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ORIGINAL PAPER

A comparison of the nutritional value, technological and sensory properties of pork loin and ham and their changes during freezer storage*

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Abstract

The aim of this study was to compare the nutritional value, technological and sensory properties of pork loin and ham, and their changes during freezer storage. After slaughter and post-slaughter processing in the Warmia Meat Processing Plant in Biskupiec, carcasses were chilled at a temperature of 2-4°C for 24 h. Samples of loin (*longissimus dorsi* muscle, LD) and ham (*semimembranosus* muscle, SM) were collected from right half-carcasses. Loin and ham samples were divided into three portions. The first portion (fresh meat) was analyzed immediately, and the second and third portions were frozen and stored at a temperature of -18°C for one month and three months, respectively. Samples of fresh and stored meat were analyzed to determine their chemical composition, active acidity, water-holding capacity (WHC), emulsifying capacity, and color (CIE L*, a*, b* color space). The values of chroma (C*) and hue angle (h°) were calculated based on the values of color parameters a* and b*. Steam-cooked samples were analyzed to determine cooking loss and sensory attributes. The content of dry matter (DM) and fat was higher, and the protein concentration was lower in ham than in loin. The chemical composition of loin and ham, in particular DM content, was also affected by freezer storage. The pH values of both muscles were comparable, which points to the high quality of the analyzed meat, and they decreased in both loin and ham during freezer storage. Changes in active acidity observed in frozen loin and ham were reflected in the functional properties of meat. The emulsifying capacity increased and the WHC decreased, which resulted in greater cooking loss. An analysis of fresh meat samples revealed that loin was characterized by lower WHC and higher cooking loss than ham. Ham was darker in color than loin, and color lightness decreased in both loin and ham with prolonged freezer storage. The storage of frozen meat had a positive influence on its sensory attributes. Meat samples stored in a freezer for three months received the highest scores in the sensory analysis, and loin scored somewhat higher than ham.

Keywords: loin, ham, freezer storage time, nutritional value, technological and sensory properties

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INTRODUCTION

Pork quality is determined by various factors, including the diet, breed, sex and type of pigs (Sobotka et. al. 2012, Przybylski et al. 2012, Śmiecińska et. al. 2021, Karpiesiuk et al. 2023). The nutritional value, sensory attributes, technological properties, and safety of meat are important quality characteristics for both producers and consumers (Kajak et al. 2007, Daszkiewicz 2022). Various methods are used to preserve meat and retain its high quality by protecting the raw materials against the adverse effects of chemical, physical, and biological factors. Freezing is one of the most common methods of meat preservation (Kozłowicz et al. 2016), preferred by processing plants, wholesalers, retailers, and consumers (Lagerstedt et al. 2008, Muela et al. 2015). It should be noted that both the freezing process and further storage at sub-zero temperatures not only preserve the raw material, but also directly affect selected technological and sensory properties of meat (Leygonie et al. 2012, Tereszkiewicz et al. 2018). Changes are observed in the pH value, color, and water-holding capacity (WHC) of meat. The dry matter (DM) content and tenderness of meat increase. Cooking loss and the gelling ability of muscle proteins also change after heat treatment (Leygonie et al. 2012, Muela et al. 2015). Meat should always be frozen as fast as possible, and the temperature in the freezer will depend on the size of the cut. Optimal freezing and frozen storage parameters may also vary depending on the type of meat and the intended storage period (PN-A-07005:2006). According to the literature, frozen meat can be stored over a wide range of temperatures, from -18°C to – 55°C (Zhou et al. 2010, Leygonie et al. 2012), and -40°C is considered to be optimal (Kozłowicz et al. 2006). Frozen meat should be stored for a limited period of time due to the risk of undesirable microbiological and enzymatic changes. In addition, lipids contained in meat undergo oxidative and hydrolytic processes, and protein denaturation and enzyme inactivation may occur during long-term frozen storage of meat.

The aim of this study was to compare the nutritional value, technological and sensory properties of pork loin (*longissimus dorsi* muscle, LD) and ham (*semimembranosus* muscle, SM), and their changes during freezer storage.

MATERIALS AND METHODS

The experiment was granted Approval no 23/2013 issued by the Animal Ethics Committee, the University of Warmia and Mazury in Olsztyn.

The experimental materials comprised meat samples collected from the carcasses of 30 crossbred fattening pigs (♀ Polish Large White x Polish Landrace) x ♂ Duroc of similar body weight (approx. 115 kg), raised on a farm administered by the Department of Animal Nutrition, Feed Science and Cattle Breeding. The experimental design is presented in Table 1.

Table 1

Experimental design

<table>
<tr><td rowspan="5">Specification</td><td colspan="6">Experimental group</td></tr>
<tr><td colspan="6">Muscle type (M)</td></tr>
<tr><td colspan="3">longissimus dorsi (LD)
loin</td><td colspan="3">semimembranosus (SM)
ham</td></tr>
<tr><td colspan="6">Storage time (T)</td></tr>
<tr><td>fresh meat</td><td>1 month</td><td>3 months</td><td>fresh meat</td><td>1 month</td><td>3 months</td></tr>
<tr><td colspan="7">Analyzed parameters</td></tr>
<tr><td>Number of meat samples (n)</td><td>30</td><td>30</td><td>30</td><td>30</td><td>30</td><td>30</td></tr>
<tr><td>Chemical composition of loin and ham</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td></tr>
<tr><td>Technological properties of fresh meat</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td></tr>
<tr><td>Technological and sensory properties of cooked meat</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td><td>+</td></tr>
</table>

+/ analyses performed in the study

The animals were housed individually in metabolism crates, and were fed diets for two-phase fattening, whose composition is specified in Table 2. Feed in a friable form (feed/water ratio of 1:1) was administered twice daily at 7^{00} a.m. and 2^{00} p.m. Pigs had free access to water. The nutritional value of complete feed diets is presented in Table 2.

After slaughter and post-slaughter processing in the Warmia Meat Processing Plant in Biskupiec, carcasses were chilled at a temp. of 2-4°C for 24 h. Samples of loin (LD muscle) and ham (SM muscle) were collected for analyses from right half-carcasses (Table 1). Adequately protected samples were delivered to the Department of Food Microbiology, Meat Technology and Chemistry. Loin and ham samples were divided into three portions. The first portion (fresh meat) was analyzed immediately, and the second and third portions were frozen and stored at a temp. of -18°C for one month and three months, respectively. After the respective freezer-storage periods, meat samples were thawed by the conventional method, under refrigerated conditions (4°C), for 24 h. Samples of fresh and stored meat were analyzed to determine their proximate chemical composition – by AOAC methods (2007), emulsifying capacity – as described by Świderski (1989), active acidity (pH) – with a Radiometer pH-meter and the PHC 4406 electrode, WHC – by the Grau and Hamm method modified by van Oeckel et al. (1999), and color – by the reflectance method in the CIE L*, a*, b* color space with a Minolta CR-400 chroma meter. The values of chroma (C*) and hue angle (h°) were calculated based on the values of color parameters a* and b* using the following equations (Mordenti et al. 2012): $C=[(a^*)^2 + (b^*)^2]^{0.5}$, $h°=b^*/a^*$.

Table 2

Composition and nutritive value of diets for growing-finishing pigs

Specification	2-phase feeding system	
	complete diets	
	Grower from 30-70 kg body weight	Finisher from 70 to 115 kg body weight
Ground wheat (%)	40.00	40.00
Ground barley (%)	37.75	42.08
Extraction soybean meal (%)	13.00	6.50
Extraction rapeseed meal ,,00" (%)	5.00	8.00
Rapeseed oil (%)	1.00	1.00
Mineral feed + premix (%) *	3.00	2.20
L-lysine HCL- 78% (%)	0.25	0.22
Nutritional value of experimental mixtures		
Crude protein (%) **	17.15	14.85
Total lysine (%) ***	0.99	0.79
Total methionine with cysteine (%) ***	0.73	0.62
Total threonine (%) ***	0.64	0.51
Total tryptophan (%) ***	0.22	0.18
Crude fiber (%) **	4.41	4.94
Metabolizable energy (MJ/kg^{-1})***	13.11	13.15

* limestone (1.0 /0.7); dicalcium phosphate (0.7/0.5); salt (0.3/0.3); mineral vitamin premix (1.0/0.7);
** values was determined according to standard methods (AOAC 2007);
*** values calculated on the basis of own research data Sobotka, Drażbo (2019) and data from the Nutrient Requirement of Pigs (2014).

The meat was heat-treated with hot steam at 100°C in a BECK FCV 4EDS (Germany) combi oven until it reached 75°C inside the product. Sensory attributes of the meat, including flavor, aroma, color and texture, were evaluated on a five-point scale. The evaluation was carried out by a 10-member team, whose members were screened for individual sensory sensitivity and trained in food sensory analysis. The tests were conducted in accordance with normative requirements, in a properly equipped sensory analysis laboratory (PN-ISO 4121:1998; PN-ISO 6658:1998; PN-EN ISO 8589:2010/A1:2014-07).

The results were processed statistically by two-way multivariate analysis of variance (MANOVA) for orthogonal designs with the use of Statistica 13.0 PL software (2017). The significance of differences between mean values in groups was determined by the Duncan's multiple range test at a significance level of $p \leq 0.05$ and $p \leq 0.01$

RESULTS AND DISCUSSION

The chemical composition of loin (LD muscle) and ham (SM muscle) depending on muscle type (M) and storage time (T) is presented in Table 3.

Table 3

Chemical composition of pork loin (*longissimus dorsi* muscle, LD) and ham (*semimembranosus* muscle, SM)

Specification	Stat. me-saure	Experimental factor					SEM	Significance level $p\leq$		
		muscle type (M)		storage time (T)				M	T	MxT interac-tion
		LD loin	SM ham	fresh meat	1 month	3 months				
Dry matter (%)	x	25.32	25.64	25.45	26.42	27.78	0.113	ns	*	ns
Ash (%)	x	1.14	1.18	1.16	1.10	1.09	0.007	ns	*	*
Protein (%)	x	21.04	20.05	20.62	20.84	20.85	0.073	*	ns	ns
Fat (%)	x	2.98	3.83	3.34	3.45	3.43	0.062	**	ns	ns

Explanation: M – muscle type, T – storage time, x – arithmetic mean, * mean values given in the table rows differ significantly at $p\leq0.05$, ** mean values given in the table rows differ significantly at $p\leq0.01$, ns – not significant

Differences were found in the chemical composition of the analyzed muscles. The content of DM (25.64%) and fat (3.83%) was higher, and protein concentration (20.05%) was lower in ham than in loin, but the noted differences were not significant ($p<0.05$). An analysis of the chemical composition of loin and ham revealed that DM content increased significantly ($p<0.05$) with prolonged freezer storage. The average DM content of fresh meat was 25.45%, and it increased to 26.42% and 27.78% after one month and three months of freezer storage, respectively. The ash content of loin and ham was also significantly ($p<0.05$) affected by storage time, and it ranged from 1.16% in fresh meat to 1.09% in frozen meat stored for three months. The content of protein and fat in meat increased during freezer storage, and the greatest change was noted after one month, but the observed differences were not significant. The protein content ranged from 20.62% in fresh meat to 20.85% in frozen meat stored for three months, and fat content ranged from 3.34% in fresh meat to 3.45% in frozen meat stored for one month. According to Farouk and Wieliczko (2003), and Domaradzki et al. (2011), the nutritional value of meat is determined mainly by its proximate chemical composition, which in turn is affected by both pre-slaughter and post-slaughter factors. The proximate chemical composition of meat may also vary depending on the applied preservation methods and changes induced by freezer storage. In the present study, the DM content of meat (i.e., its chemical composition) was significantly influenced by the time of freezer storage.

The quality of fresh and stored meat can be described with the use of various indicators (Wereńska, Okruszek 2023, Zhang et al. 2023). One of the key quality parameters is active acidity, which reflects postmortem muscle glycolysis (Chwastowska, Kondratowicz 2007, Domaradzki et al. 2012, Przybylski et al. 2012). Faoruk and Wieliczko (2003), Zhang et. al. (2021) demonstrated that after postmortem aging, changes in meat pH during prolonged storage could be due to the release of free amino acids and peptides during proteolysis. The technological properties of meat, examined in this study, are also affected by active acidity (Florek et al. 2004, Przybylski et al. 2012). They include color, one of the first quality parameters evaluated by consumers.

An analysis of the color parameters of loin and ham (Table 4) revealed that muscle type (M) affected the color of fresh meat. Ham was darker in color than loin. Highly significant differences were found between the color parameters of ham: L*(40.06), a*(11.78), C*(12.20) and loin: L*(46.21), a*(8.56), C*(9.17). Muscle type had no significant effect on the values of b*, which reached 3.29 in loin and 3.22 in ham. Greater differences were observed in the values of hue angle (h°), which were determined at 0.38 in loin and 0.27 in ham. A comparison of the color parameters of the analyzed muscles (Table 4) revealed that both loin and ham became darker in color with prolonged freezer storage (T), as shown by the values of L* ($p<0.05$) which decreased from 43.44 in fresh meat to 42.74 and 41.23 in frozen meat stored for one month and three months, respectively. The opposite trend was noted in the values of color parameters a* (redness) and b*

Table 4

Selected technological properties of pork loin (*longissimus dorsi* muscle, LD) and ham (*semimembranosus* muscle, SM)

Specification		Stat. measure	Experimental factor					SEM	Significance level $p\leq$		
			muscle type (M)		storage time (T)				M	T	MxT interaction
			LD loin	SM ham	fresh meat	1 month	3 months				
Meat color	L*	x	46.21	40.06	43.44	42.74	41.23	0.34	**	*	*
	a*	x	8.56	11.78	10.26	11.29	11.65	0.18	**	*	*
	b*	x	3.29	3.22	3.26	3.45	3.54	0.15	ns	*	ns
	C*	x	9.17	12.20	10.76	11.81	12.17	0.26	**	**	**
	h°	x	0.38	0.27	0.31	0.31	0.30	0.08	**	ns	ns
pH		x	6.03	6.02	6.03	5.83	5.69	0.17	ns	**	ns
Water-holding capacity (cm^2)		x	6.45	5.21	5.83	6.39	6.75	16.45	**	**	**
Emulsifying capacity (%) [cm^3 oil 0.1 g^{-1}]		x	78.64	82.41	80.65	81.28	82.12	0.46	**	*	**
Cooking loss (%)		x	31.55	29.47	30.51	33.33	35.32	0.32	**	**	**

Explanation: x – arithmetic mean, M – muscle type, T – storage time, * mean values given in the table rows differ significantly at $p\leq0.05$, ** mean values given in the table rows differ significantly at $p\leq0.01$, ns – not significant (yellowness). In both loin and ham, the value of a* was significantly (p<0.05) lower in fresh meat than in frozen meat (10.26 vs. 11.29-11.65), and the value of b* increased significantly (p<0.05) from 3.26 in fresh meat to 3.45-3.54 in frozen meat.

The value of chroma (C*), calculated based on the values of a* and b*, also changed during freezer storage. The value of this parameter was highly significantly lower in fresh meat (10.76) than in frozen meat stored for one month and three months (11.81 and 12.17, respectively). The value of hue angle (h°) remained relatively unchanged (0.31 in fresh meat, 0.31 after one month of freezer storage, 0.30 after three months of freezer storage).

The pH of both analyzed muscles (M) was comparable (6.03 in loin and 6.02 in ham), which points to the high quality of meat (Table 4). The value of this parameter decreased highly significantly in both loin and ham during freezer storage (T), to 5.83 and 5.69 after one month and three months of storage, respectively. The rate of changes in pH was faster in the first month and slower in the two subsequent months.

The functional properties of meat are affected by changes in pH values. The present study demonstrated that muscle type (M) had a highly significant effect on WHC (Table 4), which was higher in loin than in ham (6.45 cm^2 vs. 5.21 cm^2). The WHC of both loin and ham increased highly significantly (p<0.01) during storage (T), from 5.83 cm^2 in fresh meat to 6.75 cm^2 in frozen meat stored for three months.

Meat becomes darker in color, and the value of lightness (L*) decreases with increasing pH values and prolonged freezer storage, which was also noted in this study. Similar observations were made by Wereńska and Okruszek (2023), who also found that meat color was altered by freezer burn. The correlation between the pH and color of meat has been described in the literature (Florek et al. 2004, Kajak et al. 2007, Song et al. 2021). The cited authors demonstrated that a decrease in pH induced changes in color and decreased the WHC of meat. The present study confirmed the above relationships and revealed that the WHC of meat was directly related to cooking loss. The values of both parameters and their changes in pork stored in the freezer are consistent with those reported by other authors investigating pork, horsemeat, and beef (Orzechowska et al. 2010, Domaradzki et al. 2011, Stanisławczyk, Rudy 2017, Stanisławczyk et al. 2021).

The WHC of meat is reflected in cooking loss. In the current study (Table 4), loin was characterized by highly significantly (p<0.01) higher cooking loss than ham (31.55% vs. 29.47%). Cooking loss increased (p<0.01) with prolonged freezer storage (T) in both loin and ham, from 30.51% (fresh meat) to 35.32% (frozen meat stored for three months).

Emulsifying capacity was another technological property of meat examined in this study (Table 3). The value of this parameter was highly significantly (p<0.01) higher in ham (82.41 cm^3 oil 0.1 g^{-1}) than in loin (78.64 cm^3 oil 0.1 g^{-1}). The emulsifying capacity of both loin and ham increased highly significantly (p<0.01) during freezer storage (T), from 80.65 cm^3 oil 0.1 g^{-1} in fresh meat to 82.12 cm^3 oil 0.1 g^{-1} in frozen meat stored for three months. Previous research has shown that the emulsifying capacity and pH of meat are closely correlated (Qiao et al. 2001, Chan et al. 2011, Hemung et al., 2013). The values of emulsifying capacity reported by the cited authors are similar to those determined in this study, but the reported results are somewhat different from the present findings. In the above studies, an increase in pH was accompanied by a decrease in emulsifying capacity. However, it should be noted that previous experiments involved protein extracts obtained from meat with different pH levels, whereas meat samples were analyzed in this study.

The sensory attributes of meat are important indicators of quality for both consumers and producers. The analyzed samples of loin and ham received high scores for sensory properties (Table 5). Loin scored somewhat higher than ham in terms of taste, aroma, color, and consistency, but the

Table 5

Sensory properties of cooked pork loin (*longissimus dorsi* muscle, LD) and ham (*semimembranosus* muscle, SM)

Specification	Stat. mea-sure	Experimental factor					SEM	Significance level $p\leq$		
		muscle type (M)		storage time (T)				M	T	MxT interaction
		LD loin	SM ham	fresh meat	1 month	3 months				
Taste [points]	x	3.95	3.79	3.87	3.93	4.03	0.04	ns	ns	ns
Aroma [points]	x	3.89	3.73	3.81	3.86	3.92	0.03	ns	ns	ns
Color [points]	x	3.91	3.88	3.89	3.89	3.91	0.03	ns	ns	ns
Consistency [points]	x	3.88	3.79	3.82	3.83	4.03	0.04	ns	*	ns
Overall score [points]	x	3.85	3.80	3.83	3.88	4.00	0.04	ns	*	ns

Explanation: M – muscle type, T – storage time, x – arithmetic mean, * mean values given in the table rows differ significantly at $p\leq0.05$, ** mean values given in the table rows differ significantly at $p\leq0.01$, ns – not significant

noted differences were not significant. According to research by Kozłowicz et al. (2006), and by Stanisławczyk and Rudy (2017), prolonged freezer storage limits adverse changes in meat lipids, which may compromise the sensory quality of meat. Freezing, storage and thawing affect the water fraction of meat, thus altering its structure and texture.

The observed changes may have negative consequences, but they can also exert positive effects, mostly in terms of meat tenderness. The results of sensory analysis (Table 5) indicate that frozen loin and ham stored for prolonged periods of time scored higher for sensory attributes, and the differences in consistency were significant.

CONCLUSIONS

Differences were found in the chemical composition of the analyzed muscles. Pork loin, compared to ham, was characterized by a slightly higher amount of protein and a slightly lower content of DM and fat. The chemical composition of loin and ham, in particular DM content, was also affected by freezer storage. The pH values of both muscles were comparable, which points to the high quality of the analyzed meat, and they decreased in both loin and ham during freezer storage. Changes in active acidity observed in frozen loin and ham were reflected in the functional properties of meat. The emulsifying capacity increased and WHC decreased, which contributed to greater cooking loss. An analysis of fresh meat samples revealed that loin was characterized by lower WHC and higher cooking loss than ham. Ham was darker in color than loin, and color lightness decreased in both loin and ham with prolonged freezer storage. The storage of frozen meat had a positive influence on its sensory attributes. Meat samples stored in the freezer for three months received the highest scores in the sensory analysis, and loin scored somewhat higher than ham.

Authors' contribution

Conceptualization – W.S. and J.F.P.; methodology – J.F.P. and W.S.; validation – W.S. and J.F.P.; formal analysis – J.F.P. and. W.S.; investigation – W.S. and J.F.P.; resources – W.S and J.F.P.; data curation – W.S. and J.F.P.; writing – original draft preparation – J.F.P. and W.S.; writing – review and editing – J.F.P.; visualization – J.F.P., W.S.; supervision – J.F.P.; project administration – W.S.; funding acquisition – W.S. and J.F.P. All authors have read and agreed to the published version of the manuscript available.

Conflicts of interest

The authors declare no conflict of interest.

REFERENCES

AOAC (2007). 'Official Methods of Analysis 19thed.' Association of Official Analytical Chemists, Washington, DC, USA.

Chan, J.T.Y., Omana, D.A. and Betti, M. (2011) 'Functional and rheological properties of proteins in frozen turkey breast meat with different ultimate pH', *Poultry Science*, 90(5), 1112-1123, available: https://doi.org/10.3382/ps.2010-01185

Chwastowska, I. and Kondratowicz, J. (2007) 'Wpływ warunków zamrażalniczego przechowywania i technologii rozmrażania na jakość mięsa', *Chłodnictwo*, 42(4), 40-44.

Daszkiewicz T. (2022) 'Food production in the context of global developmental challenges', *Agriculture-Basel* 12(6), 1-11, available: https://doi.org/10.3390/agriculture 12060832

Domaradzki, P., Skałecki, P., Florek, M. and Litwińczuk, A. (2011) 'Wpływ przechowywania zamrażalniczego na właściwości fizykochemiczne mięsa wołowego pakowanego próżniowo', Żywność Nauka Technologia Jakość, 4(77), 117-126.

Estévez, M. (2011) 'Protein carbonyls in meat systems: A review', *Meat Science*, 89(3), 259-279, available: https://doi.org/10.1016/j.meatsci.2011.04.025

Farouk, M.M. and Wieliczko, K.J. (2003) 'Optimum time for using chilled beef in gelled products', *Journal of Food Science*, 68 (1), 164-167, available: https://doi.org/10.1111/j.1365-2621.2003.tb14134.x

Florek, M., Litwińczuk, A., Skałecki, P. and Topyła, B. (2004) 'Influence of pH1 of fatteners' Musculus Longissimus lumborum on the changes of its quality', *Polish Journal of Food and Nutrition Sciences*, 13/54(2), 195-198.

Grela, E.R. and Skomiał, J. (2014) 'Zalecenia żywieniowe i wartość pokarmowa pasz dla świń: monografia', Instytut Fizjologii i Żywienia Zwierząt im. Jana Kielanowskiego Polskiej Akademii Nauk.

Hemung, B.O., Benjakul, S. and Yongsawatdigul, J. (2013) 'pH-dependent characteristics of gel -like emulsion stabilized by threadfin bream sarcoplasmic proteins', *Food Hydrocolloids,* 30, 315-322, available: https://doi.org/10.1016/j.foodhyd.2012.05.023

Kajak, K., Przybylski, W., Jaworska, D. and Rosiak, E. (2007) 'Charakterystyka jakości technologicznej, sensorycznej i trwałości mięsa wieprzowego o zróżnicowanej końcowej wartości pH', Żywność Nauka Technologia Jakość*,* 1(50), 26-34.

Karpiesiuk, K., Kozera, W., Daszkiewicz, T., Lipinski, K., Kaliniewicz J., Okorski, A., Pszczółkowska A., Żak, G. and Matusevicius P. (2023) 'The effect of dietary supplementation with guar (Cyamopsistetragonoloba) meal protein on the quality and chemical composition of pig carcasses', *Annals of Animal Science*, 23(4), 1095-1104, available: https://doi.org/10.2478/aoas-2030-0020

Kozłowicz, K., Kluza, F. and Góral, D. (2006) 'Uwarunkowania jakości mięsa zamrażanego i przechowywanego w niskich temperaturach', *Chłodnictwo,* 41(1-2), 60-64.

Kozłowicz, K. (2012) 'Charakterystyka wykorzystania wybranych substancji krioochronnych w zamrażaniu i przechowywaniu żywności', *Acta Scientiarum Polonorum Technica Agraria*, 11(3-4), 13-24

Lagerstedt, Å., Enfält, L., Johansson, L. and Lundström, K. (2008) 'Effect of freezing on sensory quality, shear force and water loss in beef M. longissimus dorsi', *Meat Science*, 80(2), 457-461, available: https://doi.org/10.1016/j.meatsci.2008.01.009.

Leygonie, C., Britz, T.J., and Hoffman, L.C. (2012) 'Impact of freezing and thawing on the quality of meat: A review', *Meat Science*, 91(2), 93-98, available: https://doi.org/10.1016/j.meatsci.2012.01.013

Leygonie, C., Britz, T.J. and Hoffman, L.C. (2012) 'Meat quality comparison between fresh and frozen/thawed ostrich M. iliofibularis', *Meat Science*, 91(3), 364-368, available: https://doi.org/10.1016/j.meatsci.2012.02.020

Mordenti, A.L., Martelli, G., Brogna, N., Nannoni, E., Vignola, G., Zaghini, G. and Sardi, L. (2012) 'Effects of soybean-free diet supplied to Italian heavy pigs on fattening performance, and meat and dry-cured ham quality', *Italian Journal of Animal Science*, 11 (80), 459-465, available: DOI:10.4081/ijas.2012.e80

Muela, E., Monge, P., Sañudo, C., Campo, M.M. and Beltrán, J.A. (2015) 'Meat quality of lamb frozen stored up to 21 months: Instrumental analyses on thawed meat during display', *Meat Science*, 102, 35-40, available: https://doi.org/10.1016/j.meatsci.2014.12.003

PN-ISO 6658:1998. Analiza sensoryczna – Metodologia – Wytyczne ogólne.

PN-ISO 4121:1998. Analiza sensoryczna. Metodyka. Ocena produktów żywnościowych przy użyciu metod skalowania.

PN-EN ISO 8589:2010/A1:2014-07 Analiza sensoryczna. Ogólne wytyczne dotyczące projektowania laboratorium analizy sensorycznej.

PN-A-07005:2006 Produkty żywnościowe – Warunki klimatyczne i okresy przechowywania w chłodniach.

Orzechowska, B., Tyra, M. and Mucha, A. (2010) 'Effect of growth rate on slaughter value and meat quality of pigs', *Roczniki Naukowe Polskiego Towarzystwa Zootechnicznego*, 6(4), 341-351.

Przybylski, W., Jaworska, D., Boruszewska, K., Borejko, M. and Podsiadły, W. (2012) 'Jakość technologiczna i sensoryczna wadliwego mięsa wieprzowego', Żywność Nauka Technologia Jakość, 1(80), 116-127.

Qiao, M., Fletcher, D.L., Smith, D.P. and Northcutt, J.K. (2001) 'The effect of broiler breast meat color on pH, moisture, water-holding capacity and emulsification capacity'. *Poultry Science*, 80(5), 676-680, available: https://doi.org/10.1093/ps/80.5.676

Stanisławczyk, R. and Rudy, M. (2017) 'Zmiany wybranych właściwości fizykochemicznych mięsa i tłuszczu końskiego w czasie przechowywania chłodniczego i zamrażalniczego'. *Nauka Przyroda Technologie*, 11(2), 123-134, available: http://www.npt.up-poznan.net http://dx.doi.org/10.17306/J.NPT.00192

Stanisławczyk, R., Rudy, M. and Rudy, S. (2021) 'The quality of horsemeat and selected methods of improving the properties of this raw material', *Processes* 9(9), 1672; available: https://doi.org/10.3390/pr9091672

Sobotka, W., Pomianowski, J.F. and Wójcik, A. (2012). 'Wpływ zastosowania genetycznie zmodyfikowanej poekstrakcyjnej śruty sojowej oraz poekstrakcyjnej śruty rzepakowej „00" na efekty tuczu, właściwości technologiczne i sensoryczne mięsa świń', Żywność Nauka Technologia Jakość, 1(80), 106-115.

Sobotka, W., Drażbo A. (2020). 'Environmental impacts of diets containing different levels of crude protein and limiting amino acids fed to pigs in a phase feeding system', *Journal of Elementology*, 25(2), 645-655, available: https://doi.10.5601/jelem. 2019.24.4.1926

Song, S., Ahn, C.H., Song, M., and Kim, G.D. (2021). 'Pork loin chop quality and muscle fiber characteristics as affected by the direction of cut', *Foods*, 10(1), 43, available: https:// doi: 10.3390/foods10010043

StatSoft, Inc., (2017) STATISTICA (data analysis software system), version 13.0 PL.

Śmiecińska, K., Sobotka, W. and Fiedorowicz-Szatkowska, E. (2021) 'Carcass and meat quality in growing – finishing pigs fed diets with plant-based protein sources alternative to genetically modified soybean meal', *Agricultural and Food Science*, 30, 146-157, available: https://doi.org/10.23986/afsci.110877

Świderski, F. (1989) 'Technologia przemysłowej produkcji potraw', Wydawnictwa Naukowo-Techniczne, Warszawa, pp. 35-36.

Tereszkiewicz, K., Molenda, P., Choroszy, K. and Pigoń, M. (2018) 'Wpływ warunków przechowywania zamrażalniczego na wybrane parametry jakościowe mięsa drobiowego i wieprzowego', *Autobusy: Technika, Eksploatacja, Systemy Transportowe*, 6, 1137-1140, available: http://doi.org/10.24136/atest.2018.241

Van Oeckel, M.J., Warnants N. and Boucqueé, Ch.V. (1999) 'Comparison of different methods for measuring water holding capacity and juiciness of pork versus on-line screening methods', *Meat Science*, 51(4), 313-320, available: https://doi.org/10.1016/S0309-1740(98)00123-5

Wereńska, M., and Okruszek, A. (2023) 'Impact of frozen storage on some functional properties and sensory evaluation of goose meat'. *Poultry Science* 102, 102894, available: https://doi.org/10.1016/j.psj.2023.102894

Zhang, R., Yoo, M.J.Y., and Farouk, M.M. (2021) 'Oxidative stability, proteolysis, and in vitro digestibility of fresh and long-term frozen stored in-bag dry-aged lean beef', *Food Chemistry* 344, 128601 available: https://doi.org/10.1016/j.foodchem.2020.128601

Zhang, G., Lin, L., Zheng, X., Yang, J., Ma, Z., Chen, Z., Wang, L., Huang, Y.K., Zhang, C., Yang, X., and Dai, J. (2023) 'Effect of storage period on the quality characteristics of frozen beef and mechanisms of change from the corresponding physical and microstructural perspectives', *Journal of Food Measurement and Characterization* 17, 813-823, available: https://doi.org/10.1007/s11694-022-01650-5

Zhou, G.H., Xu, X.L. and Liu, Y. (2010) 'Preservation technologies for fresh meat – A review', *Meat Science*, 86(1), 119-128, available: https://doi.org/10.1016/j.meatsci.2010.04.033