* parameter indicates the presence of yellow colors (for positive values) and blue colors (for negative values). Colorimeter measurements were conducted on both the meat's surface (exterior) and in its cross-section, with 10 measurements for each aging and section analyzed.

To determine the pH value, a digital pH meter specially designed for meat and meat products, Hanna Instruments HI 99163, was used. pH measurements were performed five times for each type of aging on the following days of aging: 0, 4, 8, 12, 16, and 20.

The aging of the meat subjected to the analysis took place within the Meat Microproduction Workshop at the U.S.V. Iași, and the color and pH analyses were carried out in the Meat Technology and Quality Control Laboratory of the same university.

The data obtained from pH and colorimeter evaluations were processed using the ANOVA (Analysis of Variance) statistical test within the XLSTAT software for Microsoft Excel.

RESULTS AND DISCUSSIONS

Table 1 presents the results regarding the pH of the meat samples analyzed for the two types of aging studied: dry aging and wet aging. The aim was to investigate the influence of the type of aging, the influence of the aging progression (days of aging), and the interaction between these two factors on the pH value.

Following the analysis of the results in *table 1*, we can observe that the type of aging, aging progression, and the interaction between the type of aging and aging progression exhibit highly significant differences ($p < 0.001$) in the mean pH values. These results contradict those obtained by

Kim Y.H.B. *et al* (2016), who found nonsignificant differences ($p > 0.05$) regarding the influence of the type of aging on pH values.

Table 1

The average pH values during the aging period and the influences produced by the type of aging, its evolution, and the interaction between these two characteristics on the pH values

Aging time	Type of aging	
	Dry	Wet
0	5.630±0.006^{a}	5.514±0.009^{a}
4	5.726±0.009^{b}	5.546±0.004^{a}
8	5.796±0.007^{b}	5.758±0.010^{bc}
12	5.660±0.005^{ab}	5.710±0.011^{b}
16	5.976±0.012^{c}	5.716±0.007^{b}
20	6.004±0.016^{d}	5.922±0.015^{c}
p-value		
Type of aging	**< 0.0001 (***)**	
Days of aging	**< 0.0001 (***)**	
Type of Aging*Days of aging interaction	**< 0.0001 (***)**	

a, b, c, d - Superscripts on different means within the same column differ significantly, $p \leq 0.05$

The lowest average pH value was recorded on day 0 for both dry aging and wet aging (5.630±0.006 and 5.514±0.009, respectively). Subsequently, in the case of dry aging, this value gradually increased until the 12th day of aging when a slight decrease in pH was observed, reaching a mean pH value close to the initial pH (5.660±0.005), as can be seen in *figure 1*. After this decline, there was a gradual increase in pH values until the end of aging (day 20), resulting in a final pH with an average value of 6.004±0.016 (*table 1*).

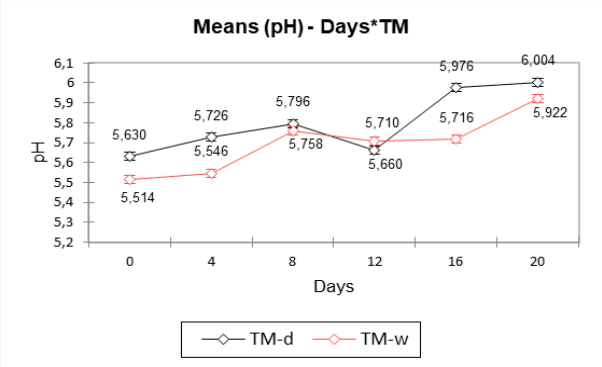

Figure 1 **The mean values of pH during wet and dry aging**

TM – type of maturation/aging; d – dry aging; w – wet aging

Similar to dry aging, wet aging also exhibited a decrease in pH values on the 12th day (5.710±0.011). However, this decrease was not as significant as that observed in dry aging, but it was only slightly lower by 0.048 compared to the previous day's pH measurements (day 8). Additionally, the subsequent increase in pH values in wet aging was less pronounced after the drop on day 12 compared to dry aging. At the end of the aging process, a lower final pH was observed in wet aging (5.922±0.015) (*table 1, figure 1*) than that obtained in dry aging (6.004±0.016) (*table 1, figure 1*).

The instrumental results of the color parameters performed on the surface of the beef sirloin are presented in *table 2*. The results are differentiated according to the type of aging applied.

The results of the statistical analysis of the studied color parameters (L*, a*, and b*) on the exterior of beef sirloin indicate a nonsignificant influence ($p > 0.05$) of the type of aging on all of them. Highly significant differences ($p < 0.001$) were identified in all the mentioned parameters for the interaction between type*days of aging. Concerning only days of aging, the CIE b parameter exhibited distinct significant differences ($p < 0.01$), while the other two analyzed colorimetric parameters (CIE L* and CIE a*) showed highly significant differences ($p < 0.001$), as can be seen in *table 2*.

The differences between the types of aging on the same days when colorimeter measurements were taken (day 0, 4, 8, 12, 16, and 20) were determined using the Tukey (HSD) test. The results obtained are presented in *table 2* and highlight highly significant differences ($p < 0.001$) for the L* parameter between the two types of aging throughout the entire aging period (from day 0 to day 20). Regarding the CIE b* parameter, significant differences ($p < 0.05$) were recorded only on days 4 and 20 (*table 2*), while for the other analyzed days, the differences were nonsignificant ($p > 0.05$). The CIE a* parameter only exhibited nonsignificant differences ($p > 0.05$) concerning the influence of the type of aging on the same aging day (*table 2*).

The highest value for the entire aging period of the CIE L* parameter was achieved by dry aging on the 8th day (45.442±0.627) of color measurements. Similarly, for the CIE a* and CIE b* parameters, the highest values were also

recorded during dry aging, specifically 21.866±1.973 (on the 4th day of aging) and 9.462±1.888 (on the first day of aging), as indicated in the data presented in *table 2*.

Table 2

The effects of aging type, evolution of aging, and the interaction between aging type and evolution of aging on color parameters (L*, a*, and b*) on the exterior of the meat

Type of aging	Aging time	Parameters		
		L*	a*	b*
Dry	0	40.944±0.741^{d}	21.798±1.493^{c}	9.462±1.888^{c}
	4	42.300±0.745^{d}	21.866±1.973^{c}	9.162±1.148^{c}
	8	45.442±0.627^{e}	19.200±0.621^{bc}	7.616±1.023^{bc}
	12	33.800±0.697^{b}	11.058±0.521^{a}	6.974±1.233^{abc}
	16	30.234±0.915^{a}	9.770±1.265^{a}	3.802±0.718^{ab}
	20	29.862±0.309^{a}	9.554±2.767^{a}	2.702±0.810^{a}
Wet	0	36.780±0.395^{c}	19.378±1.874^{bc}	7.104±0.805^{abc}
	4	36.954±0.454^{c}	16.686±1.226^{abc}	4.604±0.240^{ab}
	8	37.332±0.197^{c}	15.440±1.249^{abc}	5.644±0.351^{abc}
	12	38.072±0.456^{c}	14.692±1.917^{abc}	7.608±0.417^{bc}
	16	37.698±0.459^{c}	13.674±1.084^{ab}	6.246±0.424^{abc}
	20	38.050±0.302^{c}	16.780±1.007^{abc}	7.452±0.332^{bc}
p-value				
Type of aging		0.245	0.527	0.738
Days of aging		**<0.0001 (***)**	**<0.0001 (***)**	**0.004 (**)**
Type of aging*Days of aging interaction		**<0.0001 (***)**	**0.001 (***)**	**<0.0001 (***)**
Tukey Honest Signifficant Difference (HSD) for different type of aging (wet aging versus dry aging) in the same day				
Day 0		**0.000(***)**	0.993	0.791
Day 4		**<0.0001 (***)**	0.440	**0.037 (*)**
Day 8		**<0.0001 (***)**	0.847	0.923
Day 12		**0.000(***)**	0.873	1.000
Day 16		**<0.0001 (***)**	0.814	0.752
Day 20		**<0.0001 (***)**	0.067	**0.025 (*)**

a, b, c, d - Superscripts on different means within the same column differ significantly, $p \leq 0.05$

At the end of aging, it can be observed that dry-aged beef sirloin has lower average values on the exterior for the colorimetric parameter L* compared to the average values obtained for the same colorimetric parameter in the case of wet aging. Analyzing these data, it can be inferred that dry-aged beef sirloin has a darker color on the meat's surface due to the formation of a crust, dehydration in the superficial layer, and, consequently, the concentration of color compounds. This observation is also supported by the comparative analysis of the data in *table 2* and *table 3* regarding the CIE L* parameter, which are relatively similar for wet aging, with no significant differences. The lack of significant differences is attributed to good color compound diffusion within the beef sirloin and the absence of dehydration. The data obtained by us for the exterior of dry-aged beef sirloin are in line with the findings of Kim Y.H.B. *et al* (2016).

Table 3 presents the results of the color parameters from the cross-section of beef. By analyzing the described table above, we can observe that the type of aging had a highly significant influence ($p < 0.001$) only on the CIE L* and CIE b* parameters, while for the CIE a* parameter, its influence was significant ($p < 0.05$). As for the characteristics of days and the type of aging*days of aging interaction, highly significant differences ($p < 0.001$) were identified for all the studied colorimetric parameters (*table 3*).

After applying the Tukey (HSD) statistical test, the most significant differences between the types of aging on the same aging day were observed within the CIE b* color parameter *(table 3*). Highly significant differences ($p < 0.001$) were recorded on the 8th day of aging, while significant differences ($p < 0.05$) were observed on days 4 and 12. The colorimetric parameter a* was affected by the type of aging according to the Tukey test only on the 16th day of meat aging, where highly significant differences ($p < 0.001$) were observed, as indicated in *table 3.*

The average values of the L* parameter (*table 3*) in the meat's cross-section exhibit a relatively high degree of similarity and some linearity (minimal fluctuations in the average values between the days of analysis). The same characterization can also be attributed to the a* parameter in the meat's cross-section (*table 3*), especially in the case of dry aging, as wet aging shows more significant differences in the average values towards the end of the aging period. The b* parameter displays the largest fluctuations in average values during the meat's aging in its cross-section (*table 3*).

Table 3

The effects of aging type, evolution of aging, and the interaction between aging type and duration on meat color parameters (L*, a*, and b*) in the section of the beef sirloin

Type of aging	Aging time	Parameters		
		L*	a*	b*
Dry	0	37.436±0.578^{bc}	19.468±0.701^{d}	4.618±0.801^{ab}
	4	38.906±0.609^{de}	19.106±0.415^{bcd}	6.604±0.715^{cd}
	8	37.882±0.336^{cd}	19.060±0.808^{bcd}	7.414±0.603^{d}
	12	38.038±0.256^{cde}	18.038±0.647^{bc}	7.022±0.608^{d}
	16	37.910±0.526^{cd}	18.288±0.563^{bcd}	5.298±0.482^{bc}
	20	36.660±0.218^{ab}	18.440±0.192^{bcd}	4.536±0.328^{ab}
Wet	0	36.050±0.336^{a}	19.330±0.279^{cd}	4.108±0.296^{ab}
	4	36.890±0.428^{abc}	19.378±0.152^{cd}	4.164±0.194^{ab}
	8	36.104±0.160^{a}	18.918±0.172^{bcd}	4.134±0.171^{ab}
	12	35.958±0.372^{a}	18.820±0.330^{bcd}	4.598±0.202^{ab}
	16	39.090±0.370^{e}	14.470±0.711^{a}	6.668±0.482^{d}
	20	36.884±0.451^{abc}	17.912±0.189^{b}	3.700±0.242^{a}
p-value				
Type of aging		**0.000 (***)**	**0.040 (*)**	**<0.0001 (***)**
Days of aging		**0.000 (***)**	**<0.0001 (***)**	**0.000 (***)**
Type of aging*Days of aging interaction		**0.000 (***)**	**0.000 (***)**	**0.000 (***)**
Tukey Honest Signifficant Difference (HSD) for different type of aging (wet aging versus dry aging) in the same day				
Day 0		0ș428	1.000	1.000
Day 4		**0.044 (*)**	1.000	**0.030 (*)**
Day 8		0.119	1.000	**0.001 (***)**
Day 12		**0.033 (*)**	0.992	**0.032 (*)**
Day 16		0.665	**<0.0001 (***)**	0.667
Day 20		1.000	1.000	0.982

a, b, c, d, e - Superscripts on different meanswithin the same column differ significantly, $p \leq 0.05$

Within dry aging in the beef's cross-section (*table 3*), there is a noticeable trend of decreasing average values for all the color parameters analyzed. This could be attributed to the lack of atmospheric oxygen and, consequently, the formation of oxymyoglobin. The same can be observed in wet aging in the meat's cross-section for the colorimetric parameters a* and b* (*table 3*). These results are contrary to those obtained by Abril M. *et al* (2001). They did not analyze color parameters based on the type of aging but rather based on the final pH of the meat. Although the final pH for both types of aging used in this study fell within the pH values < 6.1 that they examined, the instrumental results for the color parameters were contradictory.

CONCLUSIONS

This scientific study aimed to investigate the influence of two types of aging (wet aging and dry aging) on the CIE L*, a*, and b* color parameters and on the pH value.

As a result of the conducted analyses, it was found that the type of aging, the stage of aging, and the interaction between the type of aging and the stage of aging significantly influence the pH value.

The CIELAB system parameters on the meat's exterior are insignificantly affected ($p>0.05$) by the type of aging, but the interaction between type and days of aging significantly affects ($p < 0.001$) all the analyzed colorimetric parameters.

In the case of the meat's cross-section, the three analyzed color parameters (CIE L*, CIE a*, and CIE b*) were significantly influenced ($p<0.001$) by the stage of aging (days of aging) and by the interaction between type and days of aging. The type of aging significantly influenced ($p<0.001$) the L* and b* parameters, but for the a* parameter, the influence was only significant ($p<0.05$).

The most significant colorimetric differences at the end of aging compared to the beginning are caused by dry aging on the meat's exterior. In the case of this type of aging, dehydration occurs on the meat's surface, leading to the formation of a brownish crust (which darkens progressively during aging). This darker color is the result of the concentration of pigment substances (mainly myoglobin) on the surface, resulting in darker meat. The most noticeable changes on the meat's exterior began to appear from day 12 of aging, intensifying until the end of the process.

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