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Carcass and meat quality in growing-finishing pigs fed diets with plant-based protein sources alternative to genetically modified soybean meal

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The objective of this study was to evaluate carcass and meat quality in growing-finishing pigs fed diets with different vegetable protein sources. It was found that partial (50% in grower diets) and complete (100% in finisher diets) replacement of protein from genetically modified soybean meal (GM-SBM) with protein from 00-rapeseed meal (00-RSM), alone or in combination with protein from faba bean seeds (FB) cv. 'Albus', yellow lupine seeds (YL) cv. 'Taper' or corn DDGS, had no significant effect on carcass quality characteristics or the chemical composition of meat. In all groups, meat samples were characterized by color typical of pork, high water-holding capacity and low pH values. A sensory analysis of the eating quality attributes of meat revealed that they were highly satisfactory; only aroma intensity was affected by the experimental factor. The study demonstrated that growing-finishing pigs can be fed complete diets containing the analyzed vegetable protein sources alternative to GM-SBM without compromising carcass or meat quality.

Key words: carcass dressing percentage, carcass lean content, pork, chemical composition, physicochemical and sensory properties

Introduction

In modern pig farming, fattening is based on complete diets whose nutritional value must support the growth rate of animals and protein deposition potential. Due to the high demand of pigs for protein, in addition to cereals as the basic feed material for mixtures, the necessary components are high-protein fodder, such as extraction meal, beans of legumes, and dry cereal decoctions.

The risk of transmission of bovine spongiform encephalopathy (BSE) and transmissible spongiform encephalopathies (TSE) is a substantial health concern in Europe. Various measures have been adopted to prevent the spread of these diseases, including a ban on the use of meat and bone meals in animal feeds, which was introduced in the European Union (EU) in 2001 (EC 2001). This ban has been amended (EU 2021) and now some of the processed animal proteins (nearly comparable to meat and bone meal) is allowed to be fed to pigs in EU.

A negative balance of trade in high-protein ingredients used for feeding monogastric farm animals has been made up by importing soybean meal (SBM). Genetically modified (GM) soybeans account for around 98% of global soybean production. However, the use of GMOs is prohibited in organic livestock production. High fluctuations in the prices and supply of GM-SBM (Woyengo et al. 2014) and the need to ensure feed protein security have prompted a search for alternative, cheaper sources of plant based protein such as legume seeds, by-products of 00-rapeseed processing and distillers grains.

00-rapeseed meal (00-RSM) is the second, after SBM, most common protein source in animal diets worldwide (Zhou et al. 2013). Protein from 00-RSM has a desirable amino acid composition. In comparison with SBM, it has higher concentrations of sulfur-containing amino acids (methionine and cystine), and lower concentrations of lysine, threonine and tryptophan. Due to its high methionine and cystine content, 00-RSM protein is characterized by higher values of the essential amino acid index (EAAI) (Sobotka et al. 2012) and the protein efficiency ratio (PER) (Aider and Barbana 2011) than SBM protein (82.1 vs. 80.4, and 2.64 vs. 2.19, respectively), which points to its higher biological value. Moreover, 00-RSM is rich in essential minerals, mostly potassium, sulfur, calcium and

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iron compounds and, most importantly, phosphorus and selenium compounds. It contains large amounts of choline, biotin, folic acid, niacin, riboflavin and thiamine (Khattab and Arntfield 2009). It also has high crude fiber content (12.7% DM), which reduces the absorption of other nutrients, including protein and minerals (Zhou et al. 2013). The low energy value of 00-RSM and the presence of antinutritional factors (mainly glucosinolates) limit its use in complete diets for monogastric animals (Mikulski et al. 2012). Breeding efforts have resulted in the development of new, double-low (00) rapeseed varieties where glucosinolate content has been decreased (Mailer et al. 2008) from 166 µmol g^{-1} defatted meal to less than 25 µmol g^{-1} defatted meal (Tripathi and Mishra 2007).

Legume seeds, including yellow lupin (YL) and faba bean (FB) seeds, are another source of protein in pig diets. The crude protein content of YL seeds ranges from 44.7% DM to 48.2% DM, depending on cultivar (Schumacher et al. 2011), and it is lower in FB seeds, ranging from 29.6% DM to 31.5% DM (Gatta et al. 2013, Sobotka and Fiedorowicz Szatkowska 2021). Globulin concentration is higher than albumin concentration in legume proteins, and legume seeds have a relatively low content of sulfur-containing amino acids (Varasundharosoth and Barnes 1985), which is more than 50% lower than in SBM. Therefore, pig diets containing legume seeds should be supplemented with other plant-based protein sources rich in sulfur-containing amino acids, e.g. 00-RSM or crystalline methionine (Jezierny et al. 2010). Similarly to 00-RSM, legume seeds contain antinutritional factors, which limits their use in complete pig diets. Lupine seeds contain mostly alkaloids (Zulak et al. 2006) and α-galactosides (Martínez-Villaluenga et al. 2006), whereas FB seeds contain tannins (Akande et al. 2010, Sobotka and Fiedorowicz-Szatkowska 2021).

Distillers grains, including distillers dried grains with solubles (DDGS), are yet another source of plant-based protein in pig diets. These by-products of bioethanol and biofuel production have recently been given considerable attention as animal feed. Corn DDGS have a high content of crude protein (23.6%–29.4%), crude fat (4.5%–10.9%) and crude fiber (5.5%–7.7%) (Cromwell et al. 2011, Foltyn et al. 2013, Świątkiewicz et al. 2013). The nutrient content of corn DDGS may be up to three times higher than in the grain, and DDGS contain large amounts of soluble and insoluble fiber fractions (Emiola et al. 2009). The amino acid composition of corn DDGS is not as diverse as that of SBM, and lysine content ranges from 0.41% to 0.88% (Xue et al. 2012). The advantage of DDGS is the possibility of reducing the need for supplemental inorganic phosphorus in animal diets. In comparison with corn grain, DDGS contain more phosphorus (59%) because most phosphorus in the grain is fixed in the form of unavailable phosphate complexes (Pedersen et al. 2007). The digestibility of phosphorus from corn DDGS (70%– 90%) is comparable to that of dicalcium phosphate (Stein and Shurson 2009).

Previous studies investigating the fattening performance of pigs have focused on single plant-based protein sources. However, the effect of 00-RSM combined with legume seeds or corn DDGS, as a partial or complete substitute for GM-SBM, on pork carcass quality has not been researched to date. In view of the above, the objective of this study was to evaluate carcass and meat quality in growing-finishing pigs fed diets with different plant-based protein sources alternative to GM-SBM. During two-phase fattening, pigs were fed GM-SBM and 00-RSM – alone or in combination with FB seeds cv. 'Albus', YL seeds cv. 'Taper' or corn DDGS.

Materials and methods

Experimental animals and diets

The animal protocol and the number of animals used in this study were consistent with regulations of the Local Institutional Animal Care and Use Committee (23/2013 Olsztyn, Poland), and the study was carried out in accordance with EU Directive 2010/63/EU on the protection of animals used for scientific purposes (EU 2010).

The experimental materials comprised 36 male hybrid DanBred growing-finishing pigs (barrows). All animals were purchased at the same pig farm. They were housed in individual pens with a surface area of 2.6 m^2 (length 1.7 m × width 0.95 m × height 1 m) with a slatted floor, equipped with nipple drinkers. During seven days preceding the feeding trial, the animals were fed an adaptation diet composed of SBM, ground barley and wheat grain, minerals, vitamins and amino acids. Then the pigs were allocated to groups based on the analogue method. Fattening pigs were fed the twice-daily dosing system (at 0730 h and 1430 h), and had free access to water.

Table 1. Feeding trial design

Group	Number of animals	Source of plant-based protein
Grower diet[1] – 50% of protein from GM-SBM was replaced with protein from the analyzed high-protein feed ingredients		
S-c	7	GM-SBM
R	7	GM-SBM + 00-RSM
R + FB	7	GM-SBM + 00-RSM + seeds of faba bean cv.'Albus'
R + YL	7	GM-SBM + 00-RSM + seeds of yellow lupine cv. 'Taper'
R + D	8	GM-SBM + 00-RSM + corn DDGS[3]
Finisher diets[2] – 100% of protein from GM-SBM was replaced with protein from 00-RSM in 50%, and with FB (50%), YL (50%), D (50%)		
S-c	7	GM-SBM
R	7	00-RSM
R + FB	7	00-RSM + seeds of faba bean cv.'Albus'
R + YL	7	00-RSM + seeds of yellow lupine cv. 'Taper'
R + D	8	00-RSM + corn DDGS

[1] – grower diets: S-c = control group – genetically modified soybean meal (GM-SBM); R = genetically modified soybean meal (GM-SBM) + 00-rapeseed meal (00-RSM); R+FB = genetically modified soybean meal (GM-SBM) + 00-rapeseed meal (00-RSM) + seeds of faba bean cv. 'Albus'; R+ YL = genetically modified soybean meal (GM-SBM) + 00-rapeseed meal (00-RSM) + seeds of yellow lupine cv. 'Taper'; D – genetically modified soybean meal (GM-SBM) + 00-rapeseed meal (00-RSM) + corn DDGS.
[2] – finisher diets: S-c = control group – genetically modified soybean meal (GM-SBM); R = 00-rapeseed meal (00-RSM); R+FB = 00-rapeseed meal (00-RSM) + seeds of faba bean cv. 'Albus'; R+ YL = 00-rapeseed meal (00-RSM) + seeds of yellow lupine cv. 'Taper'; D = 00-rapeseed meal (00-RSM) + corn DDGS.
[3] – DDGS (distillers dried grains with solubles)

In the feeding trial, pigs with initial body weight of 26 kg were divided into five groups (Table 1). They were fed complete grower diets where 50% of protein from GM-SBM was replaced with protein from 00-RSM, alone or in combination with protein from FB seeds cv. 'Albus', YL seeds cv. 'Taper' or corn DDGS, followed by finisher diets where 100% of protein from GM-SBM was replaced with the above high-protein feed ingredients. Grower and finisher diets were fed to pigs with body weight of 26–67 kg and 67–104 kg, respectively. The composition of grower and finisher diets is presented in Table 2. The nutritional value of diets was calculated based on the content of digestible nutrients (Sobotka and Fiedorowicz-Szatkowska 2021) using the formula proposed by the Rostock Feed Evaluation System (RFES) (Grela and Skomiał 2014). The animals were fed dosing system of crumbled feed that was offered wet (feed/water ratio of 1:1).

Characteristics of feedstuffs and experimental diets

Cereal grain (barley, wheat), high-protein vegetable feed ingredients (Hi-pro SBM, YL cv. 'Taper') and complementary mineral feed (Dolfos WT 2.5%) were purchased. Experimental diets were prepared based on own formulations (Table 2). Feed ingredients were weighed, ground to particle size of approximately 0.8 mm, and thoroughly mixed in a feed mixer. The remaining components were added as premix containing complementary mineral feed and crystalline lysine. At the end of the production process, rapeseed oil was added directly to the mixer, in the amount specified in the formulations. All ingredients were mixed for 15 min. The composition of Dolfos WT 2.5% (per kg) is given in the footnote under Table 2.

Analysis of carcass and meat quality

At the completion of the feeding trial, pigs with final body weight of 103–105 kg were slaughtered on the same day at a meat processing plant. The slaughtering and post-slaughter handling were carried out in accordance with the current meat industry regulations (EC 2009). Approximately 45 min *post mortem*, the pH value of muscle tissue (pH_1) was measured between the last thoracic vertebra and the second lumbar vertebra. Backfat thickness and carcass lean content were determined with the use of the CGM 100 ultrasonic device, at the level of the last thoracic vertebra, 7 cm from the dorsal midline. Loin eye height in the *longissimus dorsi* (LD) muscle and carcass dressing percentage (ratio of hot carcass weight to body weight before slaughter) were also determined. The carcasses were chilled at a temperature of 2–4 °C for 24 h, and meat samples for laboratory analyses were collected during dressing of right half-carcasses, from the LD muscle between the last thoracic vertebra and the second lumbar vertebra.

Table 2. Composition of complete grower and finisher diets (%)

Feed ingredients	Experimental diets									
	Grower (26–67 kg BW)					Finisher (67–104 kg BW)				
	S-c	R	R + FB	R + YL	R + D	S-c	R	R + FB	R + YL	R + D
Substitution of GM-SBM[1] protein, %	0.0	50	50	50	50	0.0	100	100	100	100
Wheat	40.00	38.00	36.00	38.00	37.00	44.0	41.00	39.00	42.00	39.00
Barley	40.30	37.47	35.93	37.96	35.27	43.60	41.57	39.12	41.25	39.57
Soybean meal	16.00	8.00	8.00	8.00	8.00	9.00	-	-	-	-
00 rapeseed meal	-	12.00	6.00	6.00	6.00	-	13.00	6.00	6.00	6.00
Faba bean cv. 'Albus'	-	-	10.00	-	-	-	-	12.00	-	-
Yellow lupine cv. 'Taper'				6.00	-	-	-	-	7.00	-
Corn DDGS	-	-	-	-	10.00	-	-	-	-	12.00
Rapeseed oil	1.00	1.80	1.40	1.30	1.00	1.00	2.00	1.50	1.30	1.00
L-lysine HCL (78%)	0.20	0.23	0.17	0.24	0.23	0.20	0.23	0.18	0.25	0.23
Dolfos 2.5% (WT)[2]	2.50	2.50	2.50	2.50	2.50	2.20	2.20	2.20	2.20	2.20
	Nutrition value of diets (g kg^{-1})									
ME [3] (MJ/kg)	12.86	12.79	12.81	12.75	12.79	12.81	12.72	12.85	12.77	12.86
Total protein	170.0	170.8	171.5	171.7	171.3	148.3	148.0	149.3	148.7	149.1
Digestible protein[3]	150	144	149	150	145	129	125	127	128	125
Lysine	9.71	9.69	9.77	9.70	9.69	8.11	8.06	8.17	8.03	8.05
Methionine + cystine	6.01	6.21	6.05	6.17	6.11	5.41	5.67	5.43	5.50	5.41
Threonine	6.11	6.31	6.20	6.21	6.29	5.19	5.39	5.20	5.24	5.56
Tryptophan	2.21	2.43	2.20	2.27	2.19	1.90	2.10	1.98	1.92	1.93
Crude fiber	48.3	56.5	55.5	57.7	55.4	48.2	55.7	56.2	58.3	58.7
Calcium	7.51	7.57	7.40	7.52	7.48	6.30	6.67	6.50	6.63	6.50
Total phosphorus	5.10	5.61	5.43	5.44	5.28	5.10	5.43	5.19	5.21	5.23
Sodium	1.50	1.50	1.50	1.50	1.50	1.30	1.30	1.30	1.30	1.30

[1] = genetically modified soybean meal; [2] = complementary mineral feed (Lysine 140 g; L-Lysine 110 g; Methionine 16.8; DL-Methionine+Cystine 15 g; L-Threonine 16.7 g; Tryptophan 5.4 g; Valin 7.2 g; Ca 192 g; mineral and free P 50 g; Na 51 g; Mg 16 g; vit.: A 400000 IU, D3 80000 IU, E 2200 mg, K 120 mg, B1 80 mg, B2 240 mg, B6 120 mg, B12 1200 µg, biotin 6000 µg. niacin 960 mg; pantothenic acid 480 mg; folic acid 40 mg; betaine 2480 mg; choline chloride 5360 mg; Fe 4000 mg; Zn 4000 mg; Mn 2400 mg; Cu 600 mg; I 32 mg; Se 12 mg; phytase); [3] = was calculated based on the content of digestible nutrients (Sobotka and Fiedorowicz-Szatkowska 2021) using the formula proposed by the Rostock Feed Evaluation System (RFES) (Grela and Skomiał 2014)

Analytical procedures

Qualitative analyses of the LD muscle were performed approximately 48 h *post mortem*. The chemical composition of meat (content of dry matter = DM, intramuscular fat = IMF, crude protein and minerals as ash) was determined (AOAC 2006). pH_{48} was measured in muscle homogenates, with the Hamilton combination Double Pore electrode (Hamilton Bonaduz AG, Bonaduz, Switzerland) and a 340i pH-meter equipped with the WTW temperature sensor TFK 150/E (WTW Wissenschaftlich-Technische Werkstätten, Weilheim, Germany). The water-holding capacity of meat (ability to bind own water) was determined by the Grau and Hamm method (Van Oeckel et al. 1999). Meat color was determined based on the values of CIELAB coordinates, L* (lightness), a* (redness), b*(yellowness) (CIE 1978). Color space parameters L*, a* and b* were measured by the reflectance method using the HunterLabMiniScan XE Plus spectrocolorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA) with standard illuminant D65, a 10 standard observer angle and a 2.54-cm-diameter aperture. L*, a*, b* values were the average of three independent measurements at random sites across the muscle. Shear force was measured after thermal treatment (Honikel 1998) using the Instron 5542 universal testing machine (Instron, Canton, MA, USA) fitted with a Warner-Bratzler head (500 N, speed 100 mm min^{-1}).

The sensory properties of thermally processed meat were evaluated by six trained panelists selected for their sensory sensitivity (ISO 2012). The panelists assessed samples in individual compartments. Fluorescent white lights (500 lx) that simulated daylight, installed at a height of approximately 1 m, were used to evenly illuminate the table. Relative air humidity of minimum 60% and temperature of 21 °C were maintained in the panel room. The sensory attributes of thermally processed pork were evaluated after removing external fat and epimysium. Meat was cut into 2 cm cubes. Prior to the analysis, the samples were heated in 0.6% NaCl solution at 96 °C (±2 °C) until internal temperature reached 85 °C. The serving temperature of meat samples was around 40 °C. The sensory properties of meat were evaluated on a five-point hedonic scale: aroma and taste - intensity: 5 points - very distinct, 4 points - distinct, 3 points - weakly distinct, 2 points - perceptible, 1 point - imperceptible; aroma and taste - desirability: 5 points - very desirable, 4 points - desirable, 3 points - indifferent, 2 points - slightly undesirable, 1 point - very undesirable; juiciness: 5 points - juicy, 4 points - slightly juicy, 3 points - weakly juicy, 2 points - slightly dry, 1 point - clearly dry; tenderness: 5 points - very tender, 4 points - tender, 3 points - slightly tough, 2 points - tough, 1 point - very tough;

Statistical analyses

The results were processed statistically by one-way ANOVA, using STATISTICA ver. 13.3 software (TIBCO Software Inc., Palo Alto, CA, USA). Arithmetic means, the standard error of the mean (SEM) and p-value are presented in the Tables. Duncan's test was applied to estimate the significance of differences ($p \le 0.05$ and $p \le 0.01$) in meat quality parameters between meat samples.

Results

Carcass quality characteristics

The use of the complete grower/finisher R+YL mixture (with the participation of 00-RMS and YL seeds) in the nutrition of growing-finishing pigs, had a statistically significant effect ($p \le 0.05$) on increasing the average daily gains over the entire fattening period (26–104 kg body weight of growing-finishing pigs) in relation to growing-finishing pigs from group R, R + FB and R + D group. However, in relation to growing-finishing pigs from the S-c group, the obtained growth rate of growing-finishing pigs of the R+YL group was also better. Despite this, the average values of this parameter of the analysed groups did not differ significantly ($p > 0.05$).

It was found that throughout the fattening period, the use of the evaluated sources of plant based protein significantly influenced ($p \le 0.05$) feed use. Growing-finishing pigs from the R+YL group made better use of feed in relation to the R, R+FB and R+D groups. However, in the S-c group, these differences were statistically insignificant ($p > 0.05$).

The live weight of growing-finishing pigs and carcass quality are presented in Table 3. Diets containing different vegetable protein sources had no significant ($p > 0.05$) effect on the values of the analyzed parameters.

Table 3. Fattening effects, live weight of growing-finishing pigs and carcass quality ($\overline{x}$)

Specification	Group[1]					SEM[3]	*p-value*
	S-c	R	R + FB	R + YL	R + D		
Substitution of GM-SBM[2] protein in grower/finisher diets, %	0/0	50/100	50/100	50/100	50/100		
Daily gains for the entire fattening period, g	1001	970^{b}	986^{b}	1027^{a}	983^{b}	6.181	0.041
Feed consumption per 1 kg of weight gain of fattening pig for the entire fattening period, kg	2.67	2.79^{a}	2.73^{a}	2.58^{b}	2.74^{a}	0.022	0.032
Body weight before slaughter, kg	105.21	103.11	104.78	104.39	104.88	0.296	0.376
Carcass dressing percentage, %	73.99	73.85	75.19	74.73	75.48	0.320	0.409
Backfat thickness, mm	16.29	16.39	17.00	16.14	16.26	0.261	0.387
Carcass lean content, %	56.66	56.16	56.26	56.74	56.41	0.287	0.958
Loin eye height in the LD muscle, mm	55.00	54.49	57.43	56.29	58.63	1.312	0.493

[1] – refer to Table 2; [2] = genetically modified soybean meal; [3] = standard error of the mean

The average body weight of pigs before slaughter was similar (p>0.05) in all groups. No significant (p>0.05) differences were found in carcass dressing percentage, either. Pigs fed diets containing FB seeds (group R + FB) were characterized by the highest (p>0.05) average backfat thickness. Carcass lean content was high and comparable in all groups (p>0.05). Loin eye height in the LD muscle was greatest in pigs receiving DDGS (R + D) and smallest in group R animals, but the noted differences were not statistically significant (p>0.05).

Meat quality characteristics

The chemical composition of the LD muscle in growing-finishing pigs is presented in Table 4. Diets containing different plant-based protein sources had no significant (p>0.05) effect on the proximate chemical composition of the LD muscle. The DM and crude protein content of meat was similar (p>0.05) in all groups. The IMF content of meat tended (p>0.05) to decrease in pigs receiving diets R, R + D and R + FB, compared with the animals fed diet S-c. The meat of pigs fed YL seeds had higher IMF content, but the differences relative to the remaining groups were not significant (p>0.05). The mineral (ash) content of meat was comparable in all groups (p>0.05).

Table 4. Chemical composition (%) of the *longissimus dorsi* muscle in growing-finishing pigs ($\overline{x}$)

Specification	Group[1]						
	S-c	R	R + FB	R + YL	R + D	SEM[3]	*p*-value
Substitution of GM-SBM[2] protein in grower/finisher diets, %	0/0	50/100	50/100	50/100	50/100		
Dry matter	25.74	25.72	26.16	25.98	25.28	0.122	0.176
Crude protein	22.95	22.56	23.28	23.10	22.80	0.103	0.231
Intramuscular fat	2.34	2.30	2.05	2.77	2.21	0.086	0.103
Crude ash	1.16	1.14	1.14	1.13	1.16	0.007	0.757

[1] – refer to Table 2; [2]= genetically modified soybean meal; [3] = standard error of the mean

An analysis pH value (pH_1), performed approximately 45 min *post mortem*, revealed significant (p≤0.01) differences between the groups (Table 5). pH value of the LD muscle was higher in groups S-c, R and R + FB than in group R + D. The values of ultimate pH (pH_{48}) measured in muscle homogenates were lower (p≤0.05) in group R + YL than in the remaining groups.

Water-holding capacity was significantly (p≤0.05) better in the LD muscles of pigs fed diets containing 00-RSM alone and in combination with FB seeds, compared with the LD muscles of control group animals and pigs receiving YL seeds (Table 5).

No significant (p>0.05) differences in the color lightness (L*), red (a*) and yellow (b*) color components of the LD muscle were observed between the groups (Table 5).

Table 5. Physicochemical properties of the *longissimus dorsi* muscle in growing-finishing pigs ($\overline{x}$)

Specification	Group[1]						
	S-c	R	R + FB	R + YL	R + D	SEM[3]	*p*-value
Substitution of GM-SBM[2] protein in grower/finisher diets, %	0/0	50/100	50/100	50/100	50/100		
pH_1	6.39 ^{A}	6.43 ^{A}	6.40 ^{A}	6.32	6.22 ^{B}	0.022	0.007
pH_{48}	5.47 ^{a}	5.50 ^{a}	5.45 ^{a}	5.35 ^{b}	5.47 ^{a}	0.016	0.022
Water-holding capacity, Grau and Hamm method, cm^2	6.56 ^{a}	5.64 ^{b}	5.80 ^{b}	6.50 ^{a}	6.27	0.118	0.035
L* lightness	55.26	53.19	52.97	55.09	54.80	0.350	0.095
a* redness	6.71	7.29	6.88	7.02	6.55	0.170	0.703
b* yellowness	13.49	13.76	13.45	14.26	13.47	0.115	0.129

[1] – refer to Table 2; [2] = genetically modified soybean meal; within rows, means followed by different letters are significantly different at p≤0.05 ($^{a, b}$) and p≤0.01 ($^{A, B}$); SEM – standard error of the mean

The sensory properties and shear force of the LD muscle are presented in Table 6. Aroma intensity scores were higher ($p \leq 0.05$) in group R + FB than in groups R and R + YL. No significant ($p > 0.05$) differences in the remaining sensory attributes (aroma desirability, taste intensity, taste desirability, juiciness, tenderness) were found between the groups. Diets with the analyzed vegetable protein sources had no significant ($p > 0.05$) effect on shear force values in the LD muscle.

Table 6. Sensory properties (points[1]) and shear force (N) of the cooked *longissimus dorsi* muscle in growing-finishing pigs ($\overline{x}$)

Specification	Group[2]					SEM[4]	*p*-value
	S-c	R	R + FB	R + YL	R + D		
Substitution of GM-SBM[3] protein in grower/finisher diets, %	0/0	50/100	50/100	50/100	50/100		
Aroma – intensity	4.61	4.45[b]	4.95[a]	4.55[b]	4.75	0.049	0.046
Aroma – desirability	4.73	4.71	4.71	4.64	4.75	0.050	0.991
Taste – intensity	4.65	4.92	4.83	4.62	4.81	0.047	0.377
Taste – desirability	4.75	4.72	4.92	4.75	4.81	0.051	0.087
Juiciness	4.43	4.73	4.55	4.92	4.66	0.057	0.330
Tenderness	3.82	4.35	4.63	4.03	4.65	0.126	0.857
Shear force	35.56	31.36	42.85	31.27	40.28	1.926	0.213

[1] = five-point hedonic scale: aroma and taste - intensity: 5 points - very distinct, 4 points - distinct, 3 points - weakly distinct, 2 points - perceptible, 1 point - imperceptible; aroma and taste - desirability: 5 points - very desirable, 4 points - desirable, 3 points - indifferent, 2 points - slightly undesirable, 1 point - very undesirable; juiciness: 5 points - juicy, 4 points - slightly juicy, 3 points - weakly juicy, 2 points - slightly dry, 1 point - clearly dry; tenderness: 5 points - very tender, 4 points - tender, 3 points - slightly tough, 2 points - tough, 1 point - very tough; [2] – refer to Table 2; [3] = genetically modified soybean meal; [4] = standard error of the mean; [a, b] – within rows, means followed by different letters are significantly different at $p \leq 0.05$

Discussion

Carcass quality characteristics

Analysing the results on the amount of daily gains and feed use for the entire fattening period (Table 3), a beneficial effect of supplementing rapeseed protein with faba bean seed protein, yellow lupine or corn DDGS was observed. Despite this, only statistically significant differences were found when using the yellow lupine feed set (R+YL), which turned out to be the best in relation to the feed set from the R, R+FB and R+D groups. It should be assumed that the yellow lupine protein is a good, natural supplement to the protein of rapeseed meal and better than the protein of faba bean or corn DGGS. It can also contribute to improving the protein quality of growing-finising pigs fed diets with the participation of yellow lupine and 00-rapeseed meal.

In the present study, there was no significant effect of partial and complete replacement of GM-SBM with alternative protein sources protein in grower/finisher diets on the analysed pork carcass quality. Similar results were reported by other authors who analyzed the efficacy of 00-RSM (Thacker and Newkirk 2005, McDonnell et al. 2010, Sobotka et al. 2012), corn DDGS (Yoon et al. 2010, Xu et al. 2010, Lee et al. 2011, Świątkiewicz et al. 2013), YL seeds (Roth-Maier et al. 2004, Hanczakowska and Świątkiewicz 2014) and FB seeds (Zijlstra et al. 2008, White et al. 2015) in pig nutrition.

The LD muscle has long been considered a reliable indicator of carcass lean content, and today it is also used in regression equations for estimating lean content in live animals and *post mortem*. Both the weight and dimensions (including height) of the LD muscle are important from the technological perspective because this muscle is processed into high-quality meat products. In the current experiment, there was no tendency to increase the height of the LD muscles in all experimental groups. A decrease in LD muscle dimensions and carcass lean content is usually accompanied by an increase in carcass weight and fat deposition. However, such clear relationships were not observed in this study.

It is a well-known fact that the carcasses of light pigs have higher lean content than the carcasses of heavy animals, and that carcass lean content decreases with increasing slaughter weight. In the present study, carcass lean percentage was similar in all groups, which is satisfactory because the analyzed carcasses could be assigned to class E in the SEUROP pork carcass grading system.

Backfat thickness is an indicator of carcass fat content, which in turn determines the market value of pork carcasses. Cromwell et al. (2011) noted a significant decrease in backfat thickness, from 22.5% in the control group to 21.6% in growing-finishing pigs fed diets containing 45% corn DDGS. Degola (2015) demonstrated that diets containing 20% FB seed significantly increased carcass fatness. A similar trend was observed in this study, in the group fed 50% FB seeds.

Carcass dressing percentage is one of the most important criteria of production profitability. It is determined by numerous factors which affect the final carcass weight of pigs intended for sale. One of such factors is a high content of dietary fiber, which reduces dressing percentage because fiber is not completely digested in the gastrointestinal tract. The gastrointestinal tract is removed and it is not included in carcass weight. On the other hand, concentrated and nutrient-dense feeds contribute to increasing carcass yield. Whitney et al. (2006) found that carcass dressing percentage decreased significantly (73.35% vs. 71.90%) when grower-finisher pigs were fed 30% high-quality corn DDGS. Stein and Shurson (2009) also concluded that lower carcass yield in pigs receiving corn DDGS resulted from high dietary fiber concentration. In the current study, diets with different plant-based protein sources had no significant influence on carcass dressing percentage.

Meat quality characteristics

The inclusion of various plant-based protein sources in pig diets had no significant effect on the chemical composition of the LD muscle, which corroborates the findings of other authors. The chemical composition of pork was not significantly affected by the dietary inclusion of corn DDGS (Lee et al. 2011, Świątkiewicz et al. 2013), SBM (Jansons et al. 2020), 00-RSM (Zmudzińska et al. 2020), FB seeds (Milczarek and Osek 2016) and YL seeds (Sońta et al. 2017).

The chemical composition of meat, determined in this study, was typical of the porcine LD muscle (Zaworska-Zakrzewska et al. 2020). However, in comparison with the control group, the IMF content of the LD muscle tended to be lower in in pigs fed FB seeds, and higher in those receiving YL seeds. In the current experiment, the IMF content of meat was in the 2%–3% range, which is optimal for pork. According to Jankowiak et al. (2019), IMF content of 1.8%–2.6% is indicative of high-quality pork. The minimum IMF content of 1.5% is required to ensure adequate juiciness, tenderness and taste of pork (Fortin et al. 2005). A too low IMF content of meat may adversely affect its sensory attributes and processing suitability.

The physicochemical properties of meat are the main indicators of its processing suitability and eating quality because they affect the overall appearance and shelf life of meat as well as the sensory quality of meat dishes. The pH value, which is shaped during post-slaughter glycolysis, exerts a considerable effect on meat quality because it influences the eating quality (tenderness, juiciness), technological properties (color, water-holding capacity) and microbiological stability of meat (Vermeulen et al. 2015). The typical pH values of fresh pork are $pH_1 \geq 6.0$ and $pH_{24} \geq 5.5$ (Przybylski et al. 2012). In the present study, ultimate pH (pH_{48}) was slightly below 5.5 (except in group R), which may point to a tendency towards the ASE defect. The reason for the low pH values of the analyzed meat is difficult to determine, particularly in the group fed YL seeds, because many factors contribute to quality defects in meat, including the type, quantity and quality of feed as well as genotype, housing and fattening conditions, and pre-slaughter handling of animals (Śmiecińska et al. 2011). However, according to published studies, lupin included in pig diets does not decrease meat pH, leading to quality defects (Moore et al. 2016, Hanczakowska et al. 2017).

Water-holding capacity is one of the key determinants (next to pH and color) of the technological quality of meat. It refers to the ability of meat to retain its water during thermal treatment and affects meat weight loss during storage. In the current experiment, significant differences in the water-holding capacity of meat were noted between pigs fed diets with different plant-based protein sources. Water-holding capacity was highest in group R + FB, and lower in groups R + YL and S-c. Despite the observed differences, the water-holding capacity of pork was satisfactory in all groups. Hanczakowska and Świątkiewicz (2014), and Sońta et al. (2017) demonstrated that YL seeds fed to fattening pigs had no significant effect on the water-holding capacity of their meat. Similar observations were made by Milczarek and Osek (2016) who analyzed the efficacy of FB seeds in pigs.

Color is another attribute that affects the technological quality of meat. It is one of the most important properties influencing consumer purchase decisions, because consumers perceive color as an indicator of meat freshness and wholesomeness (Mancini and Hunt 2005). There is a linear relationship between the active pH value of meat and color lightness (L*) (Kim et al. 2016, Richardson et al. 2018). An increase in meat pH causes a decrease in L*, and a decrease in meat pH induces an increase in L*. However, such a clear correlation was not observed in this study. An analysis of pork color based on the values of CIELAB coordinates revealed that the experimental factor had no had no influence on color parameters (L*a*b*), which corroborates the findings of Hanczakowska and Świątkiewicz (2014), Moore et al. (2016), Sońta et al. (2017), and Zmudzińska et al. (2020). Some studies have shown that not only the type of high-protein feed of plant origin, but also their share in compound feed for porkers, may affect the color of the meat. Partanen et al. (2003) reported that meat from growing-finishing pigs became significantly darker, and Minolta a* (redness) and b* (yellowness) values decreased linearly with increasing dietary inclusion levels of FB seeds. According to Milczarek and Osek (2016), FB seeds have no effect on the contribution of yellowness, whereas corn DDGS decreases the value of parameter b* in the LD muscle (Milczarek and Osek 2014a). Xu et al. (2010) found that increasing inclusion levels of corn DDGS (from 0% to 20%) in diets fed to grower-finisher pigs influenced meat color by decreasing the contribution of yellowness and redness. In the work of Sobotka et al. (2012), the meat of pigs receiving 00-RSM was characterized by a significantly lower contribution of redness and a higher contribution of yellowness, and it was lighter in color than the meat of control group animals.

In the consumers' opinion, sensory attributes are among the most important properties of meat. In the present study, the sensory quality of pork was not significantly affected by diets with different high-protein ingredients. The experimental factor had a significant influence only on aroma intensity, and the meat of pigs fed FB seeds scored highest for this attribute. It should be noted that aroma, taste and juiciness scores were high in all groups. Meat samples scored slightly lower for tenderness, especially in group S-c, and the shear force of the LD muscle of pigs fed FB seeds and corn DDGS tended to be higher.

Milczarek and Osek (2014b) analyzed the effect of FB seeds on the quality of meat from Pulawska pigs and found no significant differences in sensory attributes between the control and experimental groups. In a study by Partanen et al. (2003), 00-RSM and FB seeds had no significant effect on the taste of pork. Xu et al. (2010) and Moreno et al. (2009) observed no significant differences in the sensory properties of meat from growing-finishing pigs fed corn DDGS, either. Sobotka et al. (2012) found that the meat of pigs fed 00-RSM had a more desirable aroma but scored lower for consistency, relative to the control group. According to Hanczakowska and Świątkiewicz (2014), YL seeds may adversely affect the taste and aroma of meat. Lee et al. (2011) reported that diets fed to finishing pigs had no influence on the shear force of the LD muscle, which is consistent with the results of this study.

Conclusions

The results of this study indicate that partial (50% in grower diets) and complete (100% in finisher diets) replacement of protein from GM-SBM with protein from 00-RSM, alone or in combination with protein from FB seeds cv. 'Albus', YL seeds cv. 'Taper' or corn DDGS, had no significant effect on carcass quality characteristics or the chemical composition of meat. Only the IMF content of the LD muscle tended to be higher in pigs receiving YL seeds, compared with the remaining groups. In all groups, meat samples were characterized by color typical of pork, high water-holding capacity and low pH values. A sensory analysis of the eating quality attributes of meat revealed that they were highly satisfactory. Only aroma intensity was affected by the experimental factor, and the meat of pigs fed FB seeds scored highest for this attribute.

Growing-finishing pigs can be fed complete diets containing the analyzed vegetable protein sources alternative to GM-SBM without compromising carcass or meat quality.

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