

Effect of heat treatment at constant 120 °C temperature on the rheological and technological properties of pork

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Abstract. The aim of the study was to evaluate the influence of low-temperature heat treatment on the physical and technological properties of pork. The *Longissimus thoracis* muscles from four pigs were used to determine the quality indicators of pork at 24 hours after slaughtering. Meat samples were cooked at constant 120 °C in a cooking bag until the internal temperatures of 62, 67, 72, 77 and 82 °C. Raw meat was the darkest and differed considerably ($P < 0.05$) from the heat-treated meat. The colour values of the heat-treated meat differed slightly among internal temperature phases. The ultimate pH value of raw meat also differed significantly ($P < 0.05$) from that of cooked meat. The pH value of cooked meat varied only within the range of 0.05 units. The electrical conductivity of muscle decreased gradually as the temperature increased. In case of heat-treated meat, the cooking loss increased considerably (from 18.88% to 31.73%) along with the increase in the internal temperature. The Warner-Bratzler shear force value was the highest (38.50 N) in the meat cooked until 77 °C, and the lowest (28.51 N) in that cooked until 67 °C. Strong negative correlation ($P < 0.001$) between electrical conductivity and cooking loss was observed during the heating procedure. Heat treatment can significantly decrease the electrical conductivity and increase the cooking loss of meat. Meat was the toughest when the internal temperature was 77 °C. However, the best rheological properties were observed in the meat cooked until the internal temperature of 72 °C.

Key words: pork, *Longissimus thoracis*, temperature, heat treatment, technological properties, rheological parameters.

INTRODUCTION

The most important indicators of eating quality are the rheological properties of meat, especially tenderness, which can considerably be altered by heat treatment. Cooking is an acknowledged method of making meat products palatable and safe (Thornberg, 2005), defined by Davey & Gilbert (1974) as the heating of meat to a sufficiently high temperature to denature proteins. During heating denaturation of meat proteins takes place and meat becomes tougher. Heat treatment has also a considerable effect on meat colour as denaturation of myoglobin changes the colour from red to

brownish. Consumers often estimate the doneness of meat by colour (Mancini & Hunt, 2005). Colour also affects the acceptability of the finished products by consumers (Thornberg, 2005). These qualities can be controlled by selecting an appropriate cooking method, cooking time and temperature.

There are several reports available, which declare that the ultimate internal temperature has a major effect on the rheological and technological properties of meat (Cross et al., 1976; Combes et al., 2004; Barbera & Tassone, 2006; Christensen et al., 2011; Huang et al., 2011; Grujić et al., 2014). However, the cooking methods, heating parameters and internal temperatures vary among studies. An air/steam combined cooking technique was used by Gardes et al. (1995), Vittadini et al. (2005), Danovska-Oziewicz et al. (2007) at 180 or 220 °C. Air/steam cooking at considerably lower temperatures (100 to 140 °C) was carried out by Chivaro et al. (2009). Roasting of meat in an oven has usually been done at lower temperatures, e.g. Lien et al. (2002) roasted pork loin chops at 176.7 °C, while Grujić et al. (2014) used a temperature of 163 ± 2 °C. Cooking at lower temperatures may reduce energy consumption, but the final internal temperature must ensure the (hygienic) safety of meat (Smith & LeBlanc, 1990). In some studies, meat has been heat treated in a water bath (Christensen et al., 2011; Huang et al., 2011; Grujić et al., 2014). Internal temperatures of the samples vary between studies, which must be taken into account when comparing the results.

The aim of the study was to evaluate the influence of heat treatment at a low temperature (120 °C) on the physical and technological properties as well as on the textural parameters of pork.

MATERIALS AND METHODS

Sample preparation and heat treatment. Meat samples (*Longissimus thoracis*) from four randomly selected commercially reared crossbred pigs were used in this study. The pigs were slaughtered at about 6 months of age and 100 kg of live weight in the same slaughterhouse under similar conditions according to European Council Regulation No 1099/2009. Carcasses were cooled for 24 hours, after which the longest spinal muscles (*Longissimus thoracis*) were excised between the 12th thoracic vertebra and the 5th lumbar vertebra from both sides of each carcass. Muscles were packed into plastic bags and labelled as 1, 2, 3 and 4. Bags were kept in a cooling box during transportation and until the testing.

Raw meat analyses and heat-treatments of the samples were performed immediately upon arrival at the laboratory. Muscles were trimmed of visible fat and connective tissue and cut perpendicularly to muscle fibres into six 30 mm pieces. Five chops were weighed and placed into sealed cooking bags designed for heat treatment (Fig. 1). Each meat sample was supplied with a dual-channel thermocouple to continuously monitor the internal temperatures. Dry heat treatment at 120 °C was used for oven roasting. A total of four series of heat treatment experiments were carried out – one per muscles used in study.

Samples were heated to predetermined internal temperature (62, 67, 72, 77 and 82 °C), taking into account the recommendations of the U.S. Food and Drug Administration (FDA, 2013) according to which fresh pork is safe to eat when cooked to the internal temperature of 63 °C. After heat treatment, samples were cooled to room

temperature and stored in a refrigerator at 4 °C. The pH, colour, electrical conductivity and shear force of the cooked meat samples were measured after being cooled to room temperature.



Figure 1. Sealed bags with meat chops in a preheated oven.

Properties of meat. Cooking time of the samples from three different muscles used in study was similar. However, cooking time of the samples obtained from the fourth muscle was 6–8 minutes shorter than that of muscle 2, which was caused due to the smaller diameter of the muscle. Samples from, muscle 3 achieved the designated internal temperature 10–13 minutes later than those from muscle 4 (Fig. 2).

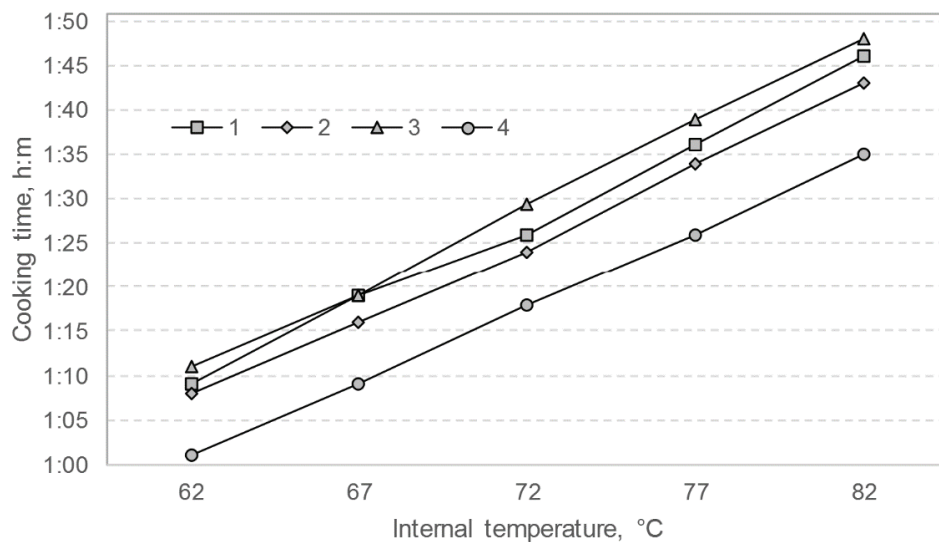


Figure 2. Cooking time to the designated internal temperatures of muscle samples 1, 2, 3 and 4.

Dry matter content and water binding capacity. The difference between the dry matter content of the raw meat samples did not exceed 1.70%, which indicated that there were no signs of abnormal muscle metabolism (PSE or DFD damage) after slaughtering. However, the water binding capacity of the muscles varied by 15.40%, ranging from 57.60 to 73.00% (Table 1).

Table 1. Properties of muscle 1–4 samples

Trait	Muscle				Average
	1	2	3	4	
Dry matter content, %	26.00	26.10	25.30	27.00	26.10
Water binding capacity, %	57.60	64.50	66.40	73.00	65.38

Cooking loss. Cooked samples were removed from bags and cooled until room temperature. Meat chops were wiped dry with blotting paper. Each sample was weighed, and cooking loss (CL) was calculated as follows:

$$CL (\%) = \frac{\text{raw sample weight} - \text{cooked sample weight}}{\text{raw sample weight}} \cdot 100 \quad (1)$$

In addition, the weight of each cooking bag with the liquid released from meat was recorded.

pH. Raw and cooked meat pH values were measured at room temperature (~21 °C) using a Testo 205 digital tester (Testo Ltd, Alton, GB). After calibration of the pH meter with standard solutions (pH 4.0 and 7.0) at room temperature, pH was recorded by sticking a probe into the samples. The pH values of raw meat were recorded 24 hours after slaughtering, and those of the heat-treated meat after cooling down the samples.

Colour. The colour of each meat sample was measured on the surface of the samples at room temperature (~21 °C) using a digital Opto-Star device (Ingenieurbüro R. Matthäus, Klaus, Germany). Raw meat optimum values are between 60–80 points, but values below 55 points indicate existence of PSE meat and above 85 points to DFD meat (LSZ Boxberg, 2011).

Electrical conductivity. The electrical conductivity of the samples was recorded with the LF-Star CPU device (Ingenieurbüro R. Matthäus, Klaus, Germany) by measuring the electric conductance between the two steel electrodes stuck into the meat samples.

Texture. The texture was measured in both raw and cooked meat after chilling at 4 °C for 24 hours. A drilling press equipped with a sampling tube was used to obtain 11 mm diameter cores. Ten cores per sample were drilled along the muscle fibre orientation. Each core was sheared once across the centre of the core with a Warner-Bratzler texture analyser TA.XTPlus (Stable Micro System Ltd, Godalming, GB) to measure the shear force. Working conditions during the test: blade speed 10 mm s⁻¹, maximal load 50 kg, and cutting range 25 mm.

Statistical analysis. The data from four randomly selected replicates were analysed using SAS software (SAS Institute Inc., Cary, USA). The two-factor analysis of variance, that included the potential influence of the muscle (1–4), was used to evaluate the effect of cooking time on different characteristics of meat. Additionally, as regards

the meat texture measurement, the interaction between the cooking time and the muscle was tested in ten replications. The differences between individual least square means were estimated using the Tukey's Studentized Range (HSD) test. Pearson correlation analysis was used. A significance level of $P < 0.05$ was chosen.

RESULTS AND DISCUSSION

Cooking loss. Cooking loss is usually defined as the loss of liquid and soluble substances from meat during heat treatment, whereas the main component is water (Heymann et al., 1990). Water is located mostly between muscle fibres and in muscle cells. Heat treatment leads to loss of water due to denaturation of myofibrillar proteins.

The internal temperature of the meat had a significant effect on cooking loss that was 18.88% at 62 °C and 31.73% at 82 °C, whereas the samples lost most of their weight due to the released liquid (18.17 and 30.21%, respectively) (Table 2). An increase in cooking loss was observed during heating, which is consistent with previous studies on pork (Christensen et al., 2011; Huang et al., 2011), beef (Obuz et al., 2004), and rabbit meat (Combes et al., 2004).

The highest weight loss was observed when the internal temperature reached 72 °C. Huang et al. (2011) demonstrated the highest cooking loss (18.80%) at internal temperatures between 60 and 80 °C. The cooking loss of each individual sample was quite similar (se = 0.08%) at 72 °C, whereas the largest differences occurred at 67 °C (1.60%).

Table 2. Least square means (\pm standard error) of meat quality traits estimated in porcine *Longissimus thoracis* at different phases of low-temperature heat treatment

Trait	Internal temperature, °C					
	18	62	67	72	77	82
Cooking loss, %		18.88 $\pm 0.92^a$	21.44 $\pm 1.60^{ab}$	23.20 $\pm 0.08^{bc}$	27.32 $\pm 1.16^c$	31.73 $\pm 1.27^d$
Cooking loss as liquid, %		18.17 $\pm 0.86^a$	20.07 $\pm 1.83^{ab}$	22.02 $\pm 0.28^{ab}$	25.84 $\pm 1.16^{bc}$	30.21 $\pm 1.20^c$
Colour (Opto-Star, points)	70.93 $\pm 2.41^a$	15.48 $\pm 0.87^b$	15.65 $\pm 1.26^b$	11.95 $\pm 1.13^b$	13.30 $\pm 0.83^b$	15.23 $\pm 1.28^b$
Ultimate pH	5.38 $\pm 0.03^a$	5.72 $\pm 0.01^b$	5.74 $\pm 0.03^b$	5.75 $\pm 0.02^b$	5.74 $\pm 0.02^b$	5.77 $\pm 0.03^b$
Electrical conductivity, mS	11.94 $\pm 0.85^a$	9.33 $\pm 0.27^b$	8.38 $\pm 0.24^{bc}$	7.88 $\pm 0.31^{bc}$	6.95 $\pm 0.31^{cd}$	5.55 $\pm 0.40^d$
Warner-Bratzler shear force, N	22.80 $\pm 0.75^a$	33.25 $\pm 0.74^b$	28.51 $\pm 0.74^c$	33.41 $\pm 0.85^b$	38.50 $\pm 0.84^d$	32.83 $\pm 0.65^b$

The letters 'a', 'b', 'c' and 'd' refer to the significance of difference between the values in row at the level of at least 95%.

Colour. Heat treatment had a visible influence on the colour of meat, which was caused by denaturation of myoglobin. Raw meat was significantly darker (70.93 points) compared to the samples cooked to the internal temperature of 62 °C (15.48 points). However, increase in the internal temperature from 62 to 82 °C did not produce a noticeable effect on meat colour (Table 2). Similar results were obtained also by Huang et al. (2011), who demonstrated that heating the samples from the initial internal

temperature of 25 to 50 °C in a water bath significantly increased the L*, a* and b* values (Minolta CR-400 Chroma Meter). They found no changes in colour when increasing the temperature from 60 to 80 °C, except for the a* value, which decreased significantly. Lien et al. (2002), however, observed some changes in the colour (measured both visually and instrumentally) of the meat cooked from 62.8 to 82.2 °C. Howe et al. (1982) reported a decrease in the visually estimated colour values when pork chops reached the internal temperature of 70 °C.

Ultimate pH. The lowest ultimate pH (5.38) was measured in raw meat. Although the ultimate pH values of cooked meat were only by 0.34–0.39 units higher, this difference proved to be significant ($P < 0.05$) (Table 2). Dal Bosco et al. (2001) and Huang et al. (2011) also found, that heat treatment of raw meat resulted in the increase in pH. Huang et al. (2011) explained that the changes in the pH values of meat during heating were caused by changes in the balance of acid-base groups. In agreement with Huang et al. (2011), the present study showed that the ultimate pH of meat samples did not differ significantly ($P > 0.5$) at different internal temperature levels (62 to 82 °C) through the temperature phases.

Electrical conductivity. Electrical conductivity of meat is related to the water content of the muscle tissue. The cooking loss experiments showed that due to the loss of water during heat treatment the samples lost their ability to conduct electricity ($r = -0.941$) (Table 3). Significant difference ($P < 0.05$) was detected between the electrical conductivity of raw meat (11.94 mS) and that of the samples cooked to the predetermined internal temperature levels. Samples cooked to the highest internal temperature (82 °C) proved to be of considerably lower conductivity (5.55 mS) than those cooked to other temperatures (Table 2). The biggest difference in the electrical conductivity values (2.61 mS) at different predetermined temperature levels was found between 18 and 62 °C.

Texture. Several authors (Bouton & Harris, 1972; Davey & Gilbert, 1974; Huang et al., 2011) have reported that toughening of meat due to heat treatment occurs in the course of the following two temperature phases: up to 60 °C, and between (60)65 and 80 °C. The explanation to this observation is that denaturation of connective tissue and myofibrillar proteins takes place at different cooking phases (temperatures). Furthermore, the method of heat treatment may also considerably affect tenderness (Huang et al., 2011; Grujić et al., 2014).

Heat treatment had a major effect on the texture of meat. The force to shear the samples increased from 22.80 to 33.25 N ($P < 0.05$) as the internal temperature of raw meat was raised to 62 °C. The shear force remained about the same at the internal temperatures of 62, 72 and 82 °C. Considerable decrease in shear force was detected at 67 °C (28.51 N), while the highest value was observed at 77 °C (38.50 N). Grujić et al. (2014) detected no textural changes in cooked meat at 61, 71 and 81 °C, while significant changes took place at 51, 91 and 100 °C. Huang et al. (2011) obtained similar results at different temperature phases (internal temperatures of 25–50 °C and 60–100 °C).

Correlations of meat quality traits. A significant ($P < 0.001$) relationship was observed between the cooking loss, the cooking loss due to the loss of liquid, and electrical conductivity (Table 3). The results confirm previous findings that both traits are affected by the water content of meat.

Contrary to Huang et al. (2011) who estimated that cooking loss was moderately or strongly ($P < 0.01$) related to the pH, shear force and colour values, the present study showed weak unreliable correlations between these characteristics. However, moderate ($P > 0.05$) correlation was found between cooking loss and shear force ($r = 0.312$).

Table 3. Pearson correlation coefficients between meat quality traits of the cooked porcine *Longissimus thoracis* muscle

	Cooking loss	Cooking loss due to loss of liquid	Colour	Ultimate pH	Electrical conductivity
Cooking loss due to loss of liquid	0.913***				
Colour	-0.164	-0.191			
Ultimate pH	0.108	0.122	0.090		
Electrical conductivity	-0.941***	-0.815***	0.131	-0.271	
WBSF	0.312	0.209	-0.193	-0.080	-0.256

*** – $P < 0.001$.

CONCLUSIONS

Heat treatment of meat at a low temperature significantly affected the physical and technological properties as well as the textural parameters of pork. Cooking loss and electrical conductivity of meat varied through all the temperature phases showing a strong negative relationship between these two traits. The latter leads to a conclusion that both traits are affected by the water content of meat. The major changes in meat colour and ultimate pH occurred already at 62 °C, whereas further heating did not considerably alter these qualities. Due to heating the meat got tougher compared to raw meat. Further heat treatment did not reveal any clear trends as regards meat texture changes, since major changes had occurred at lower temperatures. In summary, the study showed that the rheological properties were optimal in case the meat was cooked to 72 °C.

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