HOW TO OBTAIN SAFE AND TENDER PORK WHEN COOKING AT "LOW TEMPERATURE, LONG TIME" (LTLT)

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***Abstract*—Low temperature, long time (LTLT) treatment of porcine *Semitendinosus* (ST) was investigated in order to obtain safe and tender meat within a specified time-temperature range. Samples of porcine ST and *longissimus dorsi* were inoculated with *L. monocytogenes* and Salmonella strains and heat-treated at 53°C and 58°C for various times until a reduction of 5 log CFU/g was ensured. A sensory evaluation of a range of attributes was conducted, and cooking loss and shrinkage of LTLT-treated porcine ST at 53°C and 58°C for 9 h, 19 h and 32 h were measured. Investigations of LTLT treatment of porcine ST revealed that, after 9 h cooking at 53°C or 58°C, a reduction of more than 5 log CFU/g *L. monocytogenes* and Salmonella was ensured, and the meat was then evaluated as safe. At 53°C, the meat was significantly more juicy than at 58°C, and this observation was accompanied by a significantly lower cooking loss at 53°C. By increasing the cooking time from 9 h to 32 h, tenderness was significantly increased, and, furthermore, at 58°C the meat was found to be significantly more tender than at 53°C.**

***Index Terms*— pork, low temperature, long time, tenderness, safety, structural changes**

I. INTRODUCTION

The process of cooking for a long time at low temperatures (LTLT) has been investigated for decades (Machlik & Draudt, 1963; Laakkonen, Wellingt, & Sherbon, 1970; Bouton & Harris, 1981; Vaudagna et al., 2002), and all authors observed increasing tenderness during LTLT treatments. However, all previous research has focused on beef muscles, whereas knowledge on the effect of cooking pork muscles at low temperatures for long periods is lacking. Furthermore, the safety aspect of heating meat at low temperatures is important because pathogenic bacteria, such as *L. monocytogenes*, are able to survive mild heat treatments (Farber and Peterkin, 1991). Salmonella and verocytotoxin-producing *E. Coli* (VTEC) are more heat-sensitive, though several outbreaks caused by Salmonella are related to fresh pork (Anonymous, 2008). The effect of heat treatment can be evaluated theoretically by the D/z concept, though it assumes that there is a log-linear relationship between D-values and z-values. In mild heat treatments there are deviations from the log-linear kinetic (Sergelidis et al, 2009), and it is therefore very important that LTLT treatment ensures inactivation of pathogenic bacteria.

Due to the low temperatures used in LTLT treatments, lower cooking losses and therefore greater sensory-evaluated juiciness are expected compared with meat cooked at higher temperatures. During heating at various temperatures (37-75°C), meat proteins denature and cause structural changes such as transversal and longitudinal shrinkage of muscle fibres as well as connective tissue shrinkage, which result in cooking losses in meat (Honikel, 1998). Structural changes occurring during cooking of meat observed by Palka & Daun (1999) confirmed the opinion of Offer, Restall & Trinick (1984) that shrinkage of meat during cooking at 45-90°C occurs in two phases. At approx. 45-60°C, the shrinkage is primarily transverse to the fibre axis, while at 60-90°C it is primarily longitudinal. In LTLT treatments, the temperature is in the range of 50-60°C, and according to Palka & Daun (1999) only transverse shrinkage will occur at these temperatures. However, the effect of prolonged holding periods on shrinkage is not known.

The objectives of the present work were to investigate the sensory properties of LTLT-treated pork *Semitendinosus* and some structural changes occurring during cooking. Furthermore, the microbiological safety of LTLT treatments was investigated to ensure that *L. monocytogenes* and Salmonella are inactivated during the LTLT treatment.

II. MATERIALS AND METHODS

Sample preparation

Semitendinosus (ST) muscles were obtained from commercially available Danish slaughter pigs. The pH was measured, and the muscles were vacuum-packed and stored at 5°C for 4 days. The muscles were trimmed of fat and epimysium, weighed and dimensions (height, length and width) were measured. Samples were vacuum-packed and frozen at -20°C. Prior to heat treatments, samples were thawed for approx. 20 h at 4-5°C. Heat treatments were carried

out in water baths (ICC “Roner”, Frinox Aps, Hillerød, Denmark) set at 53°C and 58°C. Each water bath contained 3 samples at the same time, and heat treatments were performed for 8 h, 19 h and 32 h. Furthermore, a sous-vide treatment was conducted by heating samples at 85°C in an oven until an internal temperature of 80°C was reached.

Cooking loss

Cooking loss (CL) was measured by weighing the samples before and after heat treatments using the relationship CL = 100(mb-ma)/ma, where mb is the weight of the sample before the thermal treatment and ma is the weight of the sample after the thermal treatment. Mean values from 8 repetitions of each thermal treatment were obtained. Cooking losses were collected and frozen at -20°C.

Shrinkage

Shrinkage of the samples during heat treatments was investigated by measuring the dimensions (height, length and width) after heat treatments. Shrinkage in the 3 dimensions was expressed as percentage of dimensions before heat treatment.

Sensory evaluation

The pork (ST) was cut into 1 cm thick slices (1 slice per assessor), which were served under an aluminium cover on a pre-heated plate. Samples were evaluated by a 9-member professional panel using a 15-point unstructured scale anchored at the extremes (0 = low intensity and 15 = high intensity). All assessors had participated in 3 training sessions before the actual trial. The visual attributes were: rose colour, doneness (raw to well-done) and moist surface (meat juice on the surface). The textural attributes were: tenderness, hardness, firmness, crumbliness, chewing time and juiciness. The flavour attributes were: pork flavour, piggy flavour, and metallic flavour. The taste attributes were: sweet, bitter and acid taste. At each session, 14 samples were evaluated (each treatment twice).

Data were analysed using PanelCheck V1. 3.2. using a 2-way ANOVA. LS means were calculated and separated using probability of difference. Levels of significance: $p > 0.05$ = non-significant (ns), $0.05 > p > 0.01$ = *, $0.01 > p > 0.001$ = **, $p < 0.0001$ = ***.

Safety experiment

Longissimus dorsi (LD) and *Semitendinosus* (ST) were obtained from commercially available Danish slaughter pigs and trimmed of fat and epimysium. LD was cut into pieces measuring 12-15 cm (L) x 5 cm (H) x 10 cm (B), and from each ST a piece measuring 12-15 cm (L) x 3 cm (H) was cut.

For the experiment, five strains of *L. monocytogenes* and three strains of Salmonella were used. Each strain was grown for 24 h at 37°C, and then the strains were mixed with BHI and green fruit coloring (Dr. Oetker) in the ratio of 1:2:1. In the experiment with LD at 58°C, three strains of verocytotoxin-producing *E. coli* were included. Each piece of meat was inoculated in the geometric center with 0.1 ml of the coloured cocktail. The samples were stored at 5°C for 15 minutes before the heat treatment.

The vacuum-packed samples were placed in a water bath at 53°C or 58°C. A core temperature of 53°C and 58°C was expected after 2 h and 3 h in ST and LD, respectively. After 2 h, 8 h and 23.5 h, three samples of ST were analysed. For the LD, the analyses were performed after 3 h, 9 h and 24.5 h (n=3). The controls (meat and culture samples stored at 5°C) were performed at the same intervals for each muscle.

Nine samples for each muscle were heat-treated in a water bath at 53°C and 58°C, respectively. As controls, nine samples for each muscle and the coloured cocktail were stored at 5°C. The coloured area in the geometric center was aseptically transferred to Brain Heart Infusion (BHI, Oxoid) and 1) followed by serial dilution in physiological saline with 0.1% Bacto-peptone and 2) incubated for 2 h at 25°C followed by serial dilution in physiological saline with 0.1% Bacto-peptone and surface-plated (resuscitation). From relevant dilutions, samples were surface-plated on Oxford agar (Oxoid, CM0856) and Rambach agar (Merck 1.07500.0002) and incubated at 37°C for 48 h and 24 h, respectively.

III. RESULTS AND DISCUSSION

Cooking loss

Cooking losses of LTLT-treated pork ST at 53°C and 58°C for 8 h, 19 h and 32 h are shown in Figure 1. A significant increase in cooking loss was observed between 53°C and 58°C after both 19 and 32 hours of cooking, while cooking time had no effect on the cooking losses at any temperature. In comparison, sous-vide treated samples had a mean cooking loss of 31.2% .

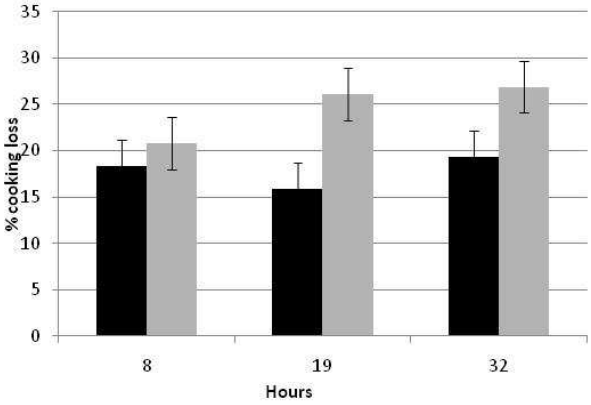

Figure 1. LS means for cooking losses in % in LTLT-treated pork *Semitendinosus* cooked at 53°C (black columns) and 58°C (grey columns) for 8, 19 and 32 hours. Bars represent standard errors (n=8).

Shrinkage

Results for shrinkage of pork ST during LTLT treatment (data not shown) show that a significant effect on shrinkage was only observed with temperature and not with time. Both longitudinal and transverse shrinkages were significantly greater at 58°C than at 53°C. Transverse shrinkage was slightly greater than longitudinal shrinkage at both temperatures, indicating that shrinkage across the fibre axis was more likely to occur at the investigated temperatures. However, during sous-vide treatment at 80°C, longitudinal shrinkage was dominant, while transverse shrinkage occurred to a lesser extent. This is in agreement with the hypothesis that meat shrinks in two phases during heating, though it cannot be specified what caused the shrinking during LTLT treatment.

Sensory evaluation

Tenderness of pork increased during LTLT treatment and was afftected by cooking time and temperature (Table 1). Tenderness increased when cooking time increased. Furthermore, tenderness was influenced by the cooking temperature during LTLT treatment, resulting in increased tenderness when cooking at 58°C compared with cooking at 53°C. The optimal cooking method depends on the desired end product. The same level of tenderness is obtained when cooking at 53° for 32 h and at 58°C for 19 h. However, the meat differs in appearance, with cooking at 58°C resulting in a more well-done appearance than cooking at 53°C. When tenderness increased, attributes as chewing time, firmness (data not shown) and hardness decreased. Furthermore, pork cooked at 53°C achieved an intense metallic flavour compared with pork cooked at 58°C, which resulted in a more intense pork flavour.

Juiciness and crumbliness are inverse correlated. Crumbliness was intensified as juiciness decreased (Table 1). Juiciness generally decreased as the cooking temperature and time increased. The juiciest pork is obtained by cooking at 53°C for 8 h, whereas sous-vide cooking to 80°C results in the least juicy pork among the treatments studied. In general, sous-vide cooking resulted in a lower eating quality compared with LTLT, with a very well-done (grey) appearance and lowest scores for tenderness and juiciness.

Table 1. LS means for sensory attributes evaluated in LTLT-treated pork cooked at 53°C (8, 19 or 32 h), at 58°C (8, 19 or 32 h) or sous-vide-treated pork cooked to 80°C (n=8).

	Attributes	53°C			58°C			80°C	p
		8h	19h	32h	8h	19h	32h	1½h	
Appearance	Rose colour	10.9^{a}	10.7^{a}	9.9^{a}	7.9^{b}	6.1^{c}	5.7^{c}	0.6^{d}	0.000
	Doneness	1.2^{a}	1.3^{b}	1.9^{c}	3.8^{d}	5.6^{e}	5.9^{e}	13.3^{f}	0.000
	Moist surface	9.7^{a}	8.2^{b}	6.8^{c}	5.2^{d}	3.5^{e}	3.3^{e}	1.0^{f}	0.000
Texture	Hardness	4.9^{b}	3.7^{c}	3.1^{cd}	3.9^{c}	2.4^{d}	1.3^{e}	7.0^{a}	0.000
	Tenderness	8.2^{b}	9.9^{c}	11.0^{cd}	9.9^{c}	11.8^{d}	13.8^{e}	6.1^{a}	0.000
	Crumbliness	3.0^{a}	3.9a	4.5^{abc}	5.2^{bc}	7.0^{d}	7.7^{d}	6.2^{cd}	0.000
	Juiciness	11.5^{a}	10.6^{ab}	9.9^{bc}	9.2^{c}	7.0^{d}	6.9^{d}	4.0^{e}	0.000
Flavour	Meat flavour	6.2^{c}	6.8^{c}	6.6^{c}	7.0^{bc}	8.5^{ab}	9.3^{a}	6.8^{c}	0.003
	Metallic	7.1^{abc}	7.5^{ab}	7.8^{a}	6.9^{bc}	6.4^{c}	5.5^{d}	3.9^{e}	0.000

Safety experiment

ST: In the inoculated samples of ST, *L. monocytogenes* and Salmonella were reduced to below the detection limit (10 log cfu/g) after 8 h heat treatment at 53°C or 58°C (2 h to reach the core temperature and 6 h at the core temperature). In the control samples stored at 5°C, no reduction in pathogens was measured. In the inoculated samples and in the coloured cocktail stored at 5°C, the plate count was maintained at a level of 6 log cfu/g and 7 log cfu/g, respectively,

during the 23.5 h storage. This indicates that heat-treated samples contained 6 log cfu/g in the core and that the green fruit colour did not inhibit the inoculated bacteria.

LD: The same results were achieved with LD after 9 h heat treatment at 53°C or 58°C (3 h to reach the core temperature and 6 h at the core temperature). In LD heat-treated to 58°C, the verotoxin-producing *E.coli* was already reduced by more than 5 log cfu/g after 3 h, corresponding to the time it took to achieve 58°C in the core.

There was no difference between plate counts with and without resuscitation. The mean values include the results for both methods. The results show that heat treatment to a core temperature of 53°C or 58°C ensures more than a 5 log reduction if the core temperature is maintained for 6 h after the core temperature has been achieved.

IV. CONCLUSION

Depending on cooking temperature and time, LTLT-treated pork differed mainly in appearance and texture. At 53°C, a rose (almost raw) appearance was obtained, the meat was very juicy and had moisture on the surface, and at this temperature the lowest cooking loss was observed. Furthermore, cooking at 53°C resulted in pork with a firm texture and metallic flavour and after-taste.

LTLT treatment at 58°C resulted in a more well-done appearance with increased tenderness and intensified pork flavour, but also more crumbliness. Cooking loss at 58°C was significantly higher than at 53°C, which was accompanied by a significantly larger transverse shrinkage of the samples.

Sous-vide treatment generally resulted in poor eating quality compared with LTLT treatment. The intensity of tenderness, juiciness and pork flavour was lower, and the appearance was very well-done and grey. Furthermore, the sous-vide treatment resulted in a significantly higher cooking loss compared with LTLT treatment.

LTLT treatment to a core temperature of 53°C and 58°C for 8 h (including heating and holding time) ensured more than a 5 log cfu/g reduction of *L. monocytogenes* and Salmonella in both ST and LD.

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REFERENCES

Anonymous (2008). Annual report on zoonoses in Denmark 2008. National Food Institute, Technical University of Denmark.

Bouton, P.E. & Harris, P.V. (1981) Changes in the Tenderness of Meat cooked at 50-65 degrees C. Journal of Food Science, 46, 475-478.

Farber, J. M., Peterkin, P.I. (1991) Listeria monocytogenes, a food-borne pathogen. Microbiology. Rev. 55(3), 476-511

Honikel, K.O. (1998) Reference methods for the assessment of physical characteristics of meat. Meat Science, 49, 447-457.

Laakonen, E., Wellingt, G.H. & Sherbon, J.W. (1970) Low-Temperature, Long-Time heating of Bovine muscle. 1. Changes in tenderness, water-binding capacity, pH and amount of water-soluble components. Journal of Food Science, 35, 175-177.

Machlik, S.M. & Draudt, H.N. (1963) Effect of heating time and temperature on shear of beef Semitendinosus muscle. Journal of Food Science, 28, 711-718.

Offer, G., Restall, D.J. & Trinick, J. (1984) Water-holding in meat. In: A.J. Bailey (Ed.), Recent Advances in the Chemistry of Meat. The Royal Society of Chemistry, London. pp. 71-86.

Palka, K. & Daun, H. (1999). Changes in texture, cooking losses, and myofibrillar structure of bovine M. Semitendinosus during heating. Meat Science, 51, 237-243.

Sergelidis, D. & Abrahim. A. (2009). Adaptive response of Listeria monocytogenes to heat and its impact on food safety. Food control, 20, 1-10, 2009.

Vaudagna, S.R., Sanchez, G., Neira, M.S., Insani, E.M., Picallo, A.B., Gallinger, M.M. & Lasta, J.A. (2002) Sous vide cooked beef muscles: effects of low temperature-long time (LT-LT) treatments on their quality characteristics and storage stability. International Journal of Food Science and Technology, 37, 425-441.