



THE EFFECT OF FEEDING FATTENER PIGS WITH HYBRID RYE ON SELECTED GROWTH AND CARCASS TRAITS AND ON MEAT QUALITY CHARACTERISTICS*

Dariusz Lisiak¹, Piotr Janiszewski^{1*}, Karol Borzuta¹, Tomasz Schwarz², Eugenia Grześkowiak¹, Urszula Siekierko¹, Jakub Lasek³

¹Department of Meat and Fat Technology, Prof. Waław Dąbrowski Institute of Agricultural and Food Biotechnology, Poznań, Poland

²Faculty of Animal Science, University of Agriculture in Kraków, Poland

³Experimental Station of the National Research Institute of Animal Production in Chorzeów, 39-331 Chorzeów, Poland

*Corresponding author: piotr.janiszewski@ibprs.pl

Abstract

Modern hybrid varieties of rye can be successfully used for feeding pigs. The aim of the research was to determine the effects of different levels (20%, 40% and 60%) of hybrid rye in diet on the growth, slaughter value, chemical composition, physical and sensory traits and the fatty acids profile in pork meat. The experiment was performed with 100 Polish Landrace pigs that were randomly allocated into 4 groups: control, without rye, and experimental with hybrid rye addition. After slaughter lean meat content estimation, carcass traits, quality characteristics and the fatty acids profile of the *longissimus lumborum* muscle were determined. No significant influence on the growth performance, carcass traits and the majority of physical traits, basic composition, cholesterol content and sensory features of the *longissimus lumborum* muscle was found. The type and levels of cereals significantly change the FA profile. More favorable values for PUFA and the ratio of n-6/n-3 acids were obtained in pigs fed with hybrid rye than with a mix of wheat with barley. In conclusion, feeding pigs with hybrid rye at the level of 20–60% in the diet results in positive effects in the fatty acids profile, without compromising daily gain, feed intake, carcass traits, physicochemical and sensory attributes of pork meat.

Key words: hybrid rye, pigs, feeding, growth, quality of meat

The basic rule in composing feed rations for slaughter animals is to cover their nutritional needs, i.e. energy, protein, minerals and vitamins in order to optimize the daily gains, lean meat content and meat nutritional value. In diets formulated for pigs there is a high percentage of grains – components with high dry matter content (85–90%) and high metabolizable energy concentration (14.2–16.7 MJ ME/kg). In practice grains provide 40 to 85% of diet energy value (Stein et al., 2016). In the concentrated feed mixtures the following grains are generally used: barley, wheat, triticale, rye and corn.

The most desirable grains in pig feeding are barley and wheat. Barley contains more amino acids and fiber and less starch than corn (Cervantes et al., 2014 a, b). The digestibility of the majority of exogenous amino acids in barley and wheat ranges from 70% to 80% and is slightly lower than in corn. Barley can be added *ad libitum* in the diets of all pig age groups even as the only grain component due to the low level of anti-nutritional substances. Wheat is similar to barley and could also be used with no restrictions in pig's diets but can be also consumed by humans and as a result its use in pig diets is reduced.

Rye is seldom used in the feeding of pigs. This cereal is grown in many European countries. Recent research has proved that the production parameters of pigs fed with a diet containing rye were similar to the parameters of pigs fed with barley (Schwarz et al., 2015). In comparison to a diet containing barley, feeding pigs with a classical rye is associated with lower daily gain of fatteners. All grains contain anti-nutritional substances but classical rye contains the greatest quantity of them compared to the other grains. Intensive genetic experiments have been performed on rye in recent years leading to a reduction of its anti-nutritional substances (Makarska et al., 2007; Schwarz et al., 2015). New hybrid rye varieties have an improved crop yield and reduced anti-nutritional substance levels such as alkylresorcinols and trypsin inhibitors and are less sensitive to ergot infection (Stein et al., 2016). The hybrid rye varieties produce a 30% higher crop yield than classical rye. In poor and average soil conditions, hybrid rye varieties produce a higher crop yield than wheat and triticale. Hybrid rye tolerates acidified soils and is frost resistant down to –30°C. It should be highlighted that rye is cheaper than other grains. These positive aspects of hybrid rye con-

*This research was supported by the National Centre for Research and Development (<https://www.ncbr.gov.pl/en/>) in Poland and conducted within the Biostrateg program [grant 'ENERGYFEED' number: BIOSTRATEG2/297910/12/NCBR/2016].

vinced Danish feed specialists to recommend up to 20–28% of hybrid rye share in the feed mixtures for piglets over 15 kg, 10–25% in mixtures for non-pregnant sows and sows at the beginning of pregnancy, and 10% for sows with piglets. The Danish Institute for Pig Breeding recently recommended up to 60% of a hybrid rye share in the diet of non-pregnant and pregnant sows and 35% for sows with piglets (Kasprowicz-Potocka, 2018).

Although a hybrid rye variety in a pig diet is an interesting subject and the number of registered hybrid rye varieties is high (30 in 2018) the knowledge of the effects of hybrid rye on meat quality is limited, possibly due to that fact that it has a low share in field crops. A rye variety can be successfully used for feeding pigs, because it is attractive in terms of price and could reduce the cost of cultivation and feeding. However, there are some restrictions in feeding with classical rye due to the presence of anti-nutritional substances. Modern varieties of rye, especially hybrid ones, have a lower content of these substances than in older varieties. It seems that the modern hybrid varieties of rye should not have a negative influence on the meat quality but this hypothesis needs to be confirmed.

The aim of this research was to study the effect of different levels of hybrid rye in pigs' diets on growth, performance, carcass traits and meat quality characteristics.

Material and methods

Experimental design: animals and diets

The experiment was conducted with 100 Polish Landrace fatteners fed in a two-phase cycle – grower and

finisher. The fattening of the pigs started from the average body weight of 28 ± 5 kg and continued until the weight of approximately 110 ± 9 kg. The animals were in individual pens, fed *ad libitum* with concentrated feed including wheat and barley middlings (Artist and Kosmos cultivars, respectively) and a Brasetto cultivar hybrid rye according to different levels (Table 1). The experiment was simultaneously carried out for all of the studied groups of pigs.

The diets for the control group included 50:50 wheat and barley middlings. The diets of the experimental groups were formulated by excluding equal parts of barley and wheat and including, 20 or 40 or 60% of the examined hybrid rye. The average fattening time was 101 ± 0.9 days. The animals were weighed individually at the beginning of the experiment and then again before slaughter. Daily gain and feed intake were recorded. After fattening the pigs were transported by vehicles from the National Research Institute of Animal Production Experimental Station in Chorzele to the slaughterhouse in Kasinka Mała located 170 km from the experimental station. After 2-hour rest the fatteners were slaughtered by firstly applying 2-electrode stunning with the following parameters: 50 Hz frequency, 250 V voltage, 1.4 A amperage and 7 s electric current application time. Hot carcass weight was measured after the slaughter process on the weighing scale with measurements at 100 g accuracy. On the left of each hot carcass meat content was measured using an Ultra Fom 300 ultrasonic device. After 24 hours of cooling at 4°C the *longissimus lumborum* (LL) muscle was dissected for further lab analyses.

Table 1. Experimental design and diets

Specification	Amount of hybrid rye in diet (%)			
	0 – control	20	40	60
Number of animals	25 pigs	25 pigs	25 pigs	25 pigs
Main ingredients of complete diets (%)				
soybean meal	9.4	10.5	11.4	12.0
barley	41.5	31.0	20.5	10.0
wheat	41.5	30.5	20.1	10.0
rye hybrid	–	20	40	60
soybean oil	1.2	1.3	1.3	1.3
wheat bran	3.7	4.0	4.0	4.0
phosphate	0.2	0.2	0.2	0.2
acidifier	0.1	0.1	0.1	0.1
premix	2.4	2.4	2.4	2.4
Chemical composition of complete diets (%)				
dry matter	89.78	90.3	90.38	89.71
ash	4.86	4.59	4.76	4.74
crude protein	18	17.19	17.04	17.36
crude fat	2.81	3.01	2.49	2.72
crude fiber	3.66	3.36	3.20	2.43
NDF	13.72	13.70	15.11	13.97
ADF	4.71	4.65	5.36	4.8
ADL	0.49	0.57	0.95	0.7
starch	52.36	52.82	52.85	50.55
sugar	7.18	8.33	8.02	8.96
metabolizable energy (MJ)	13.3	13.3	13.3	13.1

Laboratory analysis of diets

Dry matter, ash, crude protein, ether extract and acid detergent fiber (ADF) contents were determined according to AOAC (2004) (procedure numbers 934.01, 942.05, 954.01, 920.39 and 973.18, respectively). Neutral detergent fiber (aNDF) was determined according to a method of Van Soest et al. (1991) using an Ankom 220 Fiber Analyzer (ANKOM Technology, NY, USA) with heat-stable amylase. ADL was determined by a method of Robertson and Van Soest (1981). Starch content was determined by an enzymatic method (Faisant et al., 1995).

Analytical determinations

The physical traits of the LL muscle were analyzed 48 hours post mortem as well as its basic chemical composition, sensory traits and fatty acids profile. The pH of the meat and the electrical conductivity were measured using a Sydel pH-meter with dagger electrode (45 minutes and 48 hours after slaughter) and an MT-03 conductometer (after 48 hours). Meat colour was determined on the LL muscle cross-section using a Minolta Chroma Meter CR 400 device (Konica Minolta) and the colour parameters ($L^*a^*b^*$) were recorded in the CIE Lab scale (light source D65, observer 2°, head slot 8 mm, with calibration on the white standard: $L^*=97.83$; $a^*=-0.45$; $b^*=-1.88$) (AMSA, 2012).

Water holding capacity (WHC) was measured with the Grau and Hamm method (1952) modified by Pohja and Niinivaara (1957). The fat content was determined using the Soxhlet method (ISO 1444, 2000). Water content was estimated according to the standard ISO 1442 (2000). The total protein content was measured according to the Polish standard with the Kjeldahl method, using the Tecator device (PN-75/A-04018).

The LL muscle samples were cooked until the temperature inside the muscle was 70°C (Baryłko-Pikielna and Matuszewska, 2014). The cooking losses were calculated based on the differences between the muscle samples' weight before and after cooking. The sensory estimation of the cooked muscle was performed on a 5-point scale including smell, juiciness, tenderness and flavor. The sensory assessment was performed by 4 scientists (experts) from the Prof. Waław Dąbrowski Institute of Agricultural and Food Biotechnology, who were trained to test sensory sensitiveness (Baryłko-Pikielna and Matuszewska, 2014). The assessment was implemented in daylight at room temperature. On a 5-point scale: smell, juiciness, tenderness and palatability, were evaluated. The following grading scale was used: smell: 1 – very unacceptable; 5 – very acceptable; juiciness: 1 – very dry; 5 – very juicy; tenderness: 1 – very tough; 5 – very tender; palatability: 1 – very unacceptable; 5 – very acceptable. The instrumental tenderness was estimated by shear force measurement with Zwick/Roell apparatus. Cylinder cores with a round cross-section (2,54 cm in diameter) were manually removed parallel to the predominant muscle fiber orientation. The crosshead speed was

set at 200 mm/min. The average shear force of the five results was used for the statistical analyses.

In the intramuscular fat from the raw LL muscle the fatty acids profile was determined. The methyl esters of the fatty acids samples were prepared according to the PN-EN ISO 5509 method (1996). The fatty acids composition was determined by gas chromatography using a Hewlett Packard HP 6890 device (Agilent Technologies) equipped with a flame-ionic detector and a high polarized column with a BPX 70 phase. The column was 60 m long, the layer thickness 0.25 μ m, whereas its internal diameter was 0.22 mm. The analyses were performed in the programmed temperature and time. Individual fatty acids were identified by comparing the retention times to those of a standard FAME mixture (Supelco 37 Component FAME Mix and C18 FAME Isomers, Sigma-Aldrich Co.) and expressed as a relative proportion of all of the FA in the sample.

Statistical analysis

The results were statistically analyzed by calculating the average values and SEM. Data were checked for normal distribution and variance homogeneity by using the Shapiro-Wilk test. A one-factor variance analysis (ANOVA) was also performed for the studied groups. The Statistica 6.0 software was used. The significance of the differences between the average values was determined with the Tukey test (Statsoft, Statistica, 2001) at $P \leq 0.05$.

Ethics statement

All experimental procedures performed on live animals followed the EU Directive 2010/63/EU for animal experiments (2010) and the Polish law for the care of animals used in research and education. According to Polish law (Regulation, 2015), the ethical approval of research is not formally required if experiments involve only the standard operating procedures typically carried out on a commercial farm. The slaughter of animals aimed at obtaining tissues for laboratory analyses is not formally considered as a research procedure and the ethical approval of such action is not required.

Results

Slaughter and physical traits

The different feed levels of hybrid rye in the diets of the pigs did not affect the daily gain, feed intake, carcass weight, lean meat content, backfat and loin thickness measured with an Ultra Fom 300 device (Table 2). The average values of the above-mentioned slaughter traits observed in all of the fatteners groups fed with different grain amounts did not differ significantly compared to the control group. The average lean meat content in the carcasses of all of the investigated groups was between 56% and 57%, which corresponds to class E in the SEUROP classification system (EU Council 1308/2013). Also, main cuts content in carcasses did not differ among

the examined groups, except neck and shoulder content. No significant differences among groups in backfat content was in agreement with the fat thickness results. The lowest content of neck was stated in pigs with 40% amount of hybrid rye in the diet and the lower content of shoulder was observed in the group with a 20% and 40% addition of rye in the diet.

The fatteners fed with hybrid rye did not show significant differences in muscle acidity in both the warm and chilled carcasses (Table 3). No effect was observed in the tested groups on meat lightness, yellowness (b^*) and water holding capacity (WHC). The lowest redness value was observed in the group of fatteners fed with 20% of rye in the feed ration. The higher than 20% rye content in the feed ration increased the meat redness value to the normal level observed in the control group. Lower level of electrical conductivity than in the control group was found in the pig group with the 60% addition of hybrid rye in the diet, which is not related to the pH_{48} results.

Basic chemical content and quality traits of the *longissimus lumborum* muscle

No significant effect of hybrid rye addition in the diet of the fatteners on the chemical composition of the LL muscle was found (Table 4). The composition of the LL muscle was similar to the control group in all of the experimental groups fed with hybrid rye. This chemical composition was typical for lean pork and it reached approximately 73% water, 24% protein and 1.6% fat content.

The amount of hybrid rye in pigs' diet did not affect the examined sensory attributes of the LL muscle, i.e. smell, flavor, juiciness and tenderness (Table 4). All these traits obtained a score between 4 and 4.4 points on the 5-point scale in fatteners fed with hybrid rye and in the control group. Shear force of the LL muscle was also not affected by the addition of hybrid rye in the pigs diet and had the value of about 30 N in the examined groups.

Table 2. Growth and slaughter traits of pigs fed different amounts of hybrid rye grains

Growth and slaughter traits	Addition of hybrid rye grains in diet (%)				SEM	P value
	0	20	40	60		
Feed intake (kg)	281.14	296.52	296.42	286.30	3.98	0.422
Daily gain (g)	869.92	883.25	871.29	867.95	15.39	0.986
Hot carcass weight (kg)	91.48	93.27	90.12	90.59	1.111	0.765
Lean meat content (%)	57.16	56.88	56.32	56.79	0.262	0.718
Fat thickness in point F1 (mm)	15.16	15.06	15.77	14.95	1.132	0.483
Fat thickness in point F2 (mm)	15.14	16.40	17.29	16.00	0.380	0.240
Loin thickness in point M1 (mm)	54.94	55.85	54.87	55.20	0.598	0.937
Loin thickness in point M2 (mm)	55.44	55.16	52.47	53.04	0.619	0.222
Tenderloin content (%)	1.47	1.47	1.52	1.36	0.026	0.241
Loin content (%)	10.92	10.63	10.91	10.69	0.068	0.176
Neck content (%)	7.10 a	7.11 a	6.85 b	7.15 a	0.063	0.001
Leg without shank (%)	26.20	25.99	26.20	25.90	0.100	0.079
Shoulder without shank (%)	14.62 a	14.36 b	14.45 b	14.72 a	0.073	0.001
Belly content (%)	13.24	13.80	13.44	13.37	0.118	0.362
Back fat content (%)	3.10	3.35	3.50	3.15	0.070	0.092

Means marked by differ letters are significant.

Table 3. Physical traits of *longissimus lumborum* muscle of pigs fed different amounts of hybrid rye grains

Physical traits	Addition of hybrid rye grains in diet (%)				SEM	P value
	0	20	40	60		
pH_{45}	6.38	6.40	6.41	6.42	0.029	0.969
pH_{48h}	5.69	5.64	5.67	5.67	0.020	0.812
Electrical conductivity 48h (mS)	5.18 a	4.68 a	4.34 a	3.65 b	0.192	0.037
WHC (%)	31.03	31.66	31.22	30.78	0.438	0.914
Lightness colour L^*	49.93	50.16	49.71	50.06	0.305	0.960
Redness a^*	5.86 a	4.97 b	5.48 a	5.40 a	0.108	0.031
Yellowness b^*	-1.30	-1.61	-1.41	-1.48	0.166	0.926

Explanation as in Table 2.

Table 4. Basic chemical composition and sensory traits of *longissimus lumborum* muscle of pigs fed different amounts of hybrid rye grains

Quality traits	Addition of hybrid rye grains in diet (%)				SEM	P value
	0	20	40	60		
Water content (%)	73.14	72.76	72.37	72.65	0.149	0.322
Fat content (%)	1.59	1.80	1.65	1.67	0.054	0.596
Protein content (%)	23.68	23.83	24.29	24.06	0.111	0.216
Smell (points)	4.40	4.38	4.40	4.48	0.024	0.475
Flavor (points)	4.11	4.05	4.06	4.16	0.033	0.576
Juiciness (points)	4.04	3.98	4.00	4.04	0.038	0.922
Tenderness (points)	3.94	3.86	3.88	4.06	0.040	0.335
Shear force (N)	29.47	29.02	30.70	29.62	0.990	0.420

Table 5. Fatty acids content of *m. longissimus lumborum* lipids of fatteners fed different amounts of hybrid rye (%)

Fatty acids	Addition of hybrid rye grains in diet (%)				SEM	P value
	0	20	40	60		
C12:0	0.06	0.06	0.07	0.06	0.007	0.350
C14:0	1.20	1.21	1.25	1.19	0.011	0.254
C16:0	23.55	24.14	23.82	23.42	0.114	0.115
C16:1	1.94	1.99	2.15a	2.07	0.025	0.013
C18:0	14.37	14.70 a	13.53 b	14.02	0.134	0.013
C18:1 trans	0.13	0.14	0.14	0.15	0.020	0.141
C18:1 cis 9	37.88	38.23	39.23	38.93	0.199	0.060
C18:1 cis 11	2.35 a	2.39 a	2.55 b	2.47 b	0.024	0.018
C18:2	13.67 a	12.58 b	12.46 b	12.60 b	0.169	0.031
C18:3	1.13	1.08	1.13	1.14	0.015	0.401
C20:0	0.28	0.27	0.26	0.26	0.025	0.320
C20:1	1.11	1.07	1.06	1.06	0.018	0.765
SFA	39.81	40.73	39.34	39.42	0.219	0.091
MUFA	43.78 a	44.19a	45.57 b	45.16 b	0.230	0.018
PUFA	16.33 a	15.04b	15.03 b	15.22 b	0.192	0.038
PUFA n-6	14.78 a	13.57b	13.48 b	13.66 b	0.177	0.023
PUFA n-3	1.22	1.16	1.22	1.24	0.016	0.294
n-6/n-3 ratio	12.21 a	11.77 a	11.05 b	11.09 b	0.082	0.001
Cholesterol (mg/100 g)	64.77	64.36	60.11	64.72	1.021	0.320

Explanation as in Table 2.

Fatty acids profile of *longissimus lumborum* muscle

The research results indicated that feeding with 20 to 60% of hybrid rye in the diet did not affect the total SFA level in the *longissimus lumborum* muscle (Table 5). A higher MUFA level was observed in pigs fed with higher rye doses (i.e. 40% and 60%) in the diet and lower level of PUFA acids in all groups fed with the hybrid rye diets. The C18:1 cis 9 and C18:1 trans acids remained at the same level as in the control group, but the content of the

C18:1 cis 11 had the greatest value in the groups with 40–60% addition of rye.

As stated significant differences in the PUFA content in the groups of pigs fed with hybrid rye were observed and led to a decrease of the n-6 to n-3 ratio from approximately 12.2 in the control group to approximately 11 in those groups fed with 40 and 60% of rye in the diet. Rye in the diet did not have any influence on the cholesterol content that ranged from approximately 60 to 65 mg/100 g of tissue.

Discussion

Growth, performance, carcass traits and meat quality characteristics

These present studies have shown that the addition of hybrid rye in the amount of up to 60% of the daily dose did not inhibit the daily growth of the pigs, which indicates a significant impact of the lower content of anti-nutritional substances in this variety of rye on the growth of animals. It should be emphasized that this effect was achieved with the same feed intake per fattening pig, between the control and the rye groups. In all of the studied groups, the daily gain was high, approximately 870 g. It must be underlined that lack of significant differences in daily gain between pigs fed with addition of hybrid rye and control pigs is first of all as a result of the basic chemical content of feed mixture balance for all of the studied pig groups (Table 1) and mainly because of the content of crude protein (ca. 18%), crude fat (ca. 3%), starch (ca. 52%) and sugar (ca. 8%). Only the content of crude fiber was lower with increasing level of hybrid rye in diet. Nevertheless all of the studied pig groups had the diet with the same level of metabolizable energy (ca. 13 MJ). A similar, as in our study, level of daily gain was observed by other authors, e.g. Whitney et al. (2006) from 808 to 862 g and Della Casa et al. (2010) from 767 to 787 g with corn based diets. On the other hand, Bussieres (2018), who studied the influence of hybrid rye of the Brasetto variety on the development of pigs in the finisher feeding phase, achieved greater daily gains. With a level of dietary addition of rye from 10 to 50%, the average daily gain was 944 and 959 g, respectively, and did not differ significantly in comparison with the control group of pigs, fed with a mixture of barley and wheat (971 g).

The results of the present study showed that balanced nutrients in feed and the amount of hybrid rye had significant influence neither on the lean meat content in the carcass nor on backfat thickness, backfat and main carcass cuts content except the neck and shoulder content. Similar results were obtained by Schwarz et al. (2015) who showed that fatteners fed with hybrid rye and slaughtered after 110 days of fattening had similar carcass lean meat content to those fatteners from the control group fed with barley (56.0% and 55.9%, respectively). These positive effects of hybrid rye feeding are the result of the low level of anti-nutrient substances that diminish the digestibility of the feed. Similar results were indicated by Myrie et al. (2008) who evaluated the effect of different levels of anti-nutritional substances on pig development. It was found that hemicelluloses fiber level typical for commercial diets based on barley or wheat bran reduces the intestinal digestibility of amino acids by increasing endogenous losses. The research on the hybrid rye variety Brasetto at a level of 10% and 50% in different vegetation phases did not show an effect on carcass lean meat content and backfat thickness. Loin thickness was also similar (Sevillano et al., 2018).

The research results did not show any clear effect of hybrid rye on physical meat traits such as pH, water holding capacity, colour lightness and yellowness parameter. Only the intensity of meat redness (a^*) was the lowest in the group fed with 20% of rye. This does not mean that rye influences this parameter because at higher rye amounts in the diet the value was not significantly different from the control group, so the differences found may be considered as incidental. It is worth underlining the fact that final meat pH was approximately 5.6–5.7 in all of the experimental groups which is optimal acidity of pork meat (Collective work, 2011). According to Bussieres (2018) including hybrid rye in the pigs' diet in different amounts did not affect drip loss, meat color and marbling but also bacon consistency and fat iodine number. In conclusion the author confirmed that 25% of hybrid rye in the diet of fatteners during the grower fattening phase and 50% during the finisher phase did not have a negative effect on pigs' growth and on carcass slaughter traits and meat quality. The differences in some physical traits observed between the groups were not unidirectional because not all of them were connected with the grain ration increase, so the obtained results may be considered as incidental. Due to this fact the effect of the tested factors on the physical meat traits together with redness and electrical conductivity may be regarded as irrelevant. By the way, electrical conductivity is an indicator for diagnosis of meat quality defects, especially for PSE meat and its level depends on preslaughter stress but not on feeding method. In the scientific literature it was stated that normal meat has conductivity below 8 mS/cm (Pospiech, 2000). It means that average electrical conductivity obtained for all studied pig groups lays in this range and small differences, despite statistical significance, did not have influence on general meat quality.

Chemical and quality traits

The research showed that adding hybrid rye to the pigs' diet did not affect basic LL muscle composition and it was not significantly different in the control and experimental groups. The basic meat composition was similar to typical lean pork which according to the most recent research for the *longissimus dorsi* of class E is as follows: water ca. 72.25%, fat ca. 1.92%, protein ca. 22.54% (Collective work, 2015). Also, the researches of Turyk et al. (2015) and Chapman et al. (2015) confirmed a similar chemical composition of meat from fatteners fed with cereal grains.

The LL muscle sensory attributes results were not affected by any amount of hybrid rye and they were similar in the control and experimental groups.

Fatty acids profile

Today's current lifestyle and our eating habits make us prone to deliver the surplus of energy to our bodies with all the undesired health consequences. Dietitians recommend to reduce fat consumption to the level when energy is delivered by fat in not more than 25–30% of

daily intake (FAO, 1984). These recommendations indicate an optimal amount of nutrients leading to the fat desired dose and zero or limited amount of undesirable ingredients (Collective work, 2006). Such undesirable ingredient are saturated fatty acids which when excessively consumed, increase susceptibility to ischemic heart disease due to their hyper-cholesterolemic effect, i.e. by increasing total cholesterol level and its LDL fraction as well as the atherogenic effect, i.e. causing atherosclerosis.

Feeding fatteners with different hybrid rye doses did not have any effect on the level of SFA in comparison to control group. A similar level of saturated fatty acids (approx. 40%) was found in domestic fatteners and hybrids of Yorkshire $\times$ Danish Landrace, fed with industrial concentrates (Wajda et al., 2004). The authors emphasize that the content of SFA depends on many factors, but mainly on nutrition and breed. According to Grześkowiak et al. (2004), among five different breeds (Polish Large White, Polish Landrace, Duroc, Hampshire, PIC), the highest level of SFA was found in PLW pigs (41.94%) and the lowest in the Hampshire breed (36.32%). Similarly, in 9 South European pig breeds, the SFA level ranged from 33.39% (Nevo Siciliano breed) to 46.60% (Gascon breed) (Pugliese and Sirtori, 2012). The atherogenic arachidic acid C20:0 level did not depend on hybrid rye feeding of pigs. Whereas the MUFA profile was dependent on rye diet in fatteners. The higher the rye doses in the diet (40% and 60%) the higher MUFA level was demonstrated ($P < 0.05$). It was a very important observation because anti-carcinogenic effect of these fatty acids is well known (Ferguson, 2010; Woods and Fearon, 2009). The positive effect of consuming monounsaturated fatty acids, especially the C18:1 acid, in atherosclerosis prevention has been already proved (Collective work, 2006). Such research has been conducted after finding low atherosclerosis morbidity in Mediterranean Sea countries where the olive oil consumption, rich in oleic acid but poor in saturated acids, is common. Hybrid rye addition did not have any effect on C18:1 cis 9 level in pork, but in the group fed with 40% and 60% addition of the rye in the diet the level of C18:1 cis 11 was higher than in the control group.

A similar level of MUFA in PIC hybrids fed with industrial concentrate was found in the studies by Grześkowiak et al. (2004) and Pugliese and Sirtori, (2012) on Basque, Gascon, and Limousin breeds (approximately 44–45 %). A lower level of MUFA was found in the studies by Wajda et al. (2004) in four-breed hybrids (37.76 %).

A significantly lower level of PUFA was observed in all groups of pigs fed with hybrid rye (by approximately 1 p.p. lower), in comparison to the control group ($P < 0.05$). In addition, the confirmed effect of the addition of hybrid rye to the pigs' diet on the reduction of n-6 PUFA levels in comparison with the control group is evident. Confirmed differences in PUFA n-6 level influenced n-6/n-3 ratio that was more profitable in the case of hybrid

rye feeding of all experimental groups. In the meat of fatteners fed with hybrid rye this ratio declined from 12.2 in the control group to 11.8 in the group with 20% addition and 11.1 in the groups with 40 and 60% of rye in the diet.

Micek (2008) showed that the hybrid rye Fernando variety presented a n-6/n-3 ratio at the level of 6.4, which was lower from that obtained with wheat (12.28) and barley (9.89). It may be the reason for the improved results in our study for these coefficients in pigs fed with hybrid rye than with wheat and barley (control group). Feeding pigs with different oils had a great impact on n-6/n-3 ratio. Lisiak et al. (2013) found that flax seed addition to the diet decreased n-6/n-3 ratio to approx. 3 whereas the rape and fish oil addition only to approx. 5.5. In the experiment carried out by Grześkowiak et al. (2008) on 45 hybrid fatteners fed during the final fattening period with complete rations supplemented with 5% and 7.5% preparation from oil flax it was stated that the n-6/n-3 ratio in the backfat amounted to 1.62 and 2.51, i.e. two times lower than in the control group.

According to American requirements included in the Pork Composition and Quality Assessment Procedures (NPPC, 2000) pork fat should contain $< 15\%$ PUFA and $> 15\%$ stearic acid C18:0. The fat containing $> 14\%$ linoleic acid C18:2 is classified as soft fat. In many cases these limits cannot be reached and make the fat technological suitability inappropriate for some products (Della Casa et al., 2010; Collective work, 2015, 2006). Fat obtained from fatteners fed with hybrid rye fulfilled or were close to fulfilling American quality requirements and it was not classified as the soft one which made it more useful for meat products processing, especially for bacon and belly production (Collective work, 2015). No effect of hybrid rye feeding on the total cholesterol level was observed. Meat and fat tissue of fatteners usually contains on average 59 to 62 mg cholesterol in 100 g of tissue (Collective work, 2006), similar to the level obtained within this research (60–65 mg/100 g).

Conclusions

The research showed that feeding pigs with diets containing different amounts of hybrid rye (from 20% to 60%) had neither an effect on the growth nor the backfat thickness and carcass lean meat and main cuts content in comparison to the control group fed with barley and wheat. No significant effect of these grains either on the majority of the physical meat traits or on the basic chemical composition, cholesterol level and LL muscle sensory traits was observed. It was found that the more favorable values for PUFA n-3 and PUFA n-6/n-3 ratio were in the LL muscle of pigs fed with hybrid rye independent of the applied level. To conclude, feeding the pigs in the grower and finisher phase with 20% to 60% of hybrid rye showed positive effects on the fatty acid profile without having a negative effect on the growth, slaughter value, physical and chemical as well as sensory meat traits.

Conflicts of Interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

References

- AMSA Meat Color Measurement Guide (2012). American Meat Science Association.
- AOAC (2004). Official Methods of Analysis, 18th ed. Arlington, VA, USA: Association of Official Analytical Chemists.
- Baryłko-Piekielna N., Matuszewska I. (2014). Sensory food testing. Basics-Methods-Applications (in Polish). Wyd. Nauk. PTTŻ, Kraków.
- Bussières D. (2018). Impact of hybrid rye (Brasetto) on finisher pig performance, carcass and meat quality. *J. Anim. Sci.*, 96, Suppl. 2: 140–141.
- Cervantes-Pahm S.K., Liu Y., Stein H.H. (2014 a). Digestible indispensable amino acid score (DIAAS) and digestible amino acids in eight cereal grains. *Brit. J. Nutr.*, 111: 1663–1673.
- Cervantes-Pahm S.K., Liu Y., Stein H.H. (2014 b). Comparative digestibility of energy and nutrients and fermentability of dietary fibrin eight cereal grains fed to pigs. *J. Sci. Food Agri.*, 94: 841–249.
- Chapman B., Salomon D., Dyson C., Blackley K. (2015). Triticale production and utilization manual. Spring and winter triticale for grain, forage and value-added. Alberta Agric. Food Rural Develop., <http://www1.agric.gov.ab.ca/Sdepartment/deptdocs.nsf/all/fed10538>.
- Collective work (2006). Editors. Flaczyk E., Górecka D., Korczak J. *Towaroznawstwo produktów spożywczych* (in Polish). Wydawnictwo Akademii Rolniczej, Poznań, Poland.
- Collective work (2011). *Meat science and technology basis* (in Polish). SGGW, Warszawa, Poland.
- Collective work (2015). *Current dietary value of pork and its importance in the diet and impact on consumer health* (in Polish). Polski Związek Hodowców i Producentów Trzody Chlewnej POLSUS, Warszawa, Poland.
- Della Casa G., Boichicchio D., Faeti V., Marchetto G., Poletti E., Rossi A., Panciroli A., Mordenti A.L., Bronga N. (2010). Performance and fat quality of heavy pigs fed maize differing in linoleic acid content. *Meat Sci.*, 84: 152–158.
- Directive EU 2010/63/EU on the protection of animals used for scientific purposes.
- EU Council No 1308/2013 establishing a common organization of the markets in agricultural products.
- FAO (1984). WHO Food Standards.
- Faisant N., Planchot V., Kozłowski F., Pacouret M., Colonna P., Champ M. (1995). Resistant starch determination adapted to products containing high level of resistant starch. *Sci. Alimentaire*, 15: 83–89.
- Ferguson L.R. (2010). Meat and cancer. *Meat Sci.*, 84: 308–313.
- Grau R., Hamm R. (1952). Eine einfache Methode zur Bestimmung der Wasserbindung in Fleisch. *Fleischwirtschaft*, 4: 295–297.
- Grzeškowiak E., Borzuta K., Obiedziński M. (2002). Fatty acid content of pork depending on swine genotype. *Ann. Anim. Sci.*, 2: 95–100.
- Grzeškowiak E., Borzuta K., Strzelecki J., Lisiak D. (2004). Effect of APC premix added on slaughter value and fat quality of four crossbred fatteners. *Roczn. Inst. Przem. Mięsn. Tł.*, XLI: 85–93.
- Grzeškowiak E., Tratwal Z., Borzuta K., Zajac P., Lisiak D., Strzelecki J. (2008). Investigation on the effect on the addition to feed of preparation oil flax on slaughter value and carcass meat and fat quality. *Roczn. Inst. Przem. Mięsn. Tł.*, XLVI: 7–20.
- ISO 1442 (2000). Meat and meat products. Determination of water content.
- ISO 1444 (2000). Meat and meat products. Determination of free fat content.
- Kasprowicz-Potocka M. (2018). Rye – nonimportant feeding raw material (in Polish). *Trzoda Chlewna*, 8: 40–42.
- Lisiak D., Grzeškowiak E., Borzuta K., Raj S., Janiszewski P., Skiba G. (2013). Effects of supplementary vegetable and animal fats on the slaughter values of fatteners, meat quality and fatty acid profile in pig. *Czech J. Anim. Sci.*, 58: 497–511.
- Makarska E., Gruszecka D., Gardzielewska A. (2007). The content of alkylresorcinols and trypsin inhibitors activity in translocational rye strains and parental components *Secale cereale* (L.) and *Dasyphyrum villosum* (L.) P. Candargy. *Ann. Univ. Mariae Curie-Skłodowska, Lublin, LXII*: 117–121.
- Micek P. (2008). Nutritional usefulness to ruminants of grain of Polish cereal species and cultivars. *Rozprawy, Zeszyt 326*, Wyd. UR, Kraków.
- Myrie S.B., Bertolo R.F., Saner W., Ball R.O. (2008). Effect of common antinutritive factors and fibrous feedstuffs in pig diets on amino acid digestibilities with special emphasis on threonine. *J. Anim. Sci.*, 86: 609–619.
- NPPC (2000). Requirements in pork composition and quality assessment procedures.
- PN-75/A-04018. Meat and meat products. Determination of protein content by Kjedahl method.
- PN-EN ISO 5509 (1996). Animal and vegetable fats and oils – Preparation of methyl esters of fatty acids.
- Pohja N.S., Niinivaara F.P. (1957). Die Bestimmung der Wasserbindung des Fleischesmittels der Konstantdruckmethodes. *Fleischwirtschaft*, 9: 193–195.
- Pospiech E. (2000). Diagnosing of the meat quality defects (in Polish). *Gosp. Mięśna*, 4: 68–71.
- Pugliese C., Sirtori F. (2012). Quality of meat and meat products produced from southern European pig breeds. *Meat Sci.*, 90: 511–518.
- Regulation (2015) Regulation of January 15, 2015, on the protection of animals used for scientific or educational purposes.
- Robertson J.B., Van Soest P.J. (1981). The detergent system of analysis and its application to human foods. In: *The analysis of dietary fibre in food*, James W.P.T., Theander O. (eds). Marcell Dekker, New York, pp. 123–157.
- Schwarz T., Kuleta W., Turek A., Tuz R., Nowicki J., Rudzki B., Bartolewski P.M. (2015). Assessing the efficiency of using a modern hybrid rye cultivar for pig fattening with emphasis on production costs and carcass quality. *Anim. Prod. Sci.*, 55: 467–473.
- Sevillano C.A., Nicolaiciu C.V., Molist F., Pijlman J., Bergsman R. (2018). Effect of feeding cereals – alternative ingredients diets or corn-soybean meal diets on performance and carcass characteristics of growing – finishing gilts and boars. *J. Anim. Sci.*, 96: 4780–4788.
- Stein H.H., Lagos L.V., Casas G.A. (2016). Nutritional value of feed ingredients of plant origin fed to pigs. *Anim. Feed Sci. Tech.*, 218: 33–69.
- Turyk Z., Osek M., Milczarek A., Janocha A. (2015). Meat chemical composition and blood serum lipids of pigs fed mixtures containing barley or triticale. *Roczn. Nauk. PTZ*, 2: 71–79.
- Van Soest P.J., Robertson J.B., Lewis B.A. (1991). Methods for dietary fibre, neutral detergent fibre and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.*, 74: 3583–3597.
- Wajda S., Daszkiewicz T., Borzuta K. (2004). Quality of pork carcasses of different weights (in Polish). *Zesz. Nauk. Prz. Hod.*, 72: 185–191.
- Whitney M.H., Shurson G.C., Johnston L.J., Wulf D.M., Shanks B.C. (2006). Growth performance and carcass characteristic of grower-finisher pigs fed high quality corn distillers dried grain with solubles originating from modern Midwestern ethanol plant. *J. Anim. Sci.*, 84: 3357–3368.
- Woods V.B., Fearon A.M. (2009). Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs. A review. *Livest. Sci.*, 126: 1–20.

Received: 16 IX 2021

Accepted: 17 X 2022