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ORIGINAL PAPER

THE EFFECT OF A FEEDING AND REARING SYSTEM ON THE PHYSICOCHEMICAL PROPERTIES OF PORK*

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Abstract

The quality and chemical composition of pork depends on a number of factors. This study evaluated the quality of meat from pigs kept indoors in litterless pens with and without access to an outdoor run and fed complete diets or complete diets supplemented with alfalfa green forage during the fattening period. Crossbred growing-finishing pigs ♀(♀Polish Landrace x ♂ Polish Large White) x ♂ (♀ Pietrain x ♂ Duroc) were divided into six experimental groups of 15 animals each. Two groups were fed complete diets with an increased metabolizable energy (ME) content. Samples of *musculus longissimus lumborum* were collected from pig carcasses for analyses of proximate chemical composition, physicochemical properties and sensory attributes. The correlations between selected quality attributes of *m. longissimus dorsi* and selected variables were evaluated by cluster analysis. The meat of all experimental pigs was characterized by very high quality, and PSE/DFD quality defects were not noted in any of the examined carcasses. The lowest dry matter content was observed in the meat of pigs fed a complete diet with the addition of alfalfa green forage and kept indoors without access to an outdoor run. Meat samples from all experimental groups received high scores in a sensory analysis, but meat from pigs that were provided access to an outdoor run and were fed a complete diet with a higher ME content was characterized by the lowest flavor and aroma desirability. The highest value of color component a* (0.05) in the CIE Lab system was observed in group 2 relative to groups 5 and 6. The results of color lightness measurements, active acidity measurements and cluster analysis indicate that the quality of meat from all experimental pigs was suitable for processing and consumption, and that the evaluated housing systems and feeding regimes can be recommended for pig farming and pork production.

Keywords: meat quality, rearing system, cluster analysis, alfalfa green forage, growing-finishing pigs.

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INTRODUCTION

Meat quality is influenced by both genetic and environmental factors. The main indicators of meat quality which determine its processing suitability and eating attributes are pH, color (including color uniformity and stability), water-holding capacity and water-binding capacity, emulsifying and gelling properties, shelf-life, production yield, appearance, texture (tenderness and juiciness) and palatability (flavor and aroma). Genetic factors are believed to be responsible for meat quality in 30%, whereas environmental factors – in 70% (Koćwin-Podsiadła, Krzęcio 2005). The production of large quantities of high-quality pork is determined by the use of high-quality feed, a balanced diet and adequate environmental and management conditions (Karpiesiuk, Falkowski 2008, Karpiesiuk et al. 2013, Fiedorowicz-Szatkowska et al. 2017). In recent years, more attention has been paid to the quality of pork supplied by farms where the applied housing conditions and feeding regimes conform to high animal welfare standards (Gentry et al. 2004, Falkowska et al. 2010, Myung-Hwa et al. 2013, Lebret et al. 2015, Kozera et al. 2016).

Numerous research studies (Hoffman et al. 2003, Bee et al. 2004, Strudsholm, Hermansen 2005) suggest that body weight gains and the feed conversion ratio tend to be lower in free-range pigs. These observations should be validated by studies analyzing the energy content of pig diets because animals with free access to an outdoor run or pasture have different nutrient and energy requirements than pigs that are kept indoor due to higher energy expenditure resulting from increased levels of physical activity and lower outdoor temperatures. Attempts should be made to determine whether the energy value of pig diets significantly influences the quantity and quality of pork.

The availability of high-quality and safe feed poses a challenge in animal production (Okorski et al. 2017). Consumers show growing concern for animal welfare standards, including housing conditions, diets and ability to express natural behavior, which can be improved through the addition of roughage. Reliable methods for evaluating meat quality need to be developed to provide consumers with safe and appealing products. Such methods support the implementation of meat quality standards, and they increase the competitive advantage of meat products on domestic and foreign markets. Processing plants require rapid and reliable analytical methods that deliver accurate results (Zapotoczny et al. 2014). Selective breeding programs for improving the fattening performance and slaughter value of pigs should rely on comprehensive methods that support the evaluation of the nutritional value and quality of meat. In most cases, meat traits are analyzed separately, which makes the results difficult to interpret. The preferred method should support the identification of traits that best reflect meat quality and the correlations between different traits, even if determined in different measurement systems. Cluster analysis is such a method. A wide range of variables have to be analyzed to improve performance traits. In cluster analysis, groups of similar objects are identified. Data are segmented with the use of similarity measures for qualitative traits and distance measures for quantitative traits (Karpiesiuk, Falkowski 2009, Zapotoczny et al. 2014).

The objective of this study was to examine the relationship between selected quality attributes of *Longissimus lumborum* from pigs kept under different feeding and rearing systems, evaluated by cluster analysis. In this study, we analyzed the proximate chemical composition, physicochemical properties and sensory attributes of meat from growing-finishing pigs kept indoor in pens without litter and with or without access to an outdoor run and fed complete diets or diets with addition of alfalfa green forage and rapeseed oil.

MATERIALS AND METHODS

The study was performed on ninety crossbred growing-finishing pigs [F_1 sows (Polish Large White x Polish Landrace) and crossbred boars (Duroc x Pietrain)] divided into six experimental groups of fifteen animals each (five pigs per pen). Experimental animals were selected based on their litter origin, body weight, sex and age (seven ♀ and eight ♂). Their initial body weight was 35 kg. The animals were reared until they achieved the weight of approximately 116 kg.

Pigs were divided into the following groups: 1 – fed a complete diet and kept indoor with access to an outdoor run (free-range), 2 – fed a complete diet and kept indoor, 3 – fed a complete diet with an increased ME content and kept indoors with access to an outdoor run, 4 – fed a complete diet with the addition of alfalfa green forage and kept with access to on outdoor run, 5 – fed a complete diet with alfalfa green forage and kept indoor, 6 – fed a complete diet with an increased ME content and alfalfa green forage and kept indoor with access to an outdoor run. All animals were housed in litterless pens.

The animals from groups 1, 2, 4 and 5 were fed control complete cereal-soybean diet (Table 1), formulated in accordance with the Pig Nutrient Requirements (1993) and offered *ad libitum* from self-feeders. The animals from groups 3 and 6 were fed experimental complete cereal-soybean diet whose ME concentration was approximately 10% higher relative to the control diet (Table 1). The ME content of experimental diets was increased through the addition of 40 g kg^{-1} rapeseed oil. The animals from groups 4, 5 and 6 were additionally feed with alfalfa green forage addition at approximately 8 kg per pen, administered daily to the trough in a single dose at 8:00 a.m.

Slaughter was carried out in accordance with the relevant meat industry regulations.

Table 1

Composition and nutritional value of pig diets and alfalfa green forage

Specification	Control diet	Experimental diet	Alfalfa
Ground wheat (g kg^{-1})	400.0	400.0	
Ground barley (g kg^{-1})	448.8	398.8	
Soybean meal (g kg^{-1})	120.0	130.0	
Rapeseed oil (g kg^{-1})	-	40.00	
Mineral and vitamin Premix* (g kg^{-1})	30.00	30.00	
L-lysine (g kg^{-1})	1.200	1.200	
Crude protein	16.56	16.30	3.55
Metabolizable energy (MJ kg^{-1}) (calculated on the basis of Pigs Nutrition Requirements)	12.72	13.84	8.80

* vitamin A – 341600 j.m., vitamin D-3 – 54 165 j.m., vitamin E – 2166 mg, vitamin K – 75 mg, vitamin B-1 – 37,50 mg, vitamin B-2 – 116,60 mg, vitamin B-6 – 66,60 mg, vitamin B-12 – 0,58 mg, vitamin B-3 – 600 mg, pantothenic acid – 275.8 mg, folic acid – 10 mg, choline chloride – 10 000 mg, vitamin H – 1.33 mg, Fe – 3000 mg, Cu – 700 mg, Zn – 3666 mg, Mn – 2000 mg, Se – 5.33 mg, J – 13.30 mg, Co – 8,33 mg, Mg – 5 g, Na – 33,30 g, P – 40 g, Ca – 226 g, lysine – 61,66 g, methionine – 8,33 g, threonine – 9,16 g

The acidification of muscle tissue was measured in the *longissimus lumborum* (LL) 45 min after bleeding (pH_{45}) and after 24 h of carcass chilling (pH_{24}). The acidity of muscle, i.e. pH_{45} and pH_{24}, was determined with the use of a WTW 3310 pH meter and combination electrode (WTW-Wissenschaftlich-Technische Werkstaetten GmbH, Weilheim, Germany) and calibrated with the same standard solutions of pH 4.01 and 7.00 at 20°C. Additionally, their accordance was tested with meat samples at the beginning and regularly during the measuring period.

Samples of the *Longissimus lumborum* were obtained for a physicochemical analysis. The samples were collected at the level of the 1st - 3rd lumbar vertebrae. Pork samples were analyzed to determine the content of dry matter, total protein by the Kjeldahl method, crude fat by the Soxhlet method, and crude ash using the method recommended by the Association of Official Agricultural Chemists (AOAC, 2011). The water-holding capacity of meat (i.e. the ability to retain own water) was determined by the method proposed by Grau, Hamm (1952).

The surface color of meat samples was determined with a spectrophotometer (MiniScan XE Plus, Hunter Lab, an aperture of 31.8 mm, 10° observer, illuminant D65). The instrument was calibrated prior to sampling using a white and black tile. The investigated parameters were measured at the wavelength range of 400 to 700 nm with the resolution of 10 nm. Color parameters were described according to the L*a*b* standard, and average spectral distributions at selected measurement points were statistically processed. Ten random measurements were performed in every cross-section of muscle tissue.

The shear force of meat samples was determined in an Instron 5542 universal testing machine equipped with a Warner-Bratzler head (500 N). The physical properties of pork were evaluated on samples deprived of fat and external connective tissue. The samples were subjected to the same thermal processing regime that was applied in the sensory analysis. Meat was cut into 2 cm-thick slices, and cores of a diameter of 2.54 cm (1 inch) and height of 2 cm were cut out from the slices. Three cores were obtained from every sample, according to the methodology used in the laboratory of the Department of Science of Commodities of Animal Raw Materials, UWM Olsztyn. The maximum shear force required to slice the specimens (across the grain) was registered. The analysis was carried out with the Merlin material testing software.

The sensory attributes of pork were evaluated in samples deprived of fat and external connective tissues. The specimens for sensory analysis were cut against the grain into cubes of approximately 50 g. Meat cubes were cooked in 6.2 g kg^{-1} NaCl solution (2:1 solution-to-meat ratio) at 96°C until the temperature inside the sample reached 75°C. All samples were placed in covered containers and coded. They were evaluated at room temperature (20°C) on a 5-point grading scale. The following quality attributes were assessed: aroma, juiciness, tenderness, palatability. The sensory evaluation was performed by five trained panelists with higher than average sensory sensitivity (Baryłko-Pikielna et al. 1964).

A two-way analysis of variance (ANOVA) was carried out in order to assess the significance different feeding and rearing systems, except for those from the sensory analysis. Analysis was performed using the general lineal model (GLM) procedure of the StatSoft software package Statistica PL 13.3. The model of analysis was:

$$(Yijk = \mu + FTi + RSj + (FT \times RS)\ ij + \varepsilon ijk).$$

Indoor without outdoor access

1. Fed a complete diet.
2. Fed a complete diet + an increased ME content.
3. Fed a complete diet + alfalfa green forage.
4. Fed a complete diet + ME content + alfalfa green forage.

Indoor with outdoor access

1. Fed a complete diet.
2. Fed a complete diet + alfalfa green forage,

where FTi is the feeding type (i=1,2,3,4), RSj is the rearing systems (j=1,2) and (FT x RS)ij is the interaction between the feeding and rearing effects, and εijk is the residual error.

Replicates were tested before applying the final statistical model and were found to be insignificant. When data fitted the normal distribution, significance was declared at $p \le 0.05$ and $p \le 0.01$, and means were compared using the Duncan's test. Moreover, the significant differences in sensory attributes between tumbling treatments were determined by a non-parametric test with a $p \leq 0.05$ (Kruskal-Wallis).

The relationship between selected quality attributes of the *Longissimus lumborum* were determined by cluster analysis. Statistical analyses were carried out using Statistica PL 13.3 application.

The experiment was approved by the Local Ethics Committee for Animal Experimentation in Olsztyn.

RESULTS AND DISCUSSION

The results of the physicochemical analysis of meat samples from experimental pigs are presented in Table 2.

The dry matter content of pork ranged from 257.1 g kg^{-1} in group 5 (fed a complete diet with the addition of alfalfa and kept indoors without free access to an outdoor run) to 264.0 g kg^{-1} in group 1 (fed a complete diet and kept indoors with access to an outdoor run). The difference between the above groups was statistically significant ($p \leq 0.05$). The LL samples of pigs fed a control complete diet with a standard energy content, with addition of alfalfa green forage (groups 4 and 5), were characterized by lower dry matter than the meat of animals fed solely a complete diet (groups 1 and 2), a com-

Table 2

Chemical composition and physicochemical properties of meat (*Longissimus lumborum*) from experimental pigs (average)

Specification	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	free-range	indoor	free-range + ME	free-range	indoor	free-range + ME
	without alfalfa	without alfalfa	without alfalfa	with alfalfa	with alfalfa	with alfalfa
Dry matter (g kg^{-1})	264.0[b]	259.6	259.9	258.5	257.1[a]	259.7
Total protein (g kg^{-1})	232.7	233.1	233.3	234.0	232.8	232.8
Crude fat (g kg^{-1})	24.10	22.80	19.80	19.90	18.70	20.60
Crude ash (g kg^{-1})	11.70	11.90	11.90	11.60	11.90	12.00
Water-holding capacity (cm^2)	5.630	6.310	5.970	6.250	5.930	5.850
pH_{45}	6.480	6.620	6.540	6.570	6.520	6.560
pH_{24}	5.490	5.490	5.440[b]	5.500	5.490	5.520[a]
Lightness L^* 1	56.30	55.45	57.32	57.24	56.10	55.45
Chromaticity a^*1	7.330	8.140[a]	7.520	7.190	6.880[b]	6.910[b]
Chromaticity b^*1	15.02	15.11	15.31	15.19	14.74	14.73
Shear force (N cm^{-2})	33.83	28.90	31.14	33.79	29.51	32.81

Key: *a*, *b* ($p \leq 0.05$) – different letters denote statistically significant differences.

plete diet with addition of alfalfa green forage (group 4) and a diet whose ME content was 10% higher relative to control (group 3). In a study evaluating the influence of housing conditions and feeding regime on the quality of pork, Karpiesiuk et al. (2013) observed that the dry matter content of meat from pigs kept on litter and fed a complete diet was significantly ($p \leq 0.05$) and highly significantly ($p \leq 0.01$) lower in comparison with the meat of pigs reared in a litterless system, regardless of the feeding regime.

The meat of pigs from all experimental groups was characterized by similar total protein content (from 232.7 g kg^{-1} in group 1 to 234.0 g kg^{-1} in group 4). The crude ash content of the analyzed meat samples was also comparable (11.60-12.00 g kg^{-1}). The lowest crude fat content was noted in the meat of group 5 pigs (18.70 g kg^{-1}) and the highest – in group 1 (24.10 g kg^{-1}), but the observed differences were not statistically significant. In a study by Lisiak et al. (2014) who evaluated the effect of the feeding regime (intensive and extensive production systems) on pork quality, the total protein content (238.0-248.0 g kg^{-1}), fat content (16.10-20.50 g kg^{-1}) and crude ash content (11.40-12.70 g kg^{-1}) of the evaluated meat samples were similar to the values noted in this study.

In our study, the highest water-holding capacity was determined in the meat of group 1 pigs (5.63 cm^2) fed a complete diet and kept indoors with access to an outdoor run, whereas the lowest value of this parameter was noted in group 2 animals (6.31 cm^2) fed a complete diet and reared in litterless pens without outdoor access (Table 2). In our previous experiment investigating the influence of housing and feeding conditions on meat quality (Karpiesiuk et al. 2013), water-holding capacity was determined at a lower level (6.93 to 7.63 cm^2). Higher water-holding capacity was reported in other studies (Karpiesiuk, Falkowski, 2009).

The incidence of meat quality defects is highly correlated with genetic and environmental factors. According to Koćwin-Podsiadła, Krzęcio (2005), genetic factors are responsible for only 20-30% of quality defects in pork carcasses. Pork quality is largely affected by environmental factors, including pre-slaughter handling (15-25%) and slaughter conditions (40%). The evaluated carcasses did not contain PSE or partially PSE meat, and active acidity pH_{45} was determined in the range of 5.89 to 6.99. All values were within the normal acidity range according the classification system proposed by Pospiech (2000). The average values of pH_{45} (Table 2) were similar to those reported by Karpiesiuk et al. (2013) and somewhat higher than those noted by Lisiak et al. (2014). Measurements of pH_{24} are performed to determine the presence of DFD meat. In this study, pH_{24} values were determined in the range of 5.39 to 5.78, which ruled out the presence of DFD meat in the carcasses of experimental pigs. According to Pospiech (2000) and Kortz (2001), pH_{24} values higher than 6.2 and 6.3, respectively, are indicative of DFD meat.

Meat color is an important evaluation criterion which significantly influences consumer preferences and is highly correlated with other quality attributes of meat (Myung-Hwa et al. 2013). In this study, color components

L* (color lightness) and b* in the CIE Lab system did not differ significantly ($p \leq 0.05$) between groups. Only minor variations in CIE Lab parameters were observed between groups, and component L* ranged from 55.45 to 57.32. The value of component b* was the highest in group 3 at 15.31 and the lowest in group 6 at 14.73. The highest value of component a* was noted in group 2 at 8.14, and the lowest values of this parameter were observed in groups 5 and 6 at 6.88 and 6.91, respectively. The noted differences were statistically significant ($p \leq 0.05$). Lisiak et al. (2014) reported the most desirable color parameters in the meat of pigs raised in an intensive production system, but the values of color parameters determined in the CIE Lab system by the above authors were lower than those noted in our study.

In the present study, no significant differences in shear force were noted between experimental groups. Shear force tended to decrease in the meat of pigs that were reared indoors. Considerable differences in shear force values were reported by various authors. Karpiesiuk et al. (2013) reported contrary results because the meat of pigs which had outdoor access was softer.

The sensory attributes of meat are also integral components of its quality. The results of our sensory evaluation are presented in Table 3. Significant ($p \leq 0.05$) and highly significant ($p \leq 0.01$) differences in the mean values of flavor and aroma desirability were noted between experimental groups. The meat of pigs fed a complete diet with an increased ME content and provided access to an outdoor run (group 3) was characterized by significantly lower ($p \leq 0.05$) aroma desirability and highly significantly lower flavor desirability than the meat of pigs fed a complete diet and kept indoors with no access to an outdoor run (group 2) and the meat of pigs fed a complete diet with an increased ME content, with alfalfa green forage addition, which had access to an outdoor run (group 6). The effect of pig management systems on the juiciness, tenderness and aroma of meat is widely diseussed

Table 3

Sensory attributes of meat (*Longissimus lumborum*) from experimental pigs (average)

Specification	Unit	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
		free-range	indoor	free-range + ME	free-range	indoor	free-range + ME
		without alfalfa	without alfalfa	without alfalfa	with alfalfa	with alfalfa	with alfalfa
Aroma:	points						
intensity		3.940	3.620	4.180	3.870	3.940	3.620
desirability		4.750	5.000^{a}	4.430^{b}	4.810	4.930^{a}	5.000^{a}
Tenderness		4.000	4.250	4.310	4.000	3.810	4.000
Juiciness		3.250	3.370	3.560	3.560	3.370	3.560
Flavor:							
intensity		4.12	3.930	4.180	4.180	4.120	4.250
desirability		5.00^{A}	4.870^{a}	4.440^{Bb}	4.810	5.000^{A}	4.870^{a}

Key: *a*, *b* ($p \leq 0.05$) – different letters denote statistically significant differences; *A*, *B* ($p \leq 0.01$) – different letters denote statistically highly significant differences.

in the literature. According to Jonsäll et al. (1999), outdoor access reduces meat juiciness. According to Johansson et al. (1999) and Jonsäll et al. (2000), diets containing red clover silage have no significant influence on the juiciness, tenderness, flavor and aroma intensity of pork. Yang et al. (2017) researched the impact of corn condensed distiller's solubles (CCDS) and whole stillage (CWS) in pig diets, likewise failing to notice any effect on the above on the flavor, tenderness and juiciness of loin chops.

According to Przybylski et al. (2008), cluster analysis supports the identification of meat of various quality, including meat with the most desirable attributes and high eating quality. Hierarchical clustering algorithms are used to arrange the compared objects in cluster trees. Dendrograms with three sequences of clusters of quality attributes in the *Longissimus lumborum* in the evaluated groups of animals are presented in Figure 1. The first

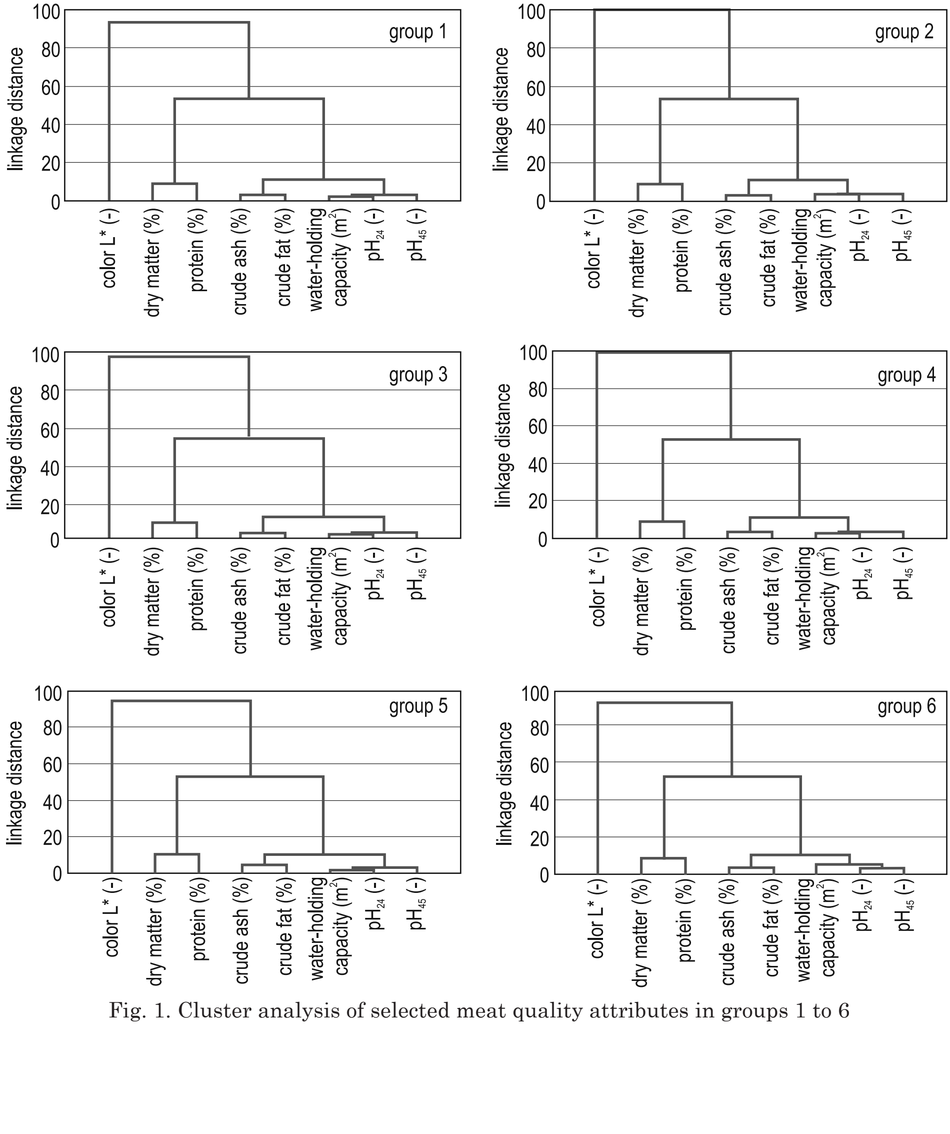

Fig. 1. Cluster analysis of selected meat quality attributes in groups 1 to 6

sequence is a cluster of pH_{45}, pH_{24} and water-holding capacity values, the second sequence combines the crude fat and crude ash content of meat, and the third sequence comprises the dry matter and protein content of meat. Color lightness L* in the CIE Lab system was a less important parameter than the remaining quality attributes. The data presented in the figure drawings clearly indicate that unchanging distances between attributes point to absence of relationships between those parameters in all experimental groups. Similar correlations were observed across the entire experimental population, but greater Euclidean distances were noted between the dry matter content, protein content and color lightness L* in the CIE Lab system and the remaining clusters (Figure 2). Similar relationship

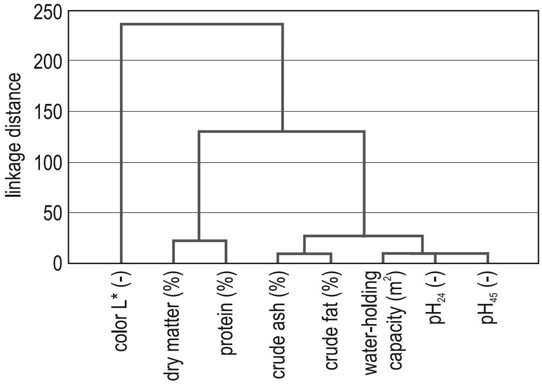

Fig. 2. Cluster analysis of selected meat attributes across the experimental population

between the analyzed attributes in a cluster analysis were reported by Karpiesiuk, Falkowski (2009) and Karpiesiuk et al. (2016). In a study by Strzelecki (2004), distances between clusters varied subject to meat type (PSE, DFD, RFN), and they were indicative of differences between the evaluated attributes. In the cited study, the correlations between pH_{45} and water-holding capacity in meat of normal quality were similar to those noted in our experiment. The analyzed relationship between selected quality attributes seem to be a simple and reliable indicators of the processing suitability of meat.

CONCLUSIONS

The analyzed rearing and feeding systems had no significant influence on the chemical composition of the *Longissimus lumborum* in pigs. The meat of pigs from all experimental groups was characterized by satisfactory quality, and suitability for processing and consumption. The experimental factors did not exert clear influence on the sensory properties of meat, which suggests that the evaluated housing and feeding conditions contribute to the high eating quality of pork. Therefore, further research is needed to determine the effect of production systems and feeding regimes on meat quality.

REFERENCES

AOAC International. 2011. Official Methods of Analysis of AOAC International. Current through revision 4. 18th Edition. Gaithersburg, Maryland, USA.

Baryłko-Pikielna N., Kossakowska T., Baldwin Z. 1964. *The choice of optimal method of samples of beef and pork meat preparation for sensory analysis*. Rocz. Inst. Przem. Mięs. Tłuszcz., 1: 111. (in Polish)

Bee G., Guex G., Herzog W. (2004). *Free-range rearing of pigs during the winter: Adaptations in muscle fiber characteristic and effects on adipose tissue composition and meat quality traits*. J. Anim. Sci. 82(4): 1206-1218. DOI: 10.2527/2004.8241206x

Falkowska A., Bugnacka D., Kozera W., Falkowski J. 2010. *Fattening results of finishing pigs fed second-stage diets with a high content of oat bran and soybean oil.* Pol. J. Nat. Sci., 25: 341-351. DOI: 10.2478/v10020-010-0031-9

Fiedorowicz-Szatkowska E., Sobotka W., Stanek M. 2017. *Fattening performance and the nutritional value of meat from finishing pigs fed diets containing different sources of vegetable protein.* J. Elem., 22(4): 1235-1242. DOI: 10.5601/jelem.2017.22.1.1305

Gentry J.G., McGlone J.J., Miller M.F., Blanton Jr. J.R. 2004. *Environmental effects on pigs performance, meat quality, and muscle characteristics*. J. Anim. Sci., 82: 209-217.

Grau R., Hamm R. (1952). *Eine einfache Methode zur Bestimmung der Wasserbindung in Fleisch.* Fleischwirtschaft, 32: 295. (in German)

Hoffman L.C., Styger E., Muller M., Brand T.S. 2003. *The growth and carcass and meat characteristics of pigs raised in a free-range or conventional system*. S. Afr. J. Anim. Sci., 33: 166-175.

Johansson L., Lundström K., Jonsäll A., Lundh T. 1999. *Effects of clover silage and ageing time on sensory characteristics and cooking losses of loin (M. longissimus dorsi) from Hampshire crosses with and without the RN- allele*. Food Qual. Prefer, 10: 299-303.

Jonsäll A., Johansson L., Lundström K. 2000. *Effects of red clover silage and RN^- genotype on sensory quality of prolonged frozen stored pork (M. longissimus dorsi).* Food Qual. Prefer, 11: 371-376.

Karpiesiuk K., Falkowski J. 2008. *Effect of the feeding and housing system on pig fattening results*. Pol. J. Nat. Sci., 23: 769-778.

Karpiesiuk K., Falkowski J. 2009. *The effect of feeding and housing conditions of growing--finishing pigs on pork quality*. Pol. J. Nat. Sci., 24: 198-206. DOI 10.2478/v10020-009-0019-5

Karpiesiuk K, Kozera W., Bugnacka D., Falkowski J. 2013. *Effect of rearing system conditions of fatteners on meat quality and profile of fatty acids in the m. longissimus dorsi*. Zywn--Nauk Technol Ja, 88: 39-50. (in Polish)

Karpiesiuk K., Falkowski J., Raubo B., Kozera W., Bugnacka D. 2016. *Effect of rearing system and feeding method of fatteners on their slaughter value and meat quality*. Zywn-Nauk Technol Ja, 108: 45-59. (in Polish) DOI: 10.15193/zntj/2016/108/148

Koćwin-Podsiadła M., Krzęcio E. 2005. *Pork quality and quality improvement methods*. Part I. *Quality and lean content of pork raw material, pork quality and quality defects*. Prz. Hod., 73: 13-20. (in Polish)

Kortz J. 2001. *The chief defects of meat and methods of detection.* Pol. J. Food. Nutr. Sci., 10: 5-10.

Kozera W., Karpiesiuk K., Bugnacka D., Falkowski J., Milewska W. 2016. *Production performance of pigs reared in different systems and fed increased energy content diets with or without green alfalfa*. S. Afr. J. Anim. Sci., 46: 70-76.

LEBRET B., ECOLAN P., BONHOMME N., MÉTEAU K., PRUNIER A. 2015. *Influence of production system in local and conventional pig breeds on stress indicators at slaughter, muscle and meat traits and pork eating quality*. Animal, 9: 1404-1413.

LISIAK D., GRZEŚKOWIAK E., JANISZEWSKI P., BORZUTA K., PEPLIŃSKI B., WAJSZCZUK K. 2014. *Effect of feeding intensity of fatteners on quality of meat*. Zywn-Nauk Technol Ja, 97: 102-112. (in Polish) DOI: 10.15193/ZNTJ/2014/97/102-112

MYUNG-HWA K., KWAN-SIK M., TAKAYUKI S. 2013. *Enhancement of pork quality from pigs fed feeds supplemented with antioxidants containing defatted sesame dregs and dried barley leaves*. Int. J. Nut. Food Sci., 2: 301-306. DOI: 10.11648/j.ijnfs.20130206.16

OKORSKI A., POLAK-SLIWINSKA M., KARPIESIUK K., PSZCZOLKOWSKA A., KOZERA W. 2017: *Real time PCR: a good tool to estimate mycotoxin contamination in pig diets*. World Mycotoxin J, 10: 219-228. DOI: 10.3920/WMJ2016.2137

Pigs Nutritiom Requirements. 1993. Omnitech Press. Warsaw, Poland.

POSPIECH E. 2000. *Diagnosing deviations in meat quality*. Gosp. Mięs., 4: 68-71. (in Polish)

PRZYBYLSKI W., JAWORSKA D., CZARNIECKA-SKUBINA E., KAJAK-SIEMIASZKO K. 2008. *Estimating the possibility of isolating high quality culinary meat on the basis of fattener meatiness and colour & ph measurements using cluster*. Zywn-Nauk Technol Ja, 59: 43-51. (in Polish)

STRUDSHOLM K., HERMANSEN J.E. 2005. *Performance and carcass quality of fully or partly outdoor reared pigs in organic production*. Liv. Prod. Sci., 96: 261-268.

STRZELECKI J. 2004. *Investigations on the anatomical-spatial distribution of meat quality defects in the pig carcasses as influenced by the rate and degree of muscle acidification*. Rocz. Inst. Przem. Mięs., 41(2).

YANG X., NATH C., DOERING A., GOIHL J., BAIDOO S.K. 2017. *Effects of liquid feeding of corn condensed distiller's solubles and whole stillage on growth performance, carcass characteristics, and sensory traits of pigs*. J. Anim. Sci. Biotechnol., 8: 1-11. DOI:10.1186/s40104-016--0140-6

ZAPOTOCZNY P., KOZERA W., KARPIESIUK K., PAWŁOWSKI R. 2014. *The use of computer-assisted image analysis in the evaluation of the effect of management systems on changes in the color, chemical composition and texture of m. longissimus dorsi in pigs*. Meat Sci., 97: 518-528. DOI: 10.1016/j.meatsci.2014.03.010