The effect of dry aging on instrumental, chemical and microbiological parameters of organic beef loin muscle

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ABSTRACT

The aim of this study was to assess the effect of aging at 1 °C for 12–36 d on instrumental, chemical and microbiological characteristics of organic beef loin muscles. There were no significant changes in pH, L*, a* and b* during prolonged aging. The aging of beef had a positive effect on its tenderness as demonstrated by decreasing of shear force. The water losses amounted to around 3.0% up to 21 d of aging, with further increase with an extended period of aging. Fresh beef had a good microbiological quality with Total Viable Count, psychrotrophic and lactic acid bacteria of 2.59 ± 0.65, 2.47 ± 0.61 and 1.04 ± 0.25 log CFU per cm² of the surface, respectively. The mean values for Total Viable Count and psychrotrophic microorganisms after 14 and more days of aging were approx. 5 log CFU/cm². Prolonged aging for more than 14 d increased tenderness but did not promote microbial growth.

1. Introduction

Tenderness is one of the most frequently studied characteristics of cooked meat (Baldwin, 2012). The tenderness of meat is influenced primarily by the composition and contractile state of muscle fibers, the amount and solubility of connective tissue, and the extent of proteolysis post mortem (Joo, Kim, Hwang, & Ryu, 2013). Proteolytic changes in the muscles after the slaughter of the animal are part of the process called meat aging. Meat aging is a complex process to which groups of endogenic proteases contribute, and this process begins immediately after the slaughter of the animal (Kemp & Parr, 2012). The structural integrity of myofibrils changes as a consequence of the degradation of muscle proteins such as titin, nebulin and desmin (Starkey, Geesink, Collins, Oddy, & Hopkins, 2016). The integrity of intramuscular connective tissue also decreases, evidently as a result of the action of collagenase with β-glucuronidase or hyaluronidase (Nishimura, 2015). The action of enzymes on meat proteins requires a certain amount of time – a minimum of around two weeks in the case of beef (Perry, 2012). In addition to the tenderness of the meat, aging also affects the juiciness and taste of the meat (Kim, Kemp, & Samuelsson, 2016).

There are, in principle, two methods of meat aging. Dry aging is performed by placing beef carcasses or primal cuts in cold stores with a managed regime of air temperature, relative humidity and air flow speed. Wet aging means the vacuum-packing of cuts of meat in foil with barrier properties and their placement in cold stores. In this case, the air temperature is the important parameter. Neither the humidity nor the speed of the air flow play any role in wet aging. Dry aging of meat is, however, preferable from the viewpoint of the taste of the meat following culinary preparation. Aromatic substances which have a favourable effect on taste and aroma are formed during dry aging. The development of these substances is proportional to the length of meat aging (Perry, 2012).

Extending the storage of meat, on the other hand, creates conditions for the growth of psychrotrophic microflora capable of multiplying on the meat at refrigeration temperatures. Dry aging, in which meat is exposed to an atmosphere of air, may provide an opportunity for aerobic gram-negative bacteria of the genus Pseudomonas which are part of the meat spoilage microbiota (Blana & Nychas, 2014). Therefore, in addition to strictly controlled temperature it is also necessary during dry aging to monitor the relative humidity in the cold store where drying of the meat surface inhibits the growth of bacteria as a result of decreasing water activity. However, if the air humidity is too low, there is a risk of greater weight losses resulting from the evaporation of water and the formation of a surface crust on the meat. This results in higher economic losses.

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There are a number of studies that consider the effect of aging on selected properties of meat (Colle et al., 2015; Kim et al., 2016; Laster et al., 2008; Lepper-Billie, Berg, Buchanan, & Berg, 2016; Starkey et al., 2016). However, the majority of them have monitored changes during the course of wet aging or evaluated quality indicators without more detailed microbiological analysis of the meat. In recent years, dry aging of beef has spread from the USA to European countries such as Germany (Bartholomä, Schering, & Horn, 2013) and the Czech Republic. There are only rare examples of publications from these countries assessing the effect of aging on the properties of meat. The aim of this study was to perform an assessment of the effect of dry aging performed on beef hind quarters directly at the slaughterhouse on the instrumental, chemical and microbiological characteristics of loin muscles.

2. Materials and methods

2.1. Samples of meat

The samples of meat were taken from cattle of Aberdeen Angus breed (bulls old 26-43 months and heifers old 18-32 months) reared under organic farming conditions on several farms in the Czech Republic. The animals were slaughtered from June to November 2016 at one slaughterhouse intended for organic meat production. After slaughter, the cattle carcasses were quartered and the quarters stored in a cold store at a temperature of 1 ± 1 °C, an air flow 0.5 ± 0.2 m s⁻¹ and a relative air humidity of 85 ± 2%. Samples of loin without bone weighing around 300 g were taken at the level of the 9th thoracic vertebra. Sample 0 was taken 24 h after slaughter and transported at 4 °C within 2 h to the laboratory at the University of Veterinary and Pharmaceutical Sciences Brno. Another sample was taken at the end of aging (12-36 d) from the same place on the second hind quarter and transported for further analyses under the same conditions. A total of 54 samples of meat from 27 carcasses (bulls n = 14; heifers n = 13) were analysed. Each group of samples (bulls, heifers) was further divided into two groups according to the length of aging – a period of aging shorter than 21 d (the average length of aging amounted to 14.6 d in heifers, n = 6, and 13.9 d in bulls, n = 8) and a period of aging longer than 21 d (the average length of aging amounted to 26.7 d in heifers, n = 7, and 26.8 d in bulls, n = 6). Instrumental and chemical parameters were analysed specifically in m. longissimus thoracis.

2.2. Instrumental analysis

Meat color was measured using a Konica Minolta CM-2600d spectrophotometer (Konica Minolta Sensing Inc., Osaka, Japan) calibrated against a white standard plate using an 8-mm diameter measuring aperture, illuminant D65 and 10° standard observer. L* (lightness), a* (redness), b* (yellowness) were measured, the value of chroma C* and hue angle h° were calculated using Equations (1) and (2):

\[
C^* = \sqrt{a^*2 + b^*2} \tag{1}
\]

\[
h^° = \arctan \frac{b^*}{a^*} \tag{2}
\]

At the beginning (Day 0) and end of the study, color measurements of the loin muscles were taken from five locations on the fresh cut.

The color change during aging was determined using the color differences coefficient (ΔE*) between the initial color and end color of the samples, calculated from Equation (3):

\[
\Delta E^* = \sqrt{(L_{end} - L_{0})^2 + (a_{end} - a_{0})^2 + (b_{end} - b_{0})^2} \tag{3}
\]

pH values were measured with a Double Pore needle probe (Hamilton, Switzerland) on a 340i WTW pH-meter (WTW, Germany). The pH values were taken from three locations on each sample.

Warner-Batzler shear force (WBSF) was measured using the method described by Honikel (1998) after heat treatment. For each heat treated sample, six strips were cut, being at least 20 mm long and with a 100-mm² (10 × 10 mm) cross-sectional area. The strips were tested on an Instron 5544 universal testing machine (Instron Cor., USA).

Heat treatment was performed on a contact grill. Samples (2 cm high) were grilled in aluminium foil for 5 min and 40 s. The samples were rotated after half this period had elapsed.

2.3. Chemical analysis

A drying method (ISO 1442, 1997) at 103 ± 2 °C for a period of 24 h was used for the determination of the content of dry matter. The fat content was determined using a SOXTEC instrument (TECATOR, Sweden). Diethyl ether (Penta Inc., Czech Republic) was used as the extraction agent. Samples were left in the drier for 3 h at 135 ± 2 °C and extracted by the agent (diethyl ether) in the instrument. The collagen content was determined spectrophotometrically at a wavelength of 550 nm in a GENESYS™ 6 spectrophotometer (Thermo Electron Corporation, USA) as the quantity of 4-hydroxyproline. The content of hydroxyproline was obtained from the calibration curve and converted into the collagen content. Proteins were determined by subsequent conversion of organic nitrogen to inorganic nitrogen in a KJELTEC instrument (TECATOR, Sweden) by the Kjeldahl method. A factor of 6.25 was used for the conversion of the nitrogen content into the protein content.

2.4. Microbiological analysis

Sampling was performed according to EN ISO 6887-2 (2003). Samples were analysed for the total viable count (TVC), numbers of psychrotrophic bacteria (PSY), lactic acid bacteria (LAB), Enterobacteriaceae, total coliform bacteria, E. coli, Pseudomonas spp., Brochothrix thermophaacta and the presence of Listeria monocytogenes.

TVC and PSY were determined using Standard Plate Count Agar (CM0463, Oxoid, UK) after incubation for 72 h at 30 °C and 10 d at 6.5 °C, respectively, according to EN ISO 4833-1 (2013) and EN ISO 17410 (2001). The quantification of LAB was performed on de Man, Rogosa and Sharpe agar (MRS Agar, CM0361, Oxoid) incubated for 72 h at 30 °C, in accordance with ISO 15214 (2000). The family Enterobacteriaceae and the coliforms were determined using Violet Red Bile Glucose agar (CM0485, Oxoid) and Violet Red Bile Lactose agar (CM0107, Oxoid), respectively, incubated for 24 h at 37 °C according to ISO 21528-2 (2004) and ISO 4832 (2006). E. coli was determined according to the ISO 16649-2 (2001) standard method using Chromocult TBX agar (116122, Merck, Germany) after incubation for 24 h at 44 °C. Brochothrix thermophaacta and Pseudomonas spp. were determined using STAA agar (CM0881, Oxoid) and Pseudomonas CFC Selective Agar (CM0559, Oxoid) according to ISO 13722 (1998) and EN ISO 13720 (2010), with incubation at 22–25 °C for 48 h.

The number of colonies formed was counted and reported as log CFU/cm² or log CFU/g for each sample.

Determination of the presence of Listeria monocytogenes was performed according to EN ISO 11290-1 (1999) using pre-enrichment in half-strength Fraser broth, followed by incubation in full-strength Fraser broth (CM0895, Oxoid) and plating on ALOA (100427, Merck, Germany) and PALCAM agar (CM0877, Oxoid). Confirmation was performed biochemically using a VITEK2 analyser (bioMérieux, France).

2.5. Statistical analysis

In total, 54 meat samples from 27 beef carcasses were used in the experiment. Verification of the difference of significance of the investigated instrumental and chemical parameters was studied using Tuckey’s test with a significance level of 0.05. Correlation between parameters at the beginning (Day 0) and end of aging was determined using Pearson’s linear correlation, and their significances were set at
P < 0.05, P < 0.01 and P < 0.001. Finally, a multivariate method of principal component analysis (PCA) based on a correlation matrix was employed to assess relationships among variables measured during aging.

The figures were constructed and all analyses of microbial growth performed using the open source statistical software R (R Development Core Team, 2009) and the nlsMicrobio (Baty & Delignette-Muller, 2015a) and nlsTools (Baty & Delignette-Muller, 2015b) packages. Smoothing by LOESS (local polynomial regression fitting by weighted least squares) was used to describe the trend of growth (Cleveland, Grose, & Shyu, 1992) and the experimental data were also fitted by the Baranyi model without lag phase (Baranly & Roberts, 1994), Equation (4),

\[ N_t = N_{max} - \log_{10}\left(1 + \frac{10^{N_{max} - N_0}}{0.05}\right) \] (4)

where \( N_t \) is the bacterial concentration (log CFU) at time \( t \) (days); \( N_{max} \) is the maximum concentration fitted by the model (log CFU); \( N_0 \) is the initial concentration fitted by the model (log CFU); \( \mu_{max} \) is the maximum specific growth rate (d\(^{-1}\)).

The goodness-of-fit was statistically assessed by the root-mean-square error (RMSE), Equation (5),

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (N_{obs,i} - N_{pred,i})^2} \] (5)

where \( N_{pred} \) is the predicted bacterial concentration (log CFU); \( N_{obs} \) is the observed bacterial concentration (log CFU); \( n \) is the number of observations.

3. Results and discussion

3.1. Instrumental and chemical analysis

Table 1 shows the results of the evaluation of color (\( L^* \), \( a^* \), \( b^* \), \( \Delta E \), \( C^* \), \( h^\circ \)), pH and texture (Warner-Bratzler test) before aging and aging. No statistically significant differences in the values of \( L^* \), \( a^* \) and \( b^* \) were seen in the CIEL*a*b* system during the course of aging. The measured values of lightness \( L^* \) and the parameters \( a^* \) and \( b^* \) were lower than those found in the same muscles by Kim et al. (2016) after aging for 14 and for 21 d in the same muscles. Statistically significant differences in tenderness scores of beef longissimus muscles were reported by Kang et al. (2017) after 20 days of dry aging at 2 °C.

Table 2 shows the results of chemical analysis of the composition of beef. The disadvantages of dry aging are the higher evaporation losses and, thereby, the lower meat yield (DeGeer et al., 2009). Statistically significant differences in the content of dry matter were found during aging in all four tested groups (Table 2). The water losses amounted to around 3.0% up to 21 d of aging, with further increases with an extended period of aging.

No statistically significant differences between the individual groups were found in any of the parameters studied.

Table 3. Statistical significant correlations between the values before aging and after aging were found in the parameters \( L^* \) (\( r = 0.41, P < 0.05 \)), \( h^\circ \) (\( r = 0.66, P < 0.001 \)), pH (\( r = 0.56, P < 0.01 \)), content of dry matter (\( r = 0.43, P < 0.05 \)) and WBSF (\( r = 0.44, P < 0.05 \)).

All samples (n = 54) characterized by color parameters (\( L^* \), \( a^* \), \( b^* \), \( C^* \), \( h^\circ \)), pH value, Warner-Bratzler shear force test and chemical composition (4 parameters) at the beginning (Day 0) and end of aging were included in principal component analysis (PCA) to explore general relationships between meat, aging and their characteristics.

One PCA is for instrumental data. The first two principal components accounted for 52.83% of total variance in the data. The projection of the variables on the factor plane confirms our previous findings of strong correlation between lightness \( L^* \), hue value \( h^\circ \), pH and Warner-Bratzler shear force (Fig. 1). Product projection on the factor plane is determined by the measured characteristics (Fig. 2). It is apparent from PCA analysis that there are some samples that differ from others.

**Table 1**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Heifers &lt; 21 d of aging n = 6</th>
<th>Heifers &gt; 21 d of aging n = 7</th>
<th>Bulls &lt; 21 d of aging n = 8</th>
<th>Bulls &gt; 21 d of aging n = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L^* )</td>
<td>BA 36.56 ± 2.11</td>
<td>36.76 ± 2.59</td>
<td>35.51 ± 2.39</td>
<td>32.79 ± 2.86</td>
</tr>
<tr>
<td>BA 33.59 ± 2.67</td>
<td>36.22 ± 1.53</td>
<td>37.21 ± 3.69</td>
<td>32.61 ± 5.29</td>
<td>32.61 ± 5.29</td>
</tr>
<tr>
<td>BA 12.03 ± 1.00</td>
<td>11.11 ± 1.88</td>
<td>12.97 ± 2.02</td>
<td>12.71 ± 0.95</td>
<td>12.71 ± 0.95</td>
</tr>
<tr>
<td>BA 11.20 ± 2.29</td>
<td>11.37 ± 2.15</td>
<td>12.91 ± 1.67</td>
<td>11.11 ± 1.28</td>
<td>11.11 ± 1.28</td>
</tr>
<tr>
<td>BA 8.71 ± 1.03</td>
<td>9.06 ± 0.98</td>
<td>9.25 ± 2.11</td>
<td>7.59 ± 1.95</td>
<td>7.59 ± 1.95</td>
</tr>
<tr>
<td>BA 7.87 ± 1.13</td>
<td>8.99 ± 1.19</td>
<td>9.71 ± 2.11</td>
<td>7.59 ± 1.95</td>
<td>7.59 ± 1.95</td>
</tr>
<tr>
<td>( \Delta E )</td>
<td>4.28 ± 2.65</td>
<td>3.91 ± 2.29</td>
<td>4.07 ± 1.62</td>
<td>3.24 ± 2.16</td>
</tr>
<tr>
<td>BA 14.98 ± 1.20</td>
<td>14.37 ± 1.90</td>
<td>15.96 ± 2.80</td>
<td>15.32 ± 1.48</td>
<td>15.32 ± 1.48</td>
</tr>
<tr>
<td>BA 13.72 ± 2.45</td>
<td>14.54 ± 1.52</td>
<td>16.22 ± 2.43</td>
<td>13.54 ± 1.91</td>
<td>13.54 ± 1.91</td>
</tr>
<tr>
<td>BA 35.84 ± 2.97</td>
<td>39.43 ± 4.19</td>
<td>35.11 ± 2.97</td>
<td>34.20 ± 5.37</td>
<td>34.20 ± 5.37</td>
</tr>
<tr>
<td>BA 35.47 ± 2.90</td>
<td>38.21 ± 3.49</td>
<td>36.64 ± 4.05</td>
<td>33.82 ± 5.67</td>
<td>33.82 ± 5.67</td>
</tr>
<tr>
<td>( pH )</td>
<td>BA 5.68 ± 0.23</td>
<td>5.53 ± 0.08</td>
<td>5.60 ± 0.05</td>
<td>5.67 ± 0.12</td>
</tr>
<tr>
<td>BA 5.68 ± 0.09</td>
<td>5.60 ± 0.04</td>
<td>5.62 ± 0.09</td>
<td>5.68 ± 0.11</td>
<td>5.68 ± 0.11</td>
</tr>
<tr>
<td>WBSF</td>
<td>BA 115.20 ± 25.57</td>
<td>124.25 ± 27.84</td>
<td>106.24 ± 28.21</td>
<td>123.62 ± 24.77</td>
</tr>
<tr>
<td>BA 98.85 ± 23.80</td>
<td>79.00 ± 15.43</td>
<td>82.54 ± 25.92</td>
<td>115.88 ± 25.02</td>
<td>115.88 ± 25.02</td>
</tr>
</tbody>
</table>

BA - samples analysed before aging.

AA - samples analysed after aging.

\( L^* \) - lightness, \( a^* \) - redness, \( b^* \) - yellowness, \( C^* \) - Chroma, \( h^\circ \) - hue, \( \Delta E \) - color differences coefficient, WBSF - Warner-Bratzler shear force.

\( a^* b^* \) statistical significant differences between value before and after aging.
Table 2

<table>
<thead>
<tr>
<th>Parameter (%)</th>
<th>Heifers &lt; 21 d of aging n = 6</th>
<th>Heifers &gt; 21 d of aging n = 7</th>
<th>Bulls &lt; 21 d of aging n = 8</th>
<th>Bulls &gt; 21 d of aging n = 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter BA</td>
<td>25.80 ± 1.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>25.86 ± 1.54&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.02 ± 3.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.87 ± 1.66&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat BA</td>
<td>2.62 ± 1.53</td>
<td>2.37 ± 1.39</td>
<td>1.66 ± 1.20</td>
<td>2.05 ± 1.79</td>
</tr>
<tr>
<td>Protein BA</td>
<td>22.19 ± 0.86</td>
<td>23.01 ± 1.98</td>
<td>22.29 ± 1.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22.64 ± 0.53&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Collagen BA</td>
<td>0.57 ± 0.17</td>
<td>0.70 ± 0.49</td>
<td>1.05 ± 0.67</td>
<td>0.83 ± 0.39</td>
</tr>
</tbody>
</table>

BA - samples analysed before aging.
AA - samples analysed after aging.

<sup>a,b</sup> statistical significant differences between value before and after aging.

Fig. 1. Position of instrumental characteristics of dry-aged beef (m. longissimus thoracis) at first two principal components of PCA (BA – before aging, AA – after aging), n = 54.

Fig. 2. Position of bulls and heifers at first two principal components of PCA according instrumental parameters, n = 54.

The second PCA is for chemical data (Fig. 3). The first two principal components accounted for 52.20% of the total variance in the data. Product projection on the factor plane is determined by the measured characteristics (Fig. 4). It is apparent from PCA analysis that there are three samples that differ from others.
Fig. 5. Numbers of Total Viable Count (1), psychrophilic bacteria (2) and Lactic Acid Bacteria (3) during dry aging of beef at +1 °C, determined on the surface (a) and in the meat (b). Full line – smoothing by LOESS, dotted line – Baranyi model, n = 54.
The decrease after approximately two weeks of storage could be
by the higher level of initial contamination in the second
storage when LOESS smoothing was used, we are fully aware that this
surface, respectively, and 2.17 ± 0.47, 2.13 ± 0.49 and 0.85 ± 0.22
log CFU/ml), and Li et al. (2013) after 14 d of dry aging at 2.9 °C (5.2
log CFU per g of meat, respectively. For comparison, the limits in EU
Regulation No. 2073/2005 state that up to 3.5 log CFU/cm² is con-
sidered satisfactory for beef carcasses for TVC and up to 5 log CFU/cm²
is still acceptable. The initial values are also similar to those in other
studies conducted on the dry aging of beef (Ahnström et al., 2006;
Campbell, Hunt, Levis, & Chambers, 2001; DeGeer et al., 2009; Li,
Babol, Walby, & Iandström, 2013; Li et al., 2014).

The numbers of bacteria increased notably during the first 2 weeks
of storage; later on the counts did not change greatly (Fig. 5). Although
in some cases there seemed to be a decreasing trend towards the end of
storage when LOESS smoothing was used, we are fully aware that this
may result from the lower number of samples taken after 30 d of aging,
for which reason the Baranyi model of growth was also applied. In
several studies on dry aging of beef, an increasing trend in TVC was
noted during 21 d of storage (Gudjonsdóttir et al., 2015; Li et al., 2014).
However, in the studies by Campbell et al. (2001) and Ahnström et al.
(2006), the numbers after 21 d were moderately lower than those after
14 d. The decrease after approximately two weeks of storage could be
the result of surface drying during aging, as the water content decreased
significantly (Table 3).

The TVC and numbers of PSY showed similar initial values (ap-
proximately 2.5 log CFU) and maximal values (< 7.0 log CFU) (Fig. 5).
The parameters of the Baranyi model showed the highest specific
growth rate for PSY and TVC on the surface and the lowest for bacteria
in deep tissue to where microorganisms infiltrate from the surface. The
mean values for TVC and PSY after 14 and more d of aging (Nmax) were
approximately 5 log CFU (Table 3). Similar results were reported by
Ahnström et al. (2006) after 14 d of dry aging at 2.6 °C (5.1 log CFU/cm²),
Gudjonsdóttir et al. (2015) after 14 d of dry aging at 4 °C (5.75
log CFU/ml), and Li et al. (2013) after 14 d of dry aging at 2.9 °C (5.2
log CFU/cm²). Other authors reported higher TVC even after just 8 d of
dry aging – 6.39 log CFU/cm² after storage at 5.1 °C (Li et al., 2014)
and 7.49 log CFU/g after storage at 2 °C (Yim et al., 2015). These higher
values can be explained by the higher storage temperature in the first
study and by the higher level of initial contamination in the second
study.

The numbers of LAB in our study were generally very low, initially
near the limit of detection, and the highest values in the samples of
aged meat did not exceed 3 log CFU/g or cm² (Fig. 5). Due to the high
variability of the data and low numbers throughout the experiment, the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TVC surface</th>
<th>PSY surface</th>
<th>TVC meat</th>
<th>PSY meat</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₀ (log CFU)</td>
<td>2.58</td>
<td>2.47</td>
<td>2.17</td>
<td>2.12</td>
</tr>
<tr>
<td>CI (95%)</td>
<td>(2.24; 2.93)</td>
<td>(2.16; 2.78)</td>
<td>(1.91; 2.43)</td>
<td>(1.81; 2.43)</td>
</tr>
<tr>
<td>Nₘₐₓ (log CFU)</td>
<td>5.26</td>
<td>5.41</td>
<td>4.72</td>
<td>4.82</td>
</tr>
<tr>
<td>CI (95%)</td>
<td>(4.81; 5.70)</td>
<td>(5.01; 5.80)</td>
<td>(4.38; 5.07)</td>
<td>(4.41; 5.23)</td>
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Gudbjartsson, M., Gauraz, M. D., Mendes, A. C., Chronakis, I. S., Jespersen, L., & Karlsson, A. H. (2015). Effects of electrospun chitosan wrapping for dry aging of beef, as studied by microbiological, physiochemical and low-field nuclear magnetic resonance analysis. Food Chemistry, 184, 167-175.