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ANALYSIS OF A RELATIONSHIP BETWEEN THE MICROSTRUCTURE OF PORK MEAT AFTER HEAT TREATMENT AND ITS TECHNOLOGICAL AND SENSORY QUALITY

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The aim of this work was to analyse a relationship between microstructure parameters of *Longissimus* muscle after heat treatment and technological and sensory quality of pork meat. The research was executed on a group of 40 hogs originating from crossing Naïma sows with hybrids P76-PenArLan boars. The animals were slaughtered at 105 kg live weight. Following the slaughter, the percent of meat in carcass was estimated with a CGM apparatus. Samples taken from the *Longissimus* muscle were determined for: pH after 45 min, 3 h and 24 h *post mortem*, colour of meat in the CIE L*a*b* system, natural drip loss, cooking yield and sensory quality after heat treatment (cooking). Photos of the microstructure of 24 selected meat samples were taken using a scanning microscope XL30 ESEM type, with 300x magnification. Results were elaborated by calculating simple and canonical correlations coefficients between the traits studied. A significant relationship was identified between technological value of meat and its sensory quality. Moderate or low values of the calculated simple correlation coefficients were obtained between microstructure parameters of meat and its technological value and sensory quality. The application of the canonical correlation made it possible to estimate the correlation degree of variable sets which characterised the technological value, sensory quality and microstructure of the muscle. This analysis showed that the quality of pork meat after heat treatment was determined in 76% by the sensory quality of meat and in 84% by its technological value.

INTRODUCTION

Pork is still the most often consumed meat in Poland. The consumption of meat and its products depends on many factors, among them sensory quality, nutrition value, safety, price, disposition and other consumer preferences have a significant meaning [Fischer, 2005].

It is very difficult to define and describe the quality of pork meat by simple, common methods. The quality of meat depends on many factors, *i.e.* physicochemical properties, chemical composition, intensity of changes in muscular tissue *post mortem*, their nutritional value, microbiological and sensory quality in relation to its acceptability by consumers [Sellier & Monin, 1994]. The quality of pork meat is also determined by genetic and environmental factors [De Vries *et al*., 1994; Koćwin-Podsiadła, 1998; Koćwin-Podsiadła *et al.*, 2004, 2006]. A number of researchers, *e.g.* Krzęcio *et al.* [2003] and Fernandez *et al*. [1999], indicated that the improvement of meatiness of pigs led to a decrease in the quantity and quality of fat. It resulted in deterioration of the whole quality of meat.

The study of Jaworska *et al.* [2007] showed that the sensory quality of pork meat after heat treatment (cooking) depended mostly on the range of pH changes after slaughter, intramuscular fat content, natural drip loss and technological and cooking yield. Channon *et al.* [2004] stated that high intramuscular fat content and high pH after slaughter with low cooking losses resulted in higher tenderness, juiciness and flavour of meat. Klont *et al.* [1993] and Bertram *et al.* [2007] showed that meat tenderness was related to muscle microstructure, *i.e.* the number and diameter of muscle fibres. The microstructure of a muscle is determined by such texture attributes as springiness, firmness, cohesiveness, fibrousnesses, juiciness and tenderness. The cytoskeletal proteins are the ones that strengthen and hold up the architecture of the myofibrillar system in a muscle, the structure of muscle tissue changes not only with animal growing and also during maturation and technological process [Tornberg, 1996]. The sensory quality of pork after heat treatment is also determined by its flavour attributes [Fortin *et al.*, 2005].

The effect of microstructure on the sensory quality has been a field of interest for many authors [Klont *et al.*, 1993; Bogucka, 2006; Bertram *et al.,* 2007; Szczepańska, 2007]. Despite this, research results remain inconclusive. The objective of this study was, therefore, to analyse a relationship between the microstructure of *Longissimus* muscle after heat treatment and technological value and sensory quality of pork meat.

MATERIAL AND METHODS

The study was carried out on 40 fatteners, derived from crossing of Naïma sows with hybrids P76-PenArLan boars. The fatteners were slaughtered in the ZM Mróz slaughterhouse in Borzęciczki at 105 kg live weight. After slaughter

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meat percentage was estimated using a CGM apparatus, based on the measurement of backfat thickness and *Longissimus* muscle thickness at the height of the last rib, 7 cm from carcass mid-line [Borzuta, 1998].

Samples of the *Longissimus* muscle (n=40, taken from behind the last rib) were determined for: natural drip loss according to the method of Prange *et al.* [1977], pH after 45 min and after 3 h and 24 h *post mortem* (using a WTW 330i pH-meter), parameters of meat colour in the CIE L*a*b* system (L – lightness, a – redness, and b – yellowness) 48 h after slaughter using a CR310 Minolta equipment (Japan), and cooking yield of meat.

To sensory analysis of pork meat, was carried out on 24 samples (selected from n=40, with different pH values). The sample of about 600 g was cut at the height of the last rib, in cephalic direction, which assures homogeneity of the material studied. The sensory quality of meat samples was determined 96 h after the slaughter. The raw meat was cooked in a salt water solution (0.8%) according to Baryłko-Pikielna *et al*. [1964]. The samples were heated up to a temperature of 72°C in the geometric centre, and next were kept covered until they achieved 75°C [Baryłko–Pikielna *et al.*, 1964]. After reaching a room temperature (21°C for 1-2 h), the samples were cut into portions of approximately equal size, weighed (about 25 g) and placed into plastic (PP) disposable covered boxes. All the samples were separately coded for the assessment (three digit codes) and were put in random order to avoid carry-over effect (*i.e.* the impact of previous sample on the next one). Cooked meat was assessed directly following heat treatment within three hours. The assessment was conducted in rooms with daily light, at a room temperature. To neutralize the taste, each evaluating person received hot tea, without sugar between the assessments of consecutive samples. The sensory analysis was conducted at the Chair of Catering Technology and Food Hygiene, WULS-SGGW, Warsaw, Poland.

The sensory quality of meat after heat treatment was determined with the sensory scaling method, using an unstructured scale (0-10 c.u.) with precisely defined anchoring points [PN--ISO 4121;1998]. The marks of anchoring points of the tested attributes were as follows for most of the attributes: no intensity – high intensity, for tenderness (tough – tender) and juiciness (dry – juicy). On the basis of the above mentioned quality characteristics, the assessing sensory panel indicated an overall sensory quality (low – high) for each sample on a separate scale. Conditions and the way of estimation were established according to Meilgaard *et al.* [1999].

The sensory panel consisted of 10 members who were appropriately prepared theoretically and practically for the sensory method applied in this experiment. The panellist had 4-year experience in the evaluation of pork meat. The sensory panel made evaluation in duplicate – so that each mean result was based on 20 individual measurements.

Specimens for the microstructure analysis were taken from 24 samples of cooked meat, characterised by different pH values. Every photo was taken on cross section of muscle fibres, cut with a scalpel. The specimens were moved onto cooling tables (temperature 1°C) and put into a microscope chamber. The research was conducted in vacuum (1 Tr), with constant humidity (20% of relative humidity), which prevented specimens from drying up. Microstructure photo for every one sample was done in triplicate, on different surfaces. Microstructure photos of *Longissimus* muscle, cut perpendicularly to muscle fibres, after heat treatment, were taken using an XL30 ESEM type scanning microscope with 300x magnification. The histological estimation of the microstructure of meat included measurements of diameter of fibres and space between them and total count of fibres on 1 mm^2 area, that was so-called "packing up" the fibres. This research was done at the Accredited Analytical Centre of the Warsaw University of Life Sciences (SGGW, Warsaw, Poland).

Relationships between the microstructure and technological value and sensory quality of meat were expressed as simple and canonical correlation coefficients. The results obtained were elaborated with the Statistica 6.0 PL software package.

RESULTS AND DISCUSSION

The fatteners studied were characterised by relatively high meatiness. Similar results for the analogous genetic material were obtained in a study by Kortz *et al.* [2002]. In the tested group, it was observed that 4% of the fatteners were characterised by acid and PSE meat. Moreover, notable differentiation were observed in the range of hot carcass weight (average 87.52±7.3), colour of meat and also in cooking yield (average 73.27±3.92), (Table 1).

TABLE 1. The characteristics of technological and sensory quality and microstructure of meat of studied group of fatteners.

Quality traits of meat		$\bar{X}$±SD	Min-max values
Technological quality traits (n=40)			
Hot carcass weight (kg)		87.52±7.30	62.00-101.60
Meatiness (%)		57.25±3.04	52.00-61.80
pH_1		6.45±0.26	5.80-6.90
pH_3		6.16±0.22	5.52-6.58
pH_{24}		5.60±0.12	5.34-5.78
Colour parameters in CIE system	L_{48}	54.89±2.60	51.31-64.06
	a_{48}	15.44±1.52	12.20-17.64
	b_{48}	6.52±1.98	3.53-10.34
Natural drip loss (%)		3.86±1.39	1.21-6.85
Cooking yield (%)		73.27±3.92	67.30-80.95
Microstructure of meat (n=24)			
Number of fibres on 1 mm^2		224.96±45.99	151.50-336.50
Diameter of fibres (μm)		46.97±9.42	33.46-73.16
Spaces between fibres (μm)		18.18±3.20	11.02-24.89
Sensory quality of meat (10 c.u.) (n=24)			
Results of meat sensory quality after heat treatment (0-10 c.u.)	Odour	7.82±0.28	7.36-8.38
	Hue of colour	8.36±0.46	7.41-9.18
	Homogeneity of colour	8.14±0.42	7.48-8.87
	Flavour	7.07±0.83	5.35-8.49
	Tenderness	6.62±1.63	2.55-9.04
	Juiciness	5.33±1.45	2.87-7.59
	Fat perception	2.28±0.43	1.43-3.37
	Overall quality	6.56±0.98	4.42-8.49

$\bar{X}$ – mean values, ±SD – standard deviation.

The analysis of the microstructure of pork meat after heat treatment indicated that the samples studied differed significantly in the number of fibres in 1 mm^2 (the so-called "packing up"). The number of fibres in 1 mm^2 was between 151 and 336, which confirmed a large variability of this feature (average 225 fibres/mm^2), (Table 1). Similar results were shown in a research by Bogucka [2006].

Moreover, in this study a significant variability was stated in relation to muscle fibre diameter. The diameters approximated from 33.5 μm up to 73.16 μm (average 46.97 μm), (Table 1). Szczepańska [2007] claimed that the number of fibres in 1 mm^2 of pork after heat treatment (cooking, steaming) reached 120-226 (average 201) and fibres diameters were in the range from 30 to 100 μm. Smaller diameters of meat fibres and lower variability in those were observed in the case of meat after treatment in water medium.

Bertram *et al.* [2007] indicated that parameters of muscle fibres were characterize by high variability. Krzęcio *et al*. [2003] and Fernandez *et al*. [1999] observed that the increasing of meatiness of pork meat led to a decreasing quantity and quality of fat. In the above-mentioned studies it was stated that fatteners with high meatiness were characterised by thicker muscle fibres occurring in a lower number. Klont *et al.* [2001] confirmed that the number of fibres in 1 mm^2 was correlated with growth rate of animals; the faster growth the higher number of thinner fibres was observed. The total number of muscle fibres was higher related to muscle weight than diameter of fibres. In this study, the spaces between fibres were also measured and ranged from 11.02 to 24.89 μm (Table 1).

Results of the sensory analysis show a large variability of meat quality in relation to tenderness and juiciness (Table 1). It was stated that tenderness, juiciness and flavour were determined by the following technological quality traits: pH_{24}, meat colour, cooking yield and natural drip loss (Table 2). The results obtained indicated that meat with higher ultimate pH was characterised by a higher sensory quality. It was observed that CY was positively related to sensory quality and that high ultimate pH influenced the sensory quality of meat; especially tenderness, juiciness, flavour and the overall quality of meat. The level of drip loss was negatively correlated with juiciness and overall quality. Similar results were obtained by Przybylski *et al.* [2007a].

According to Szczepańska [2007], the number of muscle fibres and their diameters have a significant influence on tenderness of meat. The author observed that meat with fibres with small diameter was characterised as more juicy and tender. Therefore, tenderness and juiciness of meat depended on two factors related to meat structure, *i.e.* quantity and thickness of connective tissue and thickness of fibres. Moreover, Bertram *et al.* [2007] claimed also that age and weight of slaughtered animals affected the quality of meat and determined muscle structure.

The relationships between microstructure and parameters which characterised the quality of meat were expressed as simple and canonical correlation coefficients. The analysis of the results obtained for simple correlation coefficients indicated that the relationships between the selected traits describing the technological and sensory quality and microstructure of muscle fibres were generally low and not statistically significant.

Similar results were obtained by a study by Szczepańska [2007], in which no significant and visible effect was observed between the microstructure and technological value and sensory quality of meat. However, the author indicated that in the case of samples of pale meat (PSE and ASE types), characterised by higher cooking loss, the "packing up" of fibres 193/mm^2 and numerous free spaces between fibres were observed. These findings are consistent with results obtained in this study concerning ultimate pH, meat colour, natural drip loss, cooking yield and sensory quality (Table 2). However in this work, a statistically significant and negative relationship (r=-0.42) (not presented in the table) was observed between meatiness and number of fibres, which is compatible with the results of Bertram *et al.* [2007] who found a highly significant negative correlation between the number of fibres and their diameter (r=-0.73).

Similar relationships were presented in a research by Bogucka [2006], in which a higher growth rate of pigs caused

TABLE 2. The simple correlation coefficients between parameters of technological value and sensory quality of pork meat (n=24).

Technological quality	Simple correlation coefficients							
Parameters	Odour	Hue of colour	Homogeneity of colour	Tenderness	Juiciness	Fat perception	Flavour of meat	Overall quality
Hot carcass weight	-0.12	-0.08	-0.08	-0.35	-0.28	0.16	-0.33	-0.45*
Meatiness	0.15	0.05	-0.11	-0.22	-0.38	-0.37	-0.54*	-0.20*
pH_1	0.15	0.24	0.16	0.14	0.40	0.25	0.24*	0.25
pH_3	-0.03	0.00	-0.16	0.11	0.22	0.26	0.07	0.08
pH_{24}	0.12	0.11	-0.02	0.43*	0.59*	0.09	0.45	0.50*
Colour parameters								
L*	0.01	0.48*	0.45*	-0.01	-0.17	0.10	-0.26	-0.08
a*	-0.35	-0.39	-0.30	-0.46*	-0.47*	-0.31	-0.34	-0.45
b*	-0.04	0.07	0.05	-0.23	-0.45*	-0.06	-0.57*	-0.29
Cooking yield	0.27	0.06	-0.02	0.65*	0.74*	0.38	0.49*	0.64*
Natural drip loss	-0.30	-0.26	-0.27	-0.35	-0.48*	-0.10	-0.41*	-0.52*

* – coefficient statistically significantly at p≤0.05.

TABLE 3. Canonical correlation and determination coefficients between sets characterising technological and sensory quality and microstructure.

Explanatory variable set	Explanation variable set	C_R	$C_R^2 \times 100\%$
Hot carcass weight, meatiness, pH_{24}, colour parameters in L*a*b* system, cooking yield, natural drip loss	Sensory quality attributes: odour, ton and homogeneity of colour, tenderness, juiciness, fat perception, flavour, overall quality	0.97**	94.01
Microstructure characteristic (number and diameter of muscle fibres, spaces between fibres)	Sensory quality attributes: odour, ton and homogeneity of colour, tenderness, juiciness, fat perception, flavour, overall quality	0.87*	75.64
Hot carcass weight, meatiness, pH_{24}, colour parameters in L*a*b* system, cooking yield, natural drip loss	Microstructure characteristic (number and diameter of muscle fibres, spaces between fibres)	0.91*	83.72

* – coefficient statistically significant at $p \leq 0.05$, ** coefficient statistically significant at $p \leq 0.01$.

the formation of thicker muscle fibres. The author indicated that the histological structure of muscle had an effect on selected quality traits of raw meat, but the calculated correlation was not statistically significant. In turn, Klont *et al.* [1993] claimed that meatiness was related to a greater diameter of meat muscle fibres.

Table 3 shows a simultaneous relationship of technological parameters, sensory quality of meat and microstructure characteristic of muscle fibres after heat treatment using the canonical analysis.

The obtained canonical correlation coefficients indicated a significant relationship between sets of the traits analysed (Table 3). The sensory quality of cooked meat was shown to be highly related to slaughter and technological value (*i.e.* weight of carcass, meatiness, pH_{24}, meat colour, natural drip loss and cooking yield). The calculated canonical correlation coefficient accounted for C_R=0.97 and determination coefficient for C_R^2= 0.94. Similar results were obtained by Przybylski *et al.* [2007a,b].

The coefficients of correlation between the sensory quality and microstructure traits, *i.e.* the number and diameter of muscle fibres and spaces between fibres, were C_R=0.87 and $C_R^2 \times 100\%$=75.64%. A significant relationship was also shown between the technological quality traits and microstructure of pork meat (Table 3).

The results obtained in this study indicated that although the effect of microstructure characteristics on the technological and sensory quality described by simple correlation coefficients was not statistically significant, but considering the simultaneous relationship of technological parameters, sensory quality of meat and microstructure characteristics of muscle fibres after heat treatment using the canonical analysis the significant relationship was stated. The results obtained were consistent with findings of Szczepańska [2007], who demonstrated that the technological value of meat derived from crossing high-meatiness breeds affected the histological structure of muscle and the sensory quality of meat after heat treatment. Therefore, the improvement of meatiness and quality of pork meat is very important. It should meet consumers expectations in respect of culinary meat and – on the other hand – expectations of producers and processors in relation to its usefulness for processing.

CONCLUSIONS

1. The simple correlation coefficients calculated between the measured microstructure parameters and technological value traits and sensory quality attributes indicated that the sensory quality of pork meat was related to meatiness and technological value of pork meat. In the case of a microstructure parameter – number of muscle fibres – it was significantly correlated to meatiness (r=-0.42; p<0.05).

2. The sensory quality of meat was determined both by meatiness and technological traits (94%); the highest relationships were observed in the case of meatiness, ultimate pH, drip loss and CY. These parameters could be a diagnostic value in the evaluation of meat quality.

3. The microstructure of meat was highly correlated with the sensory quality of meat (76%) even though the lack of simple relationship was observed. It can be stated that the microstructure of meat was determined in 84% by the technological value of pork meat that showed changes in meat tissue after slaughter.

REFERENCES

1. Baryłko-Pikielna N., Kossakowska T., Baldwin Z., The choice of optimal metod of beef and pork meat preparation for sensory analysis. Rocz. Inst. Przem. Mięsn. Tł., 1964, 1, 111 (in Polish).
2. Bertram H.C., Straadt I.K., Jensen J.A., Aaslyng M.D., Relationship between water mobility and distribution and sensory attributes in pork slaughtered at an age between 90 and 180 days. Meat Sci., 2007, 77, 190 -195.
3. Bogucka J., Relationship between microstructure of muscle tissue and fatten and slaughter usefulness traits, and quality of meat pigs. Acta Scientiarum Polonorum-Zootechnica, 2006, 5, 3–12 (in Polish; English abstract).
4. Borzuta K., Studies on usefulness of different methods of meatiness evaluation for the classification of porcine carcasses in the EUROP system. Rocz. Inst. Przem. Mięsn. Tł., 1998, 35, 2, 1–84 (in Polish).
5. Channon H.A., Kerr M.G., Walker P.J., Effect of Duroc content, sex and ageing period on meat and eating attributes of pork lion. Meat Sci., 2004, 66, 881–888.
6. De Vries A.G., Van der Wal P.G., Long T., Eikeleboom G.., Merks J.W.M., Genetic parameters of pork quality and production traits in Yorkshire population. Livestock Production Science, 1994, 40, 277–289.
7. Fernandez X., Monin G., Talmant A., Mourot J., Lebret B., Influence of intramuscular FAT content on the quality of pig meat – 2.- Consumer acceptability of m. longissimus lumborum. Meat Sci., 1999, 53, 67–72.
8. Fischer K., Drip loss in pork – Influence factors and relation to other meat quality traits. 2005, *in:* Materials of the Workshop:

Drip loss and water holding capacity of porcine meat. 5–6 December 2005, University of Bonn, Germany, pp. 5–6.
9. Fortin A., Robertson W.M., Tong A.K.W., The eating quality of Canadian pork and its relationship with intramuscular fat. Meat Sci., 2005, 51, 59–63.
10. Jaworska D., Przybylski W., Czarniecka-Skubina E., Wachowicz I., Sensory quality of pork meat from fatteners of various meatiness. Rocz. Inst. Przem. Mięs. Tł., 2007, 45, 51–60 (in Polish; English abstract).
11. Klont R.E., Lamboy E., Van Logtestijn J.G., Effect of preslaughter anesthesia on muscle metabolism and meat quality of pigs of different halothane genotypes. J. Anim. Sci., 1993, 71, 1477––1485.
12. Klont R.E., Hulsegge B., Hoving-Bolink A.H., Gerritzen M.A., Kurt E., Winkelman-Goedhart H.A., de Jong I.C., Kranen R.W., Relationships between behavioral and meat quality characteristics of pigs raised under barren and enriched housing conditions. J. Anim. Sci., 2001, 79, 2835–2843.
13. Koćwin-Podsiadła M., Genetic and nutritional factors modifying the quality of pork. 1998, *in:* Seminar series „Związki Nauki z Praktyką". Polagra, vol. 6, pp. 173–216 (in Polish).
14. Koćwin-Podsiadła M., Krzęcio E, Kurył J., Pospiech E., Gryeð B., Yzbert A., Sieczkowska H., Antosik K., Łuczyński, I., Influence of polymorphic forms of chosen genes on meatiness and physico-chemical properties and functional muscle tissue. (ed. M. Świtoński). 2004, Wyd. AR Poznań, pp. 259–329 (in Polish).
15. Koćwin-Podsiadła M., Krzęcio E., Przybylski W., Pork quality and methods of its evaluation – a review. Pol. J. Food Nutr. Sci., 2006, 15/56, 3, 241–248.
16. Kortz J., Rybarczyk A., Karamucki T., Gardzielewska J., Jakubowska M., Natalczyk-Szymkowska W., Characteristic of quality of pork meat originated from carcass based on the classification of porcine carcasses in the EUROP based on the meatiness measured by ULTRA-FOM or dissection method. Studies on usefulness of different methods of meatiness evaluation. Prace i Materiały Zootechniczne, Zeszyt Specjalny, 2002, 13, 77–83 (in Polish).
17. Krzęcio E., Sieczkowska H., Zybert A., Antosik K., Przybylski W., Koćwin-Podsiadła M., Quality of raw material of two-breed fatteners originating from crossing of imported breeds. Ann. Anim. Sci., 2003, Suppl., 1, 65–69.
18. Meilgaard M., Civille G.V., Carr B.T., Sensory Evaluation Techniques. 1999, 3rd ed, Boca Raton, CRC Press.
19. Polish Standard PN-ISO 4121:1998. Sensory analysis. Evaluation of food products using scaling methods (in Polish).
20. Prange H., Juggrt L., Scharner E., Untersuchungen zur Muscel Fleischqualitaet beim Schwein. Arch. Experim. Veter. Medizin, 1977, 30, 235–248.
21. Przybylski W., Jaworska D., Czarniecka-Skubina E., Półtorak A., Analysis of conditionality of sensory quality longissimuss lumborum muscle after heat treatment. E. J. Polish Agric. Univ., 2007a, 10, 4.
22. Przybylski W., Jaworska D., Czarniecka-Skubina E., Kajak-Siemaszko K., Wachowicz I., Using multidimensional analysis in the evaluation of technological value and sensory quality of pork meat. Pol. J. Food Nutr. Sci., 2007b, 57, 4(B), 449–455.
23. Sellier P, Monin G., Genetics of pig meat quality, a review. J. Muscle Foods, 1994, 5, 189–219.
24. Szczepańska A., Factors Conditioning Consumer Preferences and Sensory Quality of Culinary Pork Meat. 2007, Warsaw University of Life Sciences,, Warszawa, pp. 134–138 (in Polish).
25. Tornberg E., Biophysical aspects of meat tenderness. Meat Sci., 1996, 43, 175–191.

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