HEAT TREATMENT INFLUENCE ON RHEOLOGICAL PROPERTIES OF PORK MEAT

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Abstract
During the heating of meat, meat proteins are denaturizing, which causes various changes in the structure of the meat, such as the destruction of cell membranes, tearing of muscle fibbers, tearing and dissolution of the connective tissue proteins, coagulation and gel formation of the myofibrillar and sarcoplasmic proteins.

The aim of the study presented in this paper was to investigate the effect of heat treatment by roasting and cooking at atmospheric pressure on the rheological properties of M. longissimus dorsi of pork in the temperature range between 51 °C and 100 °C. Consequently, the TPA and Warner Bratzler tests were conducted, for both processes of heat treatment, after each of the observed temperature in a given temperature range. By TPA test were determined hardness (g), elasticity, cohesiveness, plasticity and chewiness. Warner Bratzler test determined the change of strength (N) and shear test (Ns).

The observed parameters during rheological tests showed constant statistically significant change (P < 0.001) of observed values with temperature increasing during the both heat treatment processes in the given temperature range. The most optimal temperature in the centre of the sample during thermal processing of pork meat is in the temperature range between 71 °C and 81 °C. Heat treatment by cooking gave products with more desirable rheological properties, as seen in relation to the thermal treatment by roasting.

Key words: Meat rheology, Pork meat, Heat processing of meat.

1. Introduction
For centuries, meat is an essential food in countries, whole around the world. Consequently, the meat industry and meat processing occupy an important place in the world. The way of life of population in Europe and America has long changed in terms of the foods consumption that is easy to prepare in a very short time ([1], [2]). The temperature's height in the middle of the piece of meat that is processed affects the change in proteins. As a result of changes in the structure of proteins, there is a change of textural and sensory properties of meat. The final effect is different acceptability of finished products by consumers [3].

Texture is a key quality attribute used in the fresh and processed food industry to assess product quality and acceptability. Among the texture characteristics, hardness (firmness) is one of the most important parameters ([4], [5]). Given gelled products such as muscle food, springiness, cohesiveness, adhesiveness and gumminess are significant properties for the texture evaluation ([5], [6]). Textural quality attributes of food may be evaluated by descriptive sensory or instrumental analyses [7].

Texture values in meat mainly depend on zoo technical characteristics of the animal such as breed, age and sex [8], on anatomical characteristics such as type of muscle ([8], [9]), on factors external to the animal, as handling and feeding characteristics ([9], [10]), or on technological characteristics such as electrical stimulation [10] or meat cooking method ([8], [10]). Texture includes a variety of characteristics, such as hardness (some authors call it toughness), springiness, chewiness, and some authors also include juiciness ([9], [11]). Among texture attributes, hardness is the most important to the consumer, as it decides the commercial value of a meat [12]. Texture is by definition a sensory parameter that only a human being can perceive, describe and quantify ([12], [13]). Instrumental texture assessment on meat is made by means of a texturometer, a device that allows tissue resistance both to shearing and to compression to be measured [13].

The most widespread method normally used as an indicator of meat sensory hardness (tenderness) is the Warner-Braztler (WB) shear test, which is referred to in most papers ([13], [14]). Even as a technique used for commercial application, Cierach et al. [15], Ferris et al. [16], Ranalli et al. [17] and Andrés et al.
[18] found a negative and very significant correlation between shear force and sensory tenderness in sheep meat; nevertheless, other authors have not found a good correlation between WB shear force and overall consumer acceptance ([17], [18]).

There is another method - the texture profile analysis (TPA) - that, although it is widely used for texture assessment in food ([13], [18]), it has been successfully used for texture assessment in various kinds of meat products [19]. The main advantage of TPA is that one can assess many vitiates with a double compression cycle. Varieties that can be assessed with this analysis are: hardness, springiness, cohesiveness, adhesiveness, resiliency, fracturability, gumminess, chewiness, etc. In meat the varieties assessed are hardness, springiness, and cohesiveness; the three altogether permit the calculation of chewiness ([13], [20]).

The objective of this work was to investigate the impact of temperature and which one of the two methods of thermal processing has a greater impact on meat texture changing (WB and TPA) of thermally processed M. Longissimus dorsi of pork. Consequently, in order to determine the optimal conditions of heat treatment, the meat is treated at different temperatures in a given temperature range from 51 °C to 100 °C by dry method (roasting) and by cooking in water (at atmospheric pressure). Obtained results are very useful for prediction of sensory texture for both in cooked meat and in roasted meat.

2. Materials and Methods

2.1 Samples and sample preparation

The study was conducted on the pork meat, reared on a modern farm in Bosnia and Herzegovina. Animals were under one year of age and had an average gross weight of about 130-140 kg. The animals were bled in the usual manner and under identical conditions. After that, the carcasses were subjected to an identical procedure of primary treatment. After cooling for 24 hours, from six carcasses pork are stripped back muscles (M. Longissimus dorsi). These pieces of muscle were frozen and cut into slices thickness 1.5 - 2.0 cm. After labeling the samples were packed in polyethylene bags and frozen at a temperature of -30 °C and kept at that temperature until the moment of testing. Samples were packed in sealed boxes and transferred to the laboratory where they were analyzed. By analyzing time, samples are stored at freezing temperatures, and were thawed before testing, so that they were kept overnight in a refrigerator at temperature 4 - 5 °C.

2.2 Heat treatment of samples

Thawed samples were subjected to wet and dry heat treatment. Dry heat treatment was carried out by roasting (slices thickness 1.5 - 2.0 cm) in oven type “Elit” 3kW. The samples were heated to achieve desired temperature in the center of sample. The air temperature in the oven during all the experiment was 163 ± 2 °C. Temperature in the oven and the temperature in the center of the sample was continuously monitored using a dual-channel thermocouple “TESTO” and “HANNA” HI 98810, from -50 °C to +250 °C.

Wet heat treatment is carried out in a water bath. Before putting in water, samples were wrapped in thermosetting plastic bags in absence of air, and then heated to achieve the desired temperature in the center of the sample. The temperature is continuously monitored using a dual-channel thermocouple “TESTO” and “HANNA” HI 98810, from -50 °C to +250 °C.

In the both tests samples were treated at 51 °C, 61 °C, 71 °C, 81 °C, 91 °C and 100 °C.

2.3 Meat texture analysis

The texture of meat was determined instrumentally by using texturometer TA-HD Plus Texture Analyzer. Warner-Bratzler (WB) shear test and TPA test were determined for each temperature in the observed temperature range and both heat treatment.

Preparation of samples:

After heat treatment the samples were cooled and with special tools cutted into cylinders (diameter 10mm, height 15mm). Thus prepared samples were further used for texture determination.

Working conditions were as follows:

Warner-Bratzler test: speed 1.5 mm/s; load of 5 kg (sample thermally processed at 91 °C and 100 °C, a load of 5 kg was not enough, so was used weight of 250 kg).

TPA test: pretest - speed 3 mm/s; test - speed 1 mm/s; posttest - speed 3 mm/s. Compression rate 75%.

2.4 Statistics and data analysis

The experiment was a completely randomized design with four replications. Data were subjected to analysis of variance (ANOVA) and means were separated by Duncan’s multiple range test at p < 0.05; p < 0.01; p < 0.001 significance level.

3. Results and Discussion

3.1 Results

3.1.1 Texture Profile Analysis (TPA)

In Table 1 and Table 2 are presented results of TPA analysis for samples processed by cooking and by roasting in the observed temperature range in the center of the sample from 51 °C to 100 °C.
Table 1. TPA test results of samples (*M. Longissimus dorsi*) thermally processed by roasting at different temperatures in the center of the sample (t<sub>0</sub> °C)

<table>
<thead>
<tr>
<th>t&lt;sub&gt;0&lt;/sub&gt; °C</th>
<th>Hardness (g)</th>
<th>Springiness</th>
<th>Cohesiveness</th>
<th>Gumminess</th>
<th>Chewiness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
</tr>
<tr>
<td>51</td>
<td>8127.55a ± 132.09</td>
<td>0.31a ± 0.04</td>
<td>0.49a ± 0.12</td>
<td>3922.35a ± 83.28</td>
<td>1236.50a ± 52.16</td>
</tr>
<tr>
<td>61</td>
<td>10711.05b ± 165.61</td>
<td>0.36ab ± 0.11</td>
<td>0.48a ± 0.19</td>
<td>4674.90b ± 121.36</td>
<td>1880.51b ± 66.04</td>
</tr>
<tr>
<td>71</td>
<td>11365.48b ± 187.34</td>
<td>0.38ab ± 0.14</td>
<td>0.44a ± 0.17</td>
<td>5206.59c ± 111.42</td>
<td>1894.12b ± 52.98</td>
</tr>
<tr>
<td>81</td>
<td>12431.71c ± 211.94</td>
<td>0.39b ± 0.12</td>
<td>0.43a ± 0.16</td>
<td>5284.91c ± 124.53</td>
<td>2257.48c ± 121.75</td>
</tr>
<tr>
<td>91</td>
<td>15771.74d ± 232.81</td>
<td>0.42b ± 0.17</td>
<td>0.42ab ± 0.09</td>
<td>6585.45d ± 261.28</td>
<td>3203.86d ± 143.27</td>
</tr>
<tr>
<td>100</td>
<td>20437.77e ± 312.93</td>
<td>0.44b ± 0.15</td>
<td>0.41ab ± 0.07</td>
<td>8831.90e ± 235.94</td>
<td>4122.16e ± 178.81</td>
</tr>
</tbody>
</table>

a, b, c - different letters in the same column indicate statistical significance (P ≤ 0.05); ab, bc,... letters in the same column indicate (P = 0.05).

Table 2. TPA test results of samples (*M. Longissimus dorsi*) thermally processed by cooking at different temperatures in the center of the sample (t<sub>0</sub> °C)

<table>
<thead>
<tr>
<th>t&lt;sub&gt;0&lt;/sub&gt; °C</th>
<th>Hardness (g)</th>
<th>Springiness</th>
<th>Cohesiveness</th>
<th>Gumminess</th>
<th>Chewiness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
<td>X ± SD</td>
</tr>
<tr>
<td>51</td>
<td>7219.63a ± 280.41</td>
<td>0.32a ± 0.06</td>
<td>0.47a ± 0.18</td>
<td>3361.63a ± 119.73</td>
<td>1070.36a ± 39.83</td>
</tr>
<tr>
<td>61</td>
<td>9756.01b ± 348.34</td>
<td>0.39ab ± 0.11</td>
<td>0.46a ± 0.12</td>
<td>4326.95b ± 174.62</td>
<td>1779.61b ± 94.21</td>
</tr>
<tr>
<td>71</td>
<td>12283.69c ± 431.81</td>
<td>0.44b ± 0.19</td>
<td>0.44a ± 0.14</td>
<td>5014.65c ± 215.61</td>
<td>2305.25c ± 73.42</td>
</tr>
<tr>
<td>81</td>
<td>13248.23d ± 397.13</td>
<td>0.46b ± 0.21</td>
<td>0.42a ± 0.17</td>
<td>5136.99c ± 264.69</td>
<td>2316.59c ± 87.38</td>
</tr>
<tr>
<td>91</td>
<td>13935.03d ± 362.93</td>
<td>0.47b ± 0.09</td>
<td>0.41a ± 0.18</td>
<td>5676.24cd ± 197.98</td>
<td>2505.33cd ± 94.09</td>
</tr>
<tr>
<td>100</td>
<td>16890.29e ± 549.72</td>
<td>0.49b ± 0.17</td>
<td>0.39ab ± 0.05</td>
<td>7407.52d ± 12.17</td>
<td>3443.45d ± 96.49</td>
</tr>
</tbody>
</table>

a, b, c - different letters in the same column indicate statistical significance (P ≤ 0.05); ab, bc,... letters in the same column indicate (P = 0.05).

3.1.2 Warner-Bratzler (WB) shear test

In Tables 3 and 4 are presented results of Warner-Bratzler (WB) shear test for samples processed by roasting and by cooking heat treatment.

Table 3. Warner-Bratzler (WB) shear test results of samples (*M. Longissimus dorsi*) thermally processed by roasting at different temperatures in the center of the sample (t<sub>0</sub> °C)

<table>
<thead>
<tr>
<th>t&lt;sub&gt;0&lt;/sub&gt; °C</th>
<th>Firmness (N)</th>
<th>Work of Shear (Ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>X ± SD</td>
</tr>
<tr>
<td>51</td>
<td>30.15a ± 2.74</td>
<td>180.93a ± 4.78</td>
</tr>
<tr>
<td>61</td>
<td>36.00b ± 1.85</td>
<td>191.99ab ± 3.94</td>
</tr>
<tr>
<td>71</td>
<td>36.68b ± 2.89</td>
<td>228.57c ± 6.72</td>
</tr>
<tr>
<td>81</td>
<td>48.96c ± 3.02</td>
<td>258.73d ± 3.88</td>
</tr>
<tr>
<td>91</td>
<td>55.55d ± 2.97</td>
<td>316.46e ± 5.94</td>
</tr>
<tr>
<td>100</td>
<td>59.98e ± 3.71</td>
<td>333.68e ± 6.79</td>
</tr>
</tbody>
</table>

a, b, c - different letters in the same column indicate statistical significance (P ≤ 0.05).

Table 4. Warner-Bratzler (WB) shear test results of samples (*M. Longissimus dorsi*) thermally processed by cooking at different temperatures in the center of the sample (t<sub>0</sub> °C)

<table>
<thead>
<tr>
<th>t&lt;sub&gt;0&lt;/sub&gt; °C</th>
<th>Firmness (N)</th>
<th>Work of Shear (Ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X ± SD</td>
<td>X ± SD</td>
</tr>
<tr>
<td>51</td>
<td>26.70a ± 1.12</td>
<td>149.61a ± 2.54</td>
</tr>
<tr>
<td>61</td>
<td>40.67b ± 2.62</td>
<td>201.03b ± 4.93</td>
</tr>
<tr>
<td>71</td>
<td>41.67b ± 2.94</td>
<td>224.90c ± 4.58</td>
</tr>
<tr>
<td>81</td>
<td>42.45b ± 3.24</td>
<td>236.11c ± 7.72</td>
</tr>
<tr>
<td>91</td>
<td>48.84c ± 3.79</td>
<td>283.66d ± 6.97</td>
</tr>
<tr>
<td>100</td>
<td>57.57d ± 3.92</td>
<td>322.69e ± 8.33</td>
</tr>
</tbody>
</table>

a, b, c - different letters in the same column indicate statistical significance (P ≤ 0.05).

3.2 Discussion

From Table 1 and Table 2, it can be seen that the mean values of observed parameters are generally
significantly higher (p < 0.001) for samples processed by roasting heat treatment, compared to those treated with heat treatment by cooking in the observed temperature range. Also, with the increase in temperature, during the heat treatment, the mean value of the observed parameters is increasing statistically significant (p < 0.01), except for the values related to the cohesiveness that behave inversely with temperature increasing. The mean value of cohesiveness is significantly reduced (P < 0.001) with increasing temperature during the heat treatment. With the change in method of heat treatment, there were no statistically significant changes (P>0.05) in the intensity of the cohesiveness.

From the above, it is clear that with increasing of heat treatment temperature in the center of the samples, leads to a statistically significant increasing (p < 0.001) of mean values for observed parameters. The intensity of the increase for samples processed by roasting heat treatment was significantly higher (p < 0.01) than for samples processed by cooking heat treatment. In the temperature range from 61 °C to 81 °C are clearly distinguishable slow trend of increasing in intensity of observed parameters, compared to before and after this interval. As described by Barbieri and Rivaldi [21], Bouton et al. [22], this is caused by changes in the proteins structure, because in this interval is the most intense denaturation and renovation on myofibrillar proteins, caused by the decomposition of myofibrillar structure. This decomposition causes an increase in the secretion of liquid phase and samples mass loss during heat treatment ([3], [22]).

From Table 3 can be seen that with increasing temperature in the center of the sample (t, °C) during the both heat treatment process, Firmness (N) of the sample was significantly increased (P < 0.05). The change in method of heat treatment, significantly affects the intensity of Firmness (N) increasing (P < 0.05) in the temperature range from 61 °C to 91 °C. At 51 °C and 100 °C, there were no statistically significant differences (P > 0.05) in respect to the Firmness (N) mean values with change in method of heat treatment (roast, cook).

In the Table 4 is shown, that with increasing temperature in the center of the sample, during the both heat treatment process, there is a statistically significant increase in the mean values for Work of Shear (Ns) (P < 0.001). Changing the method of heat treatment, have a statistically significant effect (P < 0.05) on the mean value of the work of shear at 51 °C, 61 °C, 81 °C and 91 °C, but significantly not affect (P > 0.05) at temperatures 71 °C and 100 °C. It is important to note that the increase in intensity of Firmness (N) and Work of Shear (Ns) for both methods of heat treatment, generally were not significantly different (P > 0.05) in the temperature range between 61 °C and 81 °C, as a result of denaturation and modification protein structures, caused by disintegration of myofibrillar structure.

According to the Bouton et al. [22], changes in rheological properties with temperature increasing are directly related to changes in the proteins (myofibrillar and connective tissue proteins). Heating leads to softening of connective tissue caused by gelling of collagen and increasing the toughness of muscle fibers, caused by thermal coagulation of myofibrillar proteins. Zayas and Naewbanij, [24], Saricoban et al. [25], indicate that the value of the parameters that define the texture of meat increases with decomposition of myofibrils, and decreased with increasing solubility of collagen. The shortening of the myofibrillar proteins chains may cause an increase in the hardness of heat-treated meat. Toldrá [1], Thornberg [3], Zayas and Naewbanij, [24], Saricoban et al. [25], indicate that heat treatment significantly affects the texture of the meat. This influence is reflected in the changes of peak force for a given property that is observed. In the temperature range from 50 °C to 60 °C, peak force for the observed texture characteristic can be increased up to 150%. Increasing the temperature from 60 °C to 80 °C peak force may to remain constant or to decrease up to 14%, with increasing temperature [26]. The results obtained in this paper are generally in agreement with results of previous authors and represent a good basis for predicting the sensory properties of heat-treated pork meat.

4. Conclusions

- Results of rheological properties, presented in this paper, showed a constant increase in hardness and firmness with increase in temperature during the heat treatment.
- Increasing of observed parameters are statistically significantly higher (P < 0.05) in samples processed by roasting than in samples processed by cooking heat treatment.
- In the temperature range from 51 °C to 61 °C there are significant (p < 0.01) increase in the values of observed parameters from TPA and WB shear test.
- From 61 °C to 81 °C, increase in the most observed parameters were significantly slowed, and some were almost constant (hardness, gumminess, chewiness) especially in samples processed by cooking heat treatment.
- The optimal temperature in the center of the sample, during the heat treatment of this type of meat is in the temperature range between 71 °C and 81 °C. Below 71 °C, next to quite satisfactory rheological properties, but according to the instructions from the American Meat Science Association [27], thermal treatment is
not suitable because of insufficient microbiological safety of thermally processed meat products. Above 81 °C, samples do not satisfy in terms of rheological properties.

- In the temperature range between 61 °C to 81 °C, heat treatment by cooking gave products with more balanced and favorable rheological properties, considered in relation to the thermal treatment by roasting.

Acknowledgement

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5. References


