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ORIGINAL PAPER

Influence of sex on the fattening and slaughter parameters, chemical composition and fatty acid profile of the *longissimus dorsi muscle* in hybrid pigs*

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Abstract

The aim of this study was to determine the effect of sex on meat quality, chemical composition, and fatty acid (FA) profile of the longissimus dorsi muscle (LD) in DanBred crossbreds. The experiment was performed on a total of 201 598 DanBred hybrid pigs. A total of four groups were analyzed: 42 178 gilts, 47 515 entire males, 87 045 surgically castrated males, and 47 515 immunologically castrated (IM) males. Fattening began at a body weight of 31 kg. The animals were housed in groups and fed a complete diet in a four-phase system. The fattened pigs were slaughtered after 94 days of fattening. Lean meat content, fat thickness, and thickness of the *longissimus lumborum muscle* were measured on the warm right side of the carcass. After cooling, 12 muscle samples were collected from each group between the 3rd and 4th lumbar vertebrae. pH24 values, color parameters, chemical composition, and fatty acid profile were measured. Lean meat content in the carcass was highest in entire males (59.61%) and gilts (60.13%), and lowest in castrated (IM) males (58.41%). Gender significantly influenced meat color saturation. Crude fat content was significantly lower in entire males and gilts than in castrated fatteners. Entire males had significantly lower saturated fatty acid (SFA) content and higher polyunsaturated fatty acid (PUFA) content. Gender had no effect on the chemical composition of *longissimus dorsi muscle*, except for dry matter content, crude fat content, and acidity. Further studies of larger sample sizes are needed to confirm or refute the current findings.

Keywords: fatty acid and meat quality, *musculus longissimus dorsi*, sex, DanBred, fattening and slaughter parameters

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INTRODUCTION

Modern pig farming focuses on the production of high-quality pork. The quality of slaughter raw material from pigs depends on genetic and environmental factors (Babicz et al. 2020), In 2023, meat consumption per capita in Poland reached 73.1 kg, and pork accounted for 55.4% of that figure at 40.5 kg per capita (GUS 2024). Therefore, pork producers are trying to increase production efficiency while meeting consumer demand for high animal welfare standards. Consumers no longer focus solely on price, but also on product quality and animal welfare. These expectations continue to grow each year (Karpiesiuk et al. 2019). There is an increasing consumer interest in food produced in farming systems that prioritize animal welfare (Zapotoczny et al. 2014) and health, and in animal-friendly systems that are free of genetically modified organisms and antibiotics (Kozera et al. 2016, Karpiesiuk et al. 2023*a*,*b*, Kropiwiec-Domańka et al. 2024). It is important to select production options which maximize both meat quality and healthiness in meat production (Kouba et al. 2003). When the effects of feeding system and nutrition of feedstuff are controlled for, different breeds and gender exhibit inherent advantages in certain aspects of carcass composition and meat quality (Channon et al. 2004, Miao et al. 2009). Producers are searching for solutions. Separate-sex rearing systems are one of such solutions. Livestock herds that differ in growth parameters and fattening performance may be difficult to manage, and differences in the animals' nutrient requirements and body weight (BW) gains is a challenge in planning slaughter operations. To overcome these difficulties, animals are grouped in separate pens or in separate farms and buildings (Dobiesz et al. 2023). Most Polish farms produce entire females (gilts) and surgically castrated males. Some farms also keep immunocastrated (IM) males (Karpiesiuk et al. 2023*b*). Before 2010, the provisions of the Regulation of the Minister of Agriculture and Rural Development of 22 June 2004 on the veterinary requirements for the production of fresh marketable meat from bovine, porcine, ovine, caprine, and soliped species prevented Polish farmers from fattening entire males. After 2010, the production of entire males has been introduced as an alternative solution. Due to lower daily weight gains, female pigs have a longer fattening period than intact males. In comparison with castrated males, the carcasses of female pigs contain 2-3% more lean meat (Nałęcz-Tarwacka 2006) and have a higher carcass dressing percentage. In Poland, male piglets can be castrated without anesthesia up to seven days of age. In other countries, including Norway, Sweden, and Germany, male pigs are castrated under general anesthesia, whereas analgesia is required in France, the Netherlands, and Belgium. Castration without analgesia is allowed in Poland, Italy, Romania, and Russia (Aluwé et al. 2020, Lin-Schilstra and Ingenbleek 2021). However, this procedure has attracted considerable criticism from animal rights groups, and alternative castration methods are being sought to both

minimize pain and eliminate boar taint. Immunocastration is an alternative approach that has been introduced several years ago in Poland and 20 years ago in the world. Male pigs are immunocastrated with the Improvac injectable vaccine that is administered twice at a four-week interval. The last dose should be given no later than one month before the planned slaughter date. The vaccine suppresses the development of reproductive organs and reduces aggressive and sexual behavior in male piglets. The greatest advantage of Improvac is that its effects last until the end of the fattening period. The main disadvantage is high cost, which is two or even three times higher than surgical castration. Raising entire males is an alternative method that has been introduced in countries such as the United Kingdom, Spain, and Ireland. In this system, entire male pigs are slaughtered before they reach sexual maturity, at a BW under 100 kg (Bonneau, Weiler 2019). This method has its strengths and weaknesses. Uncastrated males do not experience physical pain associated with the surgical procedure and are at lower risk of infection. Entire males are characterized by higher daily weight gain (by 13%), higher feed efficiency (9.5%), and lower carcass fat content (-20%) – EFSA (2004). In addition, entire males have a lower environmental impact than IM males (Kress et al. 2019). However, intact males can display aggressive behavior, and their meat can have an offensive odor. Boar taint is caused by the accumulation of skatole and androstenone in meat. The meat of entire males is harder, has lower water-binding capacity, and contains less fat. Deviations from the normal pH and color of muscle tissue have also been reported (Bonneau, Weiler 2019, Škrlep et al. 2020). Research has shown that the quality of pork carcasses can be influenced by many factors, including genotype, sex, housing conditions, and diet. The fatty acid (FA) composition of meat can affect the quality and oxidative stability of fat. Pauly et al. (2012) reported a correlation between FA concentrations in pork and the sex category of pigs. The available literature provides limited information on the sources of commercially farmed pork. Therefore, research into the influence of sex on pork quality is justified.

In view of the above, the aim of this study was to determine the effect of sex on fattening parameters and slaughter, meat quality and the chemical composition and FA profile of the *longissimus dorsi* (LD) of DanBred Hybrid pigs. This breed was selected for the study due to its growing popularity in commercial pig farms and its potential contribution to improving production efficiency.

MATERIALS AND METHODS

Animals

No approval from the Ethics Committee or Institutional Review Board is required to conduct this experiment, as it was carried out in compliance

with the European Union law, specifically Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific or educational purposes. The animals were kept in accordance with the provisions of the Minimum conditions for the keeping of pigs – Requirements and procedures for the keeping of species of farmed animals for which standards of protection are laid down in the European Union regulations (Journal of Laws of 2010, 56.344). The experimental fattening was carried out in commercial pig fattening farms. The procedures used in this study did not affect production. The consent of the animals' owner to conduct the study and to collect data was obtained. The assessment of meat quality was carried out on meat from animals slaughtered in meat plants in accordance with the applicable regulations for the meat industry (Regulation of the Minister of Agriculture and Rural Development of 9 September 2004 on the qualifications of persons authorised for professional slaughter and the conditions and methods of slaughtering and killing animals (Journal of Laws of 2004, No. 205, item 2102), as amended by the Regulation of 11 August 2006 (Journal of Laws of 2006, No. 153, item 1096) and in the Regulation of the Minister of Agriculture and Food Industry of 10 March 1999 on safety and hygiene at the workplace during the slaughter of animals and meat processing (Journal of Laws of 1999, No. 25, item 226). Council Regulation (EC) No. 1099/2009 of 24 September 2009 on the protection of animals at the time of killing).

The experiment was performed on a total of 201 598 DanBred hybrid pigs, including 42 178 gilts, 47 515 entire males, 87 045 animals castrated in the first days of life, and 24 860 IM males. The large number of animals resulted from the study being conducted under commercial production conditions, where inclusion of all animals within the same production batch allowed us to obtain results representative of practical farming systems. This approach ensured adequate statistical power and reduced random variability among groups. All animals came from the same sow farm, ensuring uniform management, genetics, and feeding protocols. Animals were managed under identical housing and feeding conditions throughout the fattening phase. All groups received the same diet, had an *ad libitum* access to feed and water, and were kept under the same temperature and ventilation regime. The animals were kept on industrial pig farms in Poland. The farm owners agreed to participate in this research. Surgical castration was performed between the second and fifth day of life. At that time, the animals were given iron injections. Immunocastration (IM males) was performed with two injections of Improvac administered at a four-week interval (Zoetis Belgium SA, Zaventem, Belgium), 2 ml/animal i.m., eight and four weeks before the planned sale to a meat processing plant. During fattening (94 days) from a body weight (BW) of approximately 32 kg to 120 kg (±5 kg), all animals were housed in buildings that met both welfare and biosecurity standards. Pigs of each sex category were kept in groups, in litterless pens (50 animals per pen). The division was made before the fattening began.

Each group was located in a separate building. There it was treated according to her needs.

All groups were fed complete diets in a four-phase system. Pigs with a BW of 23-43 kg received finisher diet 1, pigs with a BW of 43-63 kg – finisher diet 2, pigs with a BW of 63-85 kg – finisher diet 3, and finishing pigs were fed finisher diet 4. The diets were formulated according to the guidelines of SEGES Pig Research Center (SPRC). The ingredient and chemical composition of diets is presented in Tables 1 and 2.

Table 1

Ingredient composition of pig diets

Ingredients (%)	Finisher			
	1	2	3	4
Wheat	40.00	40.00	38.32	15.74
Barley	15.00	0.000	0.000	0.000
Maize	10.00	15.00	20.00	20.00
Triticale	5.560	8.630	5.000	20.00
Rye	0.000	10.00	15.00	21.40
Rapeseed meal	9.000	10.00	12.00	12.68
Soybean meal (46%)	7.000	4.000	1.500	1.500
Sunflower meal	4.000	4.000	3.000	0.000
Poultry fat	0.000	0.000	1.000	1.000
Maize distillers dried drains with solubles (DDGS)	3.000	3.000	0.000	4.000
Sunflower oil	3.000	2.000	0.900	0.700
Limestone	+	+	+	+
Blood products	+	-	-	-
Animal protein hydrolysate	-	+	+	+
Aminoacids	+	+	+	+
Premix	+	+	+	+
Enzymes – xylanase, phytase	+	+	+	+

Fattening performance

The values of the following key performance indicators (KPI) were recorded during pig fattening: initial BW of weaners, daily gain, duration of fattening, mortality, the feed conversion ratio, BW of finishing pigs transported to a meat processing plant, medical treatment costs, and management costs (Table 3). Daily body weight gain was calculated by dividing the kg of gain by the number of days of fattening. To analyze the feed conversion ratio, animals were weighed at the beginning and end of fattening, and feed intake was monitored. The ratio was calculated using the following formula:

FCR = total amount of feed consumed (kg)/ total weight gain (kg)

The data were collected for pigs sold to a meat processing plant in 2022.

Table 2

Chemical composition (%) of pig diets

Nutrient (g kg^{-1} feed)	Finisher			
	1	2	3	4
Dry matter	880.8	877.5	871.5	870.1
Crude protein	170.8	156.1	141.3	139.5
Crude fiber	40.74	43.81	36.19	35.75
Crude fat	48.24	42.24	37.52	39.49
Crude ash	46.77	42.95	38.43	37.43
Lysine	11.22	10.10	9.013	8.901
Methionine	3.660	3.346	2.949	2.905
Calcium	6.900	6.038	5.600	5.220
Phosphor	4.683	4.486	4.268	4.032
Sodium	2.000	2.000	1.500	1.400
Starch	415.3	441.3	468.4	458.7

Table 3

Fattening performance of experimental pigs (means ±SD)

Group/Parameter	Gilts	Surgically castrated males	Entire males	Immunocastrated males
Body weight at the beginning of the study (kg)	32.17±2.640	32.73±2.485	31.40±2.295	31.24±2.808
Body weight on the day of slaughter (kg)	119.8±4.663	119.3±8.214	124.3±7.286	116.9±4.769
Average daily gain (g/day)	894±0.058	866±0.102	882±0.049	876±0.065
Duration of fattening (days)	98±7.498	101±8.091	105±5.063	97±7.285
Mortality (%)	2.960±1.425	4.160±2.154	5.090±2.419	4.830±2.633
Feed conversion ratio (kg feed kg^{-1} weight gain)	2.597	2.617	2.595	2.603
Medical treatment costs (EUR kg^{-1} BW of a sold finishing pig)	0.014	0.012	0.012	0.014
Management costs (EUR kg^{-1} BW of a sold finishing pig)	1.590	1.500	1.480	1.590

Carcass traits and meat quality

Slaughter was carried out in accordance with the relevant meat industry regulations. Pigs were slaughtered with an average body weight of 116-124 kg. Due to the large number of animals and the duration of the experiment, differences occurred between the analyzed groups. All carcasses (N = 201 598) were weighed individually after slaughter and subjected to ultrasound examination.

Carcass lean content for all pigs was classified according to the EUROP system using the Sydel CGM (Lorient, France; Capteur Gras/Maigre) optical device, operated by authorized and trained personnel. The CGM is a hand-held device equipped with an optical probe, used to determine the thickness of the loin muscle and the fat layer by measuring light reflection. CGM measurements are performed on a warm or chilled pork carcass. A single puncture is made between the 3rd and 4th rib, counting from the last rib, 6 cm from the cut line, so that the probe exits 6 cm from the cut line. Measurements of backfat thickness and the *longissimus dorsi* muscle were used to calculate the meat content of pig carcasses based on the following regression equation:

$$LMCCGM = 59.42 + 0.1322M2 - 0.6275T2$$

T2 – thickness of backfat between the 3rd and 4th but last ribs, 6 cm from the line of carcass partition; M2 – thickness of the *longissimus dorsi* muscle, 6 cm from the line of carcass partition, measured within 45 minutes after stunning.

After 24 h of carcass chilling, the pH24 of muscle tissue was measured with a WTW 340i pH-meter (WissenschaftlichTechnische Werkstaetten GmbH, Weilheim, Germany) and a Hamilton-Double Pore glass combination electrode. The electrode was calibrated using the same standard solutions with a pH of 4.01 and 7.00 at a temp. of 20°C, and checked and adjusted if needed both at the beginning and during the measurement. The pH 24 measurement was performed on 48 samples of the *longissimus dorsi* muscle (12 from each group analyzed) in the region between the 3rd and 4th lumbar vertebrae.

After 24 h of carcass chilling at a temperature of 4°C, samples of the *longissimus dorsi* (LD) muscle were collected from the right half-carcasses in the area between the 3rd and 4th lumbar vertebrae for meat quality analysis. A total of 48 LD muscle samples (12 samples per group) with a thickness of around 10 cm were collected. Representative samples were taken. The selection criterion was the body weight of the animals in each group. The animals were slaughtered on one day. Animals selected for meat sampling were chosen randomly among those representing the average live weight of each group at slaughter. This ensured that the sample was representative, and helped avoid a selection bias.

The collected LD muscle samples were analyzed to determine their proximate chemical composition dry meter, crude protein, crude fat and crude ash (AOAC 2007).

Color parameters (CIE $L^*a^*b^*$ color space) were measured on the cross-section of LD muscle samples. The color on the surface of muscle samples was determined using a spectrophotometer (MiniScan XE Plus, Hunter Lab, 31.8 mm aperture, 10° observer, D65 illuminant). The device was calibrated before the measurement with the use of a white and black tile. The analyzed parameters were measured at a 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 processed statistically.

Fatty acid methyl esters (FAMEs) were prepared according to the modified Peisker method (methanol: chloroform: concentrated sulfuric acid, 100:100:1, v/v). They were stored in tightly sealed tubes and analyzed by gas chromatography with flame ionization detection (GC-FID; column: 50 m × 0.25 mm × 0.25 µm). The GC injection port was set to 225°C in split mode (split ratio 50:1). The carrier gas was helium at a constant flow rate of 1.2 ml min^{-1}. The detector temp. was 250°C, and the column temp. was 200°C. To identify fatty acids, their retention times were compared with those of pure FAME standards (Sigma-Aldrich, St. Louis, Missouri, USA) and with those of the samples analyzed. Supelco FAME 37-Component Mix (47885-U) was used as a known reference standard. The relative fatty acid content was expressed as a percentage of the total area of all fatty acids detected in the samples.

$$DFA = UFA + C_{18:0} \quad OFA = SFA - C_{18:0}$$

DFAs – hypocholesterolemic fatty acids, UFAs – unsaturated fatty acids, OFAs – hypercholesterolemic fatty acids, SFAs – saturated fatty acids,

Statistical analysis

The results were processed statistically by analysis of variance with the use of the GLM model to include fixed and random factors:

$$Y_{ij} = \mu + a_i + cov(_x) + e_{ij}$$

where: y_{ij} – $_{ij}^{th}$ observation, µ – mean value, a_i – fixed effect of i^{th} sex (1, 2, 3, 4), $cov(_x)$ – covariate for the effect of live weight at slaughter (x), e_{ij} – random error.

All calculations were performed using the Statistica v. 13.3 data analysis software system (StatSoft, Inc. 2014, www.statsoft.com). The significance of differences between the analyzed groups was determined using the Duncan's test with 2 consequences of significance ($p \leq 0.05$ and $p \leq 0.01$).

RESULTS AND DISCUSSION

Fattening performance

The initial body weight of the animals was similar in each of the analyzed groups. The final weight varied due to daily gains and fattening duration. Gilts grew the fastest, while hogs grew the slowest. The higher final body weight and lower FCR in boars resulted from the action of androgens, which stimulate muscle tissue synthesis (Pauly et al. 2009, Bonneau, Weiler 2019). The higher mortality in this group could be related to greater aggres-

sion and stress, as confirmed by Rydhmer et al. (2013). As a result of early surgical castration, males grew slower, a finding also reported by Zamamaratskaia et al. (2008). Similar results were obtained by Dunshea et al. (2013). Higher mortality rates were observed in males compared to gilts. The lowest FCR, the most economical result, was observed in entire males. This influenced the total cost of maintaining a given sex group. Due to the costs of vaccination and higher FCR, the highest costs were incurred in the case of breeding immunocastrated males. Gender did not influence antibiotic use during fattening.

Carcass traits

The results of carcass quality assessment in each experimental group are presented in Table 4.

Table 4

Carcass traits in pigs of different sex categories (means ±SD)

Specification	Gilts	Surgically castrated males	Entire males	Immunocastrated males
Carcass weight (kg)	96.65±1.852	95.71±17.265	96.25±1.379	91.72±1.752
Slaughter yield (%)	77.41±1.074	78.07±1.326	76.56±0.983	77.58±1.329
Lean meat content (%)	60.13^{A}±1.510	59.18±1.390	59.61^{a}±0.988	58.41^{Bb}±1.387
Backfat thickness at TM (mm)	12.33±2.498	11.83±3.397	12.33±1.969	13.41±2.275
Thickness of the LD muscle (mm)	63.91^{a}±5.838	57.17±11.137	60.00±9.145	56.66^{b}±6.471

a, *b* – data in the same row followed by different letters differ significantly ($p \leq 0.05$),
A, *B* –data in the same row followed by different letters differ significantly ($p \leq 0.01$)

The lowest BW was noted in IM males because they are slaughtered before six months of age to prevent the development of boar taint. The highest slaughter yield was recorded in the surgically castrated males, while the lowest meat content in the carcass was recorded in entire males. There were no significant differences in slaughter yield between groups, meaning that it was similar across the tested groups. Lean meat content, expressed as a percentage, was significantly ($p \leq 0.05$) highest in gilts and entire males, relative to IM males. For surgically castrated males, no statistical differences were observed compared to the other groups. Backfat thickness was highest in IM males, but no significant differences were found between groups. Surgically castrated males were characterized by the lowest backfat thickness and carcass lean content. Thickness of the LD muscle was lowest in IM males, and the difference was significant relative to gilts. The results of this study are consistent with those reported by Dobiesz et al. (2023), which may suggest that DanBred Hybrid pigs have high carcass lean content. Aluwé et al. (2015) demonstrated that male pigs, the offspring of Piétrain sire × hybrid sow, subjected to surgical castration with or without anesthesia or analgesia, were characterized by higher backfat thickness than entire males. Similar

observations were made by Daza et al. (2016), in whose study the carcasses of IM females had higher carcass fat content than those of entire females, animals castrated in the first days of life, and IM males. Castration affects the amount of fat deposited in the carcass (Kouba, Sellier 2011). Uncastrated and immunocastrated females showed intermediate fat values that did not differ significantly from either male group. This pattern aligns with the known effects of surgical castration on lipid metabolism, which promotes increased fat deposition (Batorek et al. 2012). Studies show that immunocastrated males had backfat that was 2.07 mm thinner than surgically castrated males and 0.77-1.7 mm thicker than entire males (Poulsen Nautrup et al. 2018). Fat saturation increases with the thick-ness of backfat, which results in a higher amount of fatty acids (SFA) and monounsaturated fatty acids (MUFA). It increases in the following order: entire males, immunocastrated males and surgically castrated males (Pauly et al. 2018). High levels of saturated fats negatively impact the human body. They may increase the risk of cardiovascular disease and heart attacks. Furthermore, palmitic acid has been shown to have hypercholesterolemic effects.

Quality of meat from the LD muscle (proximate composition, pH24, color)

An analysis of the chemical composition of LD muscle samples revealed significant differences in the content of dry matter ($p \leq 0.05$) and crude fat ($p \leq 0.05$, $p \leq 0.01$) between the analyzed sex groups (Table 5.).

Table 5

Physicochemical analysis of the *longissimus lumborum* muscle (means ±SD)

Specification	Gilts	Surgically castrated males	Entire males	Immunocastrated males
Dry matter (%)	32.06^{a}±4.486	30.35±2.685	28.47^{b}±2.778	30.15±2.667
Crude protein (%)	21.81±1.647	22.46±1.178	22.27±0.846	22.67±1.238
Crude ash (%)	1.073±0.098	1.086±0.076	1.089±0.049	1.050±0.084
Crude fat (%)	3.073^{bc}±0.508	3.585^{Aa}±0.689	2.628^{Bb}±0.463	3.185^{ac}±0.649
pH_{24}	5.255±0.085	5.230±0.058	5.230±0.041	5.197±0.122
L*	60.18±4.991	61.79±3.649	62.23±2.579	62.84±3.010
a*	3.885±1.422	3.967±1.398	3.765±1.224	4.037±0.874
b*	13.29^{B}±0.965	14.03^{A}±0.554	14.05^{A}±0.455	14.07^{A}±0.475

a, *b*, *c* – data in the same row followed by different letters differ significantly ($p \leq 0.05$),
A, *B*– data in the same row followed by different letters differ significantly ($p \leq 0.01$)

The dry matter content of the LD muscle was highest in gilts, and the noted difference was significant relative to entire males ($p \leq 0.05$). Crude fat content in the LD muscle was highest in surgically castrated males and IM males, and was also significantly higher in males castrated in the first days

of life than in gilts ($p \leq 0.05$), as well as in intact males ($p \leq 0.01$), and significantly higher in IM males than in intact males ($p \leq 0.05$). Sex had no effect on meat acidity 24 h postmortem. Regardless of sex, meat pH24 ranged from 5.22 to 5.41. In this study, meat color was also assessed and significant differences in the values of this parameter were observed between the sex groups. The contribution of redness to meat color was not significantly affected by sex. The proportion of yellowness in the LD muscle differed statistically significantly between sexes ($p \leq 0.01$). The color parameter b* in the LD muscle was significantly higher in surgically castrated males, entire males, and IM males than in gilts ($p \leq 0.01$). The highest value of this attribute was noted in males after application of Improvac. The study found that gilt LD muscle had significantly lower fat content than immunocastrates. Castrated males' LD muscle samples had the highest crude fat content. The lowest crude fat content was observed in entire males. The values differed statistically significantly. Increasing intramuscular fat content in meat is desirable because it enhances the sensory quality and processing suitability of animal-based products (Jankowiak et al. 2019). The values of pH24 determined in this study are consistent with those reported by Karpiesiuk et al. (2023*b*) and Dobiesz et al. (2023). Meat color is affected by various factors, and it is correlated with qualitative attributes such as acidity, color saturation, muscle pigments, and natural drip loss (Kang 2013, Bocian et al. 2015). However, previous research findings are inconclusive in this respect. Karpiesiuk et al. (2023*b*) found that meat from surgically castrated DanBred Hybrid males was darker than meat from gilts and IM males. In turn, Dobiesz et al. (2023) reported that sex had no influence on meat lightness. Meat consumers pay attention to the product's overall appearance, including its lightness. An excessively light color is considered undesirable. In turn, a darker color is often associated with a shorter shelf life and bacterial growth. High-quality pork should be pinkish red (Trevisan, Brum 2020). The results of color assessment performed on meat from IM males are consistent with the findings of Karpiesiuk et al. (2023*b*). However, the cited authors, i.e. Karpiesiuk et al. (2023*b*), reported that meat from surgically castrated males had a lower contribution of yellowness than meat from gilts. In a study by Daza et al. (2016), meat from IM females was redder than meat from IM males, and meat from surgically castrated males had a more intense color and tended to have lower oxymyoglobin and metmyoglobin levels than meat from entire females.

Quality of meat from the LD muscle (fatty acid profile)

In the present study (Table 6), the FA profile of meat varied across sex groups. Meat from the LD muscle of entire males was characterized by a significantly ($p \leq 0.05$) lower content of SFAs, particularly palmitic acid (C16:0), compared with all other sex groups (gilts, surgically castrated males, and IM males). No significant differences in the proportion of MUFAs

Table 6

Fatty acid profile of the longissimus dorsi muscle of pigs (g 100 g^{-1} total fatty acids) – means ±SD

Specification	Gilts	Surgically castrated males	Entire males	Immunocastrated males
C 12:0	0.093^{a}±0.061	0.075±0.018	0.055^{b}±0.007	0.062^{b}±0.023
C 14:0	1.164±0.158	1.037±0.172	1.055±0.118	1.108±0.137
C 15:0	0.042±0.011	0.036±0.013	0.041±0.010	0.043±0.010
C 16:0	33.21^{A}±3.605	32.79^{a}±3.164	29.35^{Bb}±3.311	33.43^{A}±2.750
C 16:1	1.644±0.285	1.881±0.608	1.692±0.428	1.698±0.282
C 17:0	0.184^{b}±0.070	0.208±0.072	0.206±0.061	0.251^{a}±0.084
C 17:1	0.070±0.030	0.081±0.032	0.086±0.026	0.088±0.023
C 18:0	18.46±1.724	18.18±2.689	16.62±2.451	18.56±2.496
C 18:1 c9	39.39±2.521	39.40±3.160	38.45±2.076	38.30±2.734
C 18:2	4.693^{B}±3.134	5.266^{B}±3.049	10.94^{A}±4.070	5.564^{B}±2.521
C 18:3	0.086^{B}±0.186	0.092^{b}±0.107	0.247^{Aa}±0.183	0.061^{B}±0.051
C 20:0	0.203^{Aa}±0.039	0.172^{b}±0.031	0.162^{B}±0.018	0.175^{b}±0.051
C 20:1	0.487±0.146	0.431±0.033	0.492±0.054	0.424±0.052
C 20:2	0.098^{B}±0.110	0.112^{B}±0.072	0.261^{A}±0.116	0.114^{B}±0.063
C 20:4	0.132±0.334	0.216±0.193	0.320±0.356	0.105±0.079
C 22:0	0.019±0.022	0.014±0.009	0.009±0.010	0.011±0.008
SFAs	53.39^{a}±5.038	52.52^{a}±6.307	47.50^{b}±5.440	53.64^{a}±5.217
UFAs	46.61^{b}±5.038	47.48^{b}±6.307	52.49^{a}±5.440	46.36^{b}±5.217
MUFAs	41.59±2.696	41.79±3.680	40.72±2.249	40.51±2.970
PUFAs	5.010^{B}±3.731	5.687^{B}±3.319	11.77^{A}±4.659	5.845^{B}±2.690
n-3 PUFAs	0.086^{b}±0.186	0.091^{b}±0.107	0.246^{Aa}±0.183	0.061^{B}±0.051
n-6 PUFAs	4.924^{B}±3.553	5.595^{B}±3.236	11.52^{A}±4.484	5.784^{B}±2.639
DFAs=UFAs+C18:0	65.07^{B}±3.667	65.66^{b}±3.808	69.12^{Aa}±3.395	64.92^{B}±2.914
OFAs=C14:0+C16:0	34.93^{A}±3.667	34.33^{a}±3.808	30.88^{Bb}±3.395	35.08^{A}±2.914

a, *b* – data in the same row followed by different letters differ significantly ($P<0.05$),
A, *B* – data in the same row followed by different letters differ significantly ($P<0.01$),
SFAs – saturated fatty acids, UFAs – unsaturated fatty acids, MUFAs – monounsaturated fatty acids, PUFAs – polyunsaturated fatty acids, DFAs – hypocholesterolemic fatty acids, OFAs – hypercholesterolemic fatty acids

in meat were found between the groups analyzed. In addition, meat from entire males had significantly higher concentrations of UFAs ($p\leq0.05$), especially PUFAs ($p\leq0.01$). The higher proportion of PUFAs in meat from entire males was due to significantly higher levels of α-linolenic acid (C18:3 *n*-3, $p\leq0.01$, $p\leq0.05$), linoleic acid (C18:2 *n*-6, $p\leq0.01$), and eicosadienoic acid (C20:2 *n*-6, $p\leq0.01$). In the current study, no significant differences in the

total content of the analyzed FA groups were observed between gilts vs. surgically castrated males and IM males. The proportion of n-6 PUFAs in meat from IM males was comparable to that in meat from gilts and significantly higher than that in meat from surgically castrated males. The proportion of n-6 PUFA in the LD muscle of entire males was highly significant compared to the other sex groups. The proportion of *n*-3 PUFA in castrated gilts and males was significantly higher than in immunocastrated males. The content of hypocholesterolemic fatty acids (DFAs) was significantly higher in the LD muscle of entire males, compared with gilts, IM ($p \leq 0.01$) and surgically castrated males ($p \leq 0.05$). The opposite was observed in the content of hypercholesterolemic fatty acids (OFAs).

Both fat content and the FA profile influence the quality and processing suitability of pork (Faustman et al. 2010). The FA profile may vary depending on animal species and sex, anatomical location of a given muscle, and diet (Blicharski et al. 2013). Czech et al. (2022) found that the sex of PIC pigs had no significant effect on the FA profile of the analyzed tissues. They also demonstrated that a wet diet, compared with a dry diet, improved the FA composition of the *longissimus lumborum* (LL) muscle, backfat, and perirenal fat.

Poklukar et al. (2020) reported that in commercial Landrace × Piétrain crosses, meat from surgically castrated males had a higher proportion of SFAs and a lower proportion of PUFAs than meat from immunocastrates and entire males. Karpiesiuk et al. (2023*b*), who compared the FA profile of meat from the *longissimus lumborum* (LL) muscle of DanBred Hybrid gilts, surgically castrated males, and IM males, also obtained different results from the present findings. The cited authors found that meat from gilts had a significantly lower total content of SFAs and a higher content of UFAs, compared with meat from surgically castrated males. In general, FA concentrations in meat are usually intermediate in IM males, placing them between entire males and surgically castrated males (Grela et al. 2013, Mackay et al. 2013). However, Dobiesz et al. (2023) observed no significant differences in the FA content of meat between entire males and gilts. Similar observations were made by Karpiesiuk et al. (2023*b*). In their study, the concentrations of DFAs and OFAs in meat from the LL muscle were comparable in gilts and castrated males, with no significant differences between the examined sex categories. Pauly et al. (2008) observed that the concentration of polyunsaturated fatty acids (PUFA) in backfat was higher in GnRF-vaccinated males than in bar-rows, while other authors found no differences in total PUFA between the two treatments (Boler et al. 2011, Font-i-Furnols et al. 2012). The higher PUFA content may be due to lipid metabolism during growth in entire males, which is regulated by anabolic steroid activity. These influence lipogenesis and promote lipid expenditure (Kelly, Jones 2013). It is available during puberty in males (Claus et al. 1994). Immunocastration, on the other hand, causes a slowdown in the metabolic rate and,

consequently, the accumulation of more fat tissue in the muscles (Škrlep et al. 2020). According to Argemí-Armengol (2021), FA concentrations in the body, particularly in muscles and reserve fat, depend on the type of feed consumed by animals (including the source of dietary fat) and feeding system. However, it should be noted that elevated n-6 PUFA levels in meat and backfat have a negative influence on their oxidative stability and storage properties (Wood et al. 2004). The optimal ratio of n-6 to n-3 acids is below 4. Essential unsaturated fatty acids (NNKT) are materials for the biosynthesis of hormones such as prostaglandins and leukotrienes. They also lower serum cholesterol levels.

CONCLUSIONS

The results of this study indicate that castration affects both the carcass traits and meat quality of DanBred Hybrid pigs. Carcass lean content was highest in entire males and gilts, and lowest in IM males. Loin eye height was lowest in IM males, significantly lower than in gilts. Castration had no significant effect on backfat thickness. An analysis of the chemical composition of the LD muscle revealed that the dry matter content of meat was significantly lower in entire males than in gilts. The crude fat content of meat was significantly lower in entire males and gilts than in surgically castrated males and IM males. Sex had a significant influence on the contribution of the yellow component (b*) in the LD muscle. Meat from males (entire males, surgically castrated males, and IM males) was characterized by significantly higher yellowness than meat from gilts. The castration method did not induce changes in the contribution of redness to meat color. In comparison with the other sex categories (gilts, surgically castrated males, and IM males), entire males were characterized by a significantly lower content of SFAs and a higher content of PUFAs, including higher concentrations of α-linolenic acid, linoleic acid, and eicosadienoic acid in the LD muscle. Further studies of larger sample sizes are needed to confirm or refute the current findings.

Author contributions

K.D., K.K – conceptualization.; K.D., K.K., W.K., M.D., J.K., C.P. – methodology; K.K. and W.K. – validation; K.K. – formal analysis; K.K., W.K., M.B-S., M.D. P.F., M.P., M.S-N, Z.K. – investigation; K.D., K.K., M.B-S. – resources; K.D., K.K., M.D. – data curation; K.D., K.K., W.K. – writing – original draft preparation; K.D., K.K., M.B-S. – writing – review and editing; K.K, W.K., M.B-S. – visualization; K.K. – supervision; K.K. – project administration; K.K., W.K., C.P. – funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

Aluwé, M., Heyrman, E., Almeida, J., Babol, J., Battacone, G., Čítek, J., Font i Furnols, M., Getya, A., Karolyi, D., Kostyra, E., Kress, K., Kušec, G., Mörlein, D., Semenova, A., Škrlep, M., Stoyanchev, T., Tomašević, I., Tudoreanu, L., Van Son, M., Żakowska-Biemans, S., Zamaratskaia, G., Van den Broeke A. and Egea, M. (2020) 'Exploratory survey on European consumer and stakeholder attitudes towards alternatives for surgical castration of piglets', Animals. 2020, 10 (10), 1758. available: https://doi.org/10.3390/ani10101758

Aluwé, M., Tuyttens, F.A.M. and Millet S. (2015) 'Field experience with surgical castration with anaesthesia, analgesia, immunocastration and production of entire male pigs: performance, carcass traits and boar taint prevalence' Animal, 9(3), 500-508, available: https://doi.org/10.1017/s1751731114002894

AOAC. (2007). Association of Official Analytical Chemists. Official Methods of Analysis. 19th Edition, Arlington.

Argemí-Armengol, I., Villalba, D., Bertolín, J.R., Latorre, M.Á., Panella-Riera, N. and Álvarez-Rodríguez, J. (2021) 'Dietary silage supplement modifies fatty acid composition and boar taint in pork fat', *Annals of Animal Science*, available: https://doi.org/10.2478/aoas-2021-0086

Babicz, M. and Kasprzyk, A. (2019) 'Comparative analysis of the mineral composition in the meat of wild boar and domestic pig', Italian Journal of Animal Science, 18(1), pp. 1013-1020, doi:10.1080/1828051X.2019.1610337

Batorek, N., Škrlep, M., Prunier, A., Louveau, I., Noblet, J., Bonneau, M. and Čandek-Potokar M. (2012) 'Effect of feed restriction on hormones, performance, carcass traits, and meat quality in immunocastrated pigs', *Journal of Animal Science*, 90(12), 4593-4603, available: https://doi.org/10.2527/jas.2012-5330

Blicharski, T., Książek, P., Pośpiech, E., Migdał, W., Jóźwik, A., Poławska, E., Lisiak, D., Hammermeister, A. and Warda, A. (2013) 'Aktualna wartość dietetyczna wieprzowiny, jej znaczenie w diecie i wpływ na zdrowie konsumentów', available: https://doi.org/10.13140/RG.2.1.2213.7048

Bocian, M., Jankowiak, H. and Kapelański W. (2015) 'Zmiany barwy mięsa w trakcie przechowywania', *Nauka Przyroda Technologie*, available: https://doi.org/10.17306/J.NPT.2015.4.57

Boler, D.D., Clark, D.L., Baer, A.A., Meeuwse, D.M., King, V.L., McKeith, F.K. and Killefer, J. (2011) 'Effects of increasing lysine on further processed product characteristics from immunologically castrated male pigs', *Journal of Animal Science*, 89(7), 2200-2209, available: https://doi.org/10.2527/jas.2010-3641

Bonneau, M. and Weiler, U. (2019) 'Pros and cons of alternatives to piglet castration: welfare, boar taint, and other meat quality traits', *Animals*, 9(11), 884, available: https://doi.org/10.3390/ani9110884

Channon. H. A., Kerr, M. G. and Walker, P. J. (2004) 'Effect of duroc content, sex and ageing period on meat and eating quality attributes of pork loin', *Meat Science*, 66(4), 881–888, available: https://doi.org/10.1016/j.meatsci.2003.08.010

Claus, R., Weiler, U. and Herzog, A. (1994) 'Physiological aspects of androstenone and skatole formation in the boar – A review with experimental data', *Meat Science*, 38(2), 289-305, available: https://doi.org/10.1016/0309-1740(94)90118-x

Czech, A., Kusior, G., Zięba, G., Łukaszewicz, M. and Grela, E.R. (2022) 'Effect of immunocastration on the steroid hormones content, serum lipid profile, and fatty acid profile in tissues of porkers fed dry or wet diet', *Animal Science Papers and Reports*, 2022, 40 (2), 171-184, available: https://www.igbzpan.pl/uploaded/FSiBundleContentBlockBundleModelTranslatableBlockTranslatableFilesElement/filePath/2132/str171-184.pdf

Daza, A., Latorre, M.A., Olivares, A. and López Bote, C.J. (2016) 'The effects of male and female immunocastration on growth performances and carcass and meat quality of pigs intended for dry-cured ham production: A preliminary study', *Livestock Science*, 190, 20-26, available: https://doi.org/10.1016/j.livsci.2016.05.014

Dobiesz, K., Kozera, W., Okorski, A., Żak, G., Krzysztoń, J. and Karpiesiuk, K. (2023) 'Wpływ płci tuczników na skład chemiczny i profil kwasów tłuszczowych mięśnia najdłuższego grzbietu świń hybrydowych DanBred', *Roczniki Naukowe Zootechniki*. 2023, 50(2), 311-320, available: https://doi.org/10.58146/dwdy-6661

Dunshea, F.R., Allison, J.R., Bertram, M., Boler, D.D., Brossard, L., Campbell, R. and Mullan, B.P. (2013) 'The effect of immunization against GnRF on nutrient requirements, growth performance, carcass characteristics, and meat quality of male pigs', Animal, 7(10), 1760-1772, available: https://doi.org/10.1017/S1751731113001401

EFSA (Europejski Urząd ds. Bezpieczeństwa Żywności) (2004) 'Opinia o Panel naukowy ds. zdrowia i dobrostanu zwierząt na wniosek Komisji dotyczący aspektów kastracji prosiąt związanych z dobrostanem', Efsa J. 2004, 91:1–18

Faustman, C., Sun, Q., Mancini, R. and Suman, S.P. (2010) 'Myoglobin and lipid oxidation interactions: Mechanistic bases and control', *Meat Science*, 86(1), 86-94, available: https://doi.org/10.1016/j.meatsci.2010.04.025

Font-i-Furnols, M., Gispert, M., Soler, J., Diaz, M., Garcia-Regueiro, J.A., Diaz, I. and Pearce, M.C. (2012) 'Effect of vaccination against gonadotrophin-releasing factor on growth performance, carcass, meat and fat quality of male Duroc pigs for dry-cured ham production', *Meat Science*, 91(2), 148-154, available: https://doi.org/10.1016/j.meatsci.2012.01.008

Grela, E.R., Kowalczuk-Vasilev, E. and Klebaniuk, R. (2013) 'Performance, pork quality and fatty acid composition of entire males, surgically castrated or immunocastrated males, and female pigs reared under organic system', *Polish Journal of Veterinary Sciences*, 16(1), 107-114, available: https://doi.org/10.2478/pjvs-2013-0015

Jankowiak, H., Bocian, M. and Barczak, J. (2019) 'The effect of intramuscular fat content on the meat quality of plw x pl pigs', *Italian Journal of Food Science*, 2019, 31, 87-97, available: https:/doi.org/10.14674/IJFS-1141

Kang, M.H. (2013) 'Enhancement of pork quality from pigs fed feeds supplemented with antioxidants containing defatted sesame dregs and dried barley leaves', *International Journal of Nutrition and Food Sciences*, 2(6), 301, available: https://doi.org/10.11648/j.ijnfs.20130206.16

Karpiesiuk, K., Bugnacka, D., Penkowski, A., Falkowski, J., Woźniakowska, A., Jarocka, B. and Kozera, W. (2019) 'The effect of a feeding and rearing system on the physicochemical properties of pork', *Journal of Elementology*, (3/2019), available: https://doi.org/10.5601/jelem.2019.24.1.1737

Karpiesiuk, K., Kozera, W., Daszkiewicz, T., Lipiński, K., Kaliniewicz, J., Okorski, A., Pszczółkowska, A., Żak, G. and Matusevičius, P. (2023a) 'The effect of dietary supplementation with guar (Cyamopsis tetragonoloba) meal protein on the quality and chemical composition of pig carcasses', *Annals of Animal Science*, available: https://doi.org/10.2478/aoas-2023-0020

Karpiesiuk, K., Kozera, W., Cybulska, A., Okorski, A. and Findura, P. (2023b) 'The effect of sex on meat quality and the fatty acid profile of the longissimus lumborum muscle in growing -finishing pigs', *Journal of Elementology*, (3/2023), available: https://doi.org/10.5601/jelem.2023.28.2.3029

Kelly, D.M. and Jones, T.H. (2013) 'Testosterone: a metabolic hormone in health and disease', *Journal of Endocrinology*, 217(3), 25-45, available: https://doi.org/10.1530/joe-12-0455

Kouba, M., Enser, M., Whittington, F.M., Nute, G.R. and Wood, J.D. (2003) 'Effect of a high--linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig1', *Journal of Animal Science*, 81(8), 1967–1979, available: https://doi.org/10.2527/2003.8181967x

Kouba, M. and Sellier, P. (2011) 'A review of the factors influencing the development of intermuscular adipose tissue in the growing pig', *Meat Science*, 88(2), 213-220, available: https://doi.org/10.1016/j.meatsci.2011.01.003

Kozera, W., Karpiesiuk, K., Bugnacka, D., Falkowski, J. and Milewska, W. (2016) 'Production performance of pigs reared in different systems and fed increased energy content diets with or without green alfalfa', *South African Journal of Animal Science*, 46(1), 70, available: https://doi.org/10.4314/sajas.v46i1.9

Kress, K., Millet, S., Labussière, É., Weiler, U. and Stefanski, V. (2019) 'Sustainability of pork production with immunocastration in Europe', *Sustainability*, 11(12), 3335, available: https://doi.org/10.3390/su11123335

Kropiwiec-Domańska, K., Babicz, M., Szyndler-Nędza, M., Tyra, M. and Skrzypczak, E. (2024) 'Analysis of Physical Parameters and Chemical Composition of Offal From Puławska Fattening Pigs Raised in Deep Litter and Slatted Floor Housing Systems', Annals of Animal Science, Vol. 24 (Issue 1), 269-276. https://doi.org/10.2478/aoas-2023-0070

Lin-Schilstra, L. and Ingenbleek, P.T.M. (2021) 'Examining alternatives to painful piglet castration within the contexts of markets and stakeholders: A comparison of four EU Countries', *Animals*, 11(2), 486, available: https://doi.org/10.3390/ani11020486

Mackay, J., Pearce, M.C., Thevasagayam, S. and Doran, O. (2013) 'Fatty acid composition and lipogenic enzyme protein expression in subcutaneous adipose tissue of male pigs vaccinated against boar taint, barrows, and entire boars', *Journal of Animal Science*, 91(1), 395-404, available: https://doi.org/10.2527/jas.2011-4685

Miao, Z.G., Wang, L.J., Xu, Z.R., Huang, J.F. and Wang, Y.R. (2009) 'Developmental changes of carcass composition, meat quality and organs in the Jinhua pig and Landrace', *Animal*, 3(3), 468-473, available: https://doi.org/10.1017/s1751731108003613

Nałęcz - Tarwcka T. (2006) 'Produkcja zwierzęca cz.2., Bydło i trzoda chlewna', Wydawnictwo Hortpress Sp. z o.o. 2006

Pauly, C., Spring, P., O'Doherty, J.V. and Bee, G. (2008) 'Effect of castration of male pigs on fat quality', In Proc. 59th EAAP Annual Meeting 2008, Vilnius, 27, 8, 8

Pauly, C., Spring, P O'Doherty, J.V., Kragten, S.A. and Bee, G. (2009) 'Growth performance, carcass characteristics and meat quality of boars, castrated and gilts fed diets with different energy levels', Animal, 3(7), 1147-1155, available: https://doi.org/10.1017/S1751731109004658

Pauly, C., Luginbühl, W., Ampuero, S. and Bee, G. (2012) 'Expected effects on carcass and pork quality when surgical castration is omitted — Results of a meta-analysis study', *Meat Science*, 92(4), 858-862, available: https://doi.org/10.1016/j.meatsci.2012.06.007

Poklukar, K., Čandek-Potokar, M., Vrecl, M., Batorek-Lukač, N., Fazarinc, G., Kress, K., Weiler, U., Stefanski, V. and Škrlep, M. (2020) 'The effect of immunocastration on adipose tissue deposition and composition in pigs', *Animal*, 100118, available: https://doi.org/10.1016/j.animal.2020.100118

Poulsen Nautrup, B., Van Vlaenderen, I., Aldaz, A. and Mah, C.K. (2018) 'The effect of immunization against gonadotropin-releasing factor on growth performance, carcass characteristics and boar taint relevant to pig producers and the pork packing industry: A meta-analysis', *Research in Veterinary Science*, 119, 182-195, available: https://doi.org/10.1016/j.rvsc.2018.06.002

Rydhmer, L., Zamaratskaia, G., Andersson, H.K., Algers, B., Guillemet, R. and Lundstrom, K. (2013) 'Aggressive and sexual behaviour of growing and finishing pigs reared in groups without castration', Acta Agriculturae Scandinavica, Animal Science, 63(3), 119-127, available: https://doi.org/10.1080/09064702.2013.853166

Škrlep, M., Poklukar, K., Kress, K., Vrecl, M., Fazarinc, G., Batorek Lukač, N., Weiler, U., Stefanski, V. and Čandek-Potokar, M. (2020) 'Effect of immunocastration and housing conditions on pig carcass and meat quality traits', *Translational Animal Science*, 4(2), 1224-1237, available: https://doi.org/10.1093/tas/txaa055

Škrlep, M., Tomašević, I., Mörlein, D., Novaković, S., Egea, M., Garrido, M.D., Linares, M.B., Peñaranda, I., Aluwé, M. and Font-i-Furnols, M. (2020) 'The use of pork from entire male and immunocastrated pigs for meat products – an overview with recommendations', *Animals*, 10(10), 1754, available: https://doi.org/10.3390/ani10101754

Statystyczny, P.G.U. (2024) 'Rocznik statystyczny', Nakład Głównego Urzędu Statystycznego. Warszawa. https://stat.gov.pl/

Trevisan, L. and Brum, J.S. (2020) 'Incidence of pale, soft and exudative (PSE) pork meat in reason of extrinsic stress factors', *Anais da Academia Brasileira de Ciências*, 92(3), available: https://doi.org/10.1590/0001-3765202020190086

Wood, J.D., Richardson, R.I., Nute, G.R., Fisher, A.V., Campo, M.M., Kasapidou, E., Sheard, P.R. and Enser, M. (2004) 'Effects of fatty acids on meat quality: a review', *Meat Science*, 66(1), 21-32, available: https://doi.org/10.1016/s0309-1740(03)00022-6

Zamaratskaia, G., Andersson, H.K., Chen, G., Andersson, K., Madej, A. and Lundstrom, K. (2008) 'Effect of a gonadotropin-releasing hormone vaccine (immunocastration) on steroid hormones, boar taint compounds and performance in male pigs', Journal of Animal Science, 86(10), 2527-2535, available: https://doi.org/10.2527/jas.2007-0714

Zapotoczny, P., Kozera, W., Karpiesiuk, K. and 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 Science*, 97(4), 518-528, available: https://doi.org/10.1016/j.meatsci.2014.03.010