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Assessing the efficiency of using a modern hybrid rye cultivar for pig fattening, with emphasis on production costs and carcass quality

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Abstract. There were two goals of the present experiment, namely (1) to determine and compare the concentrations of basal nutrients and anti-nutrients in the grain of a modern hybrid rye and barley cultivars, and (2) to compare the effectiveness of the rye- and barley-containing diets for pig fattening. Crude protein and starch contents were greater ($P < 0.01$) in rye (cv. Visello) than in barley (cv. Bryl) but fibre and total lipid concentrations were lower ($P < 0.01$) in rye grain. Mean concentrations of alkylresorcinols and pentosans, as well as the activity of trypsin inhibitors, were all higher ($P < 0.01$) in rye grain. In all, 150 PIC gilts were randomly divided into two equinumerous groups; control pigs were fed a diet containing barley as the main cereal ingredient (starter phase (SP), 35% of feed content; grower phase (GP), 40% of feed content; and finisher phase (FP), 65% of feed content), while the experimental group received a diet with rye replacing a proportion of barley (10% during SP, 25% during GP and 50% during FP); the diets for both subsets of animals also contained wheat and soybean meal to obtain a proper level of nutritional value. The average weight gain of the rye-fed gilts (783 ± 183 g/day; mean ± s.d.) was greater ($P < 0.05$) than that of control animals (747 ± 218 g/day). This difference in weight gain was due mainly to an increase in daily feed intake (2.35 ± 0.21 and 2.15 ± 0.19 kg/day in the experimental and control groups, respectively; $P < 0.01$) recorded during the grower and finisher phase. Carcasses from both groups exhibited the same lean meat content; however, the percentage of carcasses in the higher classes according to the EUROP quality scale tended to be greater in the experimental group, which resulted in a higher ($P < 0.05$) carcass value than for barley-fed controls. The present results indicated that a modern rye cv. Visello is a safe and cost-effective feed for growing pigs, and yields significantly better outcomes than commonly used barley-containing diets in terms of carcass quality and price.

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Introduction

In the 20th-century Europe, rye was the basic feed for working horses and, given as the blanched mash with potatoes, for hogs (Ferrin 1927). The growth of pigs fed rye-based diets seemed to be satisfactory, although there were reports of inconsistent outcomes (Ferrin 1927). Ground barley is a main grain feed for pigs and so all other feeds are compared with it (Sullivan *et al*. 2005). Research over the past 10 years showed that production parameters of pigs that received the diets containing rye were generally similar to those in animals fed barley-containing mixes (Hooper *et al.* 2002; Meyer *et al.* 2012). In comparison to barley, however, feeding the dry rye mixes is associated with a lower feed-conversion rate and weight gain of fattener pigs (Nehring *et al*. 1961). All grain crops contain anti-nutrients, but rye grain contains more anti-nutrient substances than does any other grain (Puztai 1967; Wieringa 1967). However, there are several advantages of cultivating rye, namely the low soil-quality requirements, tolerance for a wide range of climate conditions and high resistance to pests and moulds (Jürgens *et al*. 2012). While rye cultivation is relatively inexpensive, the yields are typically as high as for other cereals (Bujak and Dopierała 2007; Hübner *et al*. 2013). High protein content, combined with the low percentage of fibre, make new rye varieties an attractive choice for commercial pig feeding. Rye grain could be a valuable component of daily feed rations for fattener pigs if deprived of main anti-nutrients.

In recent years, intensive work in rye genetics focussed on the development of cultivars with reduced concentrations of anti-nutrient substances (Makarska *et al*. 2007). A hybrid rye cv. Visello is a relatively new product (year of registration 2007) that possesses all of the characteristics of hybrid rye varieties (such as e.g. winter hardiness and low soil requirements) and the application of the POLLENPLUS technology significantly decreased the cultivar's susceptibility to ergots (www.kws-lochow.pl/odmiany/wszystkie-odmiany/zboze/zyto/odmiana/visello.html and http://www.kws-lochow.pl/odmiany/wszystkie-odmiany/pollenplusr.html, verified 6 February 2014). However, the utility of using this cultivar in pig fattening has yet to be determined. Barley, peas and vegetable waste remain a very effective principal diet for pigs (Sullivan *et al*. 2005), but using the rye-containing mixes could be a more economical option. Hence, the main objective of the present study was to compare the cost and outcomes of commercial pig fattening using the rye-supplemented diet with those of a conventional nutrition regimen that utilises barley-containing feedstuff. The present feed trial was preceded by a standard laboratory analysis of rye and barley grain, and it culminated in the estimation of carcass quality and prices.

Materials and methods

Chemical analyses

All grain samples were initially examined by the Blattin Poland analytical laboratory (Schodnia, Poland). Spring barley (cv. Bryl) and winter hybrid rye (cv. Visello; KWS Lochow, Kondratowice, Poland) were analysed by the Fourier transform–near-infrared (FT–NIR) spectroscopy. Briefly, each sample was exposed to electromagnetic radiation in the near-infrared range that is absorbed by the sample and causes the vibrations of chemical bonds. These vibrations alter the output signal reaching the detector such that it contains readable information about the chemicals contained in the sample. The built-in software analyses points that are specific to individual chemical bonds and identifies individual compounds with high accuracy. Then, the sample spectra are compared with a mathematical model created during the calibration of the device, to determine the qualitative and quantitative chemical composition of the sample.

The second set of samples was sent to the Department of Chemistry at the University of Life Sciences in Lublin, Poland, where concentrations of anti-nutrients were determined using three different methods. The concentrations of akylresorcinols were determined using the method described by Tłuścik (1978). After extraction with acetate, a complex of resorcinols with p-nitroalanin was formed. The concentrations of resorcinols in this complex were measured by spectrophotometry ($\lambda = 435$ nm); a standard curve was prepared using orcinol (Sigma, St Louis, MO, USA). The concentrations of pentosans were determined using the method described by Hashimoto *et al*. (1987). Briefly, after sample extraction with HCl, the material was digested with sodium carbonate (Na_2CO_3), leading to the formation of a complex with iron chloride ($FeCl_3$) and orcinol. The concentration of pentosans in this complex was then measured by spectrophotometry (λ = 670 nm), with a standard curve prepared using xylose (Sigma, St Louis, MO, USA). Last, the activity of trypsin inhibitors was determined using the method described by Kakade *et al*. (1974) and modified by Polanowski (1976). After extraction with an acetate buffer, an enzymatic reaction with casein in phosphate buffer (pH 7.6) was performed. This reaction was then compared with a standard reaction using pure trypsin (Sigma, St Louis, MO, USA).

Animals and experimental procedures

All experimental procedures performed on live animals were in compliance with the EU Directive 2010/63/EU for animal experiments and the Polish law for the care and use of experimental animals (2 August 1997), and had been approved by the local Animal Care and Ethics in Research Committee. The trial was conducted in a commercial farm located in Pilczyca, Poland, and it utilised 150 hybrid gilts (offspring of Camborough sows 22 × boars 337; Pig Improvement Co. (PIC), Warsaw, Poland) in three replicates, each using 50 animals of the same age; at the beginning of the experiment, all pigs were 50 days of age. There were three phases of fattening, using the dry-fodder mixes prepared according to the German DLG standards (DLG 2011) and supplemented with a special premix for PIC pigs (Blattin Poland, Schodnia, Poland). Pigs were randomly divided into two equal groups of 25 animals, the control group and the experimental group. Animals from both groups were kept in five group pens of five animals each. The isocaloric and isonitrogenous diets were then prepared for both subsets of animals studied. In the feedstuff mixes given to experimental animals, a proportion of barley was replaced with the rye cv. Visello, as detailed in Table 1; the final content of rye was 10%, 25% and 50% in the starter, grower and finisher mixes, respectively. The entire fattening period lasted 110 days (25, 35 and 50 days for the starter, grower and finisher phases, respectively). Pigs were fed *ad libitum* by using the Domino feeder system (Domino Co., Tørring, Denmark) and had unrestricted access to water through drinking troughs. The liveweight of all animals was taken at the outset of the experiment, as well as after each fattening phase and before slaughter.

Table 1. Main ingredients, chemical composition and metabolic energy of the control (C) and experimental (E) group diets

Ingredient (%)	Starter		Grower		Finisher	
	C	E	C	E	C	E
Soybean meal	20	20	18.5	18.5	8	7
Rape grain meal	–	–	–	–	4	4
Wheat	40	40	37.2	37.2	25	25
Barley	35	25	40	15	60.5	11.5
Rye	–	10	–	25	–	50
Soybean oil	1	1	1	1	–	–
Minerals and vitamins	4	4	3.3	3.3	2.5	2.5
Dry matter	87.5	87.5	87.4	87.4	87.3	87.3
Ash	6.6	6.6	5.7	5.5	5.1	4.8
Crude protein	17.5	17.5	17.3	17.4	14.5	14.4
Fat	2.7	2.7	2.7	2.6	1.8	1.6
Starch	40.6	41.1	41.5	42.6	46.4	46.7
Monosaccharides	3.8	4.2	3.7	4.6	3.1	4.8
Fibre	3.7	3.4	3.9	3.0	4.6	3.2
Calcium (g/kg)	8.5	8.5	7.6	7.6	6.5	6.6
Phosphorus (g/kg)	6.3	6.2	5.5	5.2	5.4	5.1
Lysine	1.2	1.2	1.1	1.1	0.8	0.8
Methionine + cysteine	0.7	0.7	0.6	0.6	0.6	0.6
Threonine	0.8	0.7	0.7	0.7	0.5	0.5
Tryptophan	0.2	0.2	0.2	0.2	0.2	0.2
Metabolic energy (MJ/kg)	13.08	13.14	13.15	13.28	12.94	12.98

Assessment of carcass quality and prices

After 110 days of fattening, animals were sold to a local abattoir. Carcass weights were taken immediately after the pigs were eviscerated. The lean meat content of carcasses was assessed using an Ultra-Fom 300 apparatus (Carometec Denmark, Herlev, Denmark). Subsequently, the carcasses were assessed using the EUROP standard system and appraised according to the current market prices. The EUROP system for carcasses comprises six different classes varying in the lean meat content by ~5% (from Class S, over 60%, to Class P, <40%). The price of 1 kg of carcass for different classes was as follows: S class, 5.46 Polish currency (PLN); E class, 5.41 PLN; U class, 5.15 PLN; R class, 4.94 PLN; O class, 4.45 PLN; and P class, 3.36 PLN. All cost-related variables analysed in the study had initially been calculated in PLN, but were then converted to $US to provide a clearer comparison to international readers.

Statistical analyses

Mean concentrations of nutrients and anti-nutrients in rye and barley cultivars, and production and economic parameters calculated for the control and experimental groups were assessed by Student's *t*-test, using the Statistica ver. 9 software (StatSoft Poland, Cracow, Poland). Variables listed in Tables 3–6 were analysed and compared between the two subsets of animals used in the study. Data presented in Tables 3 and 5 were analysed from the outset on a per gilt basis (n = 3 replicates × 25 animals/group), whereas data presented in Tables 4 and 6 were initially calculated for the groups of animals placed in a pen (n = 3 replicates × 5 pens × 5 gilts for the treatment and control groups) as the values for daily feed intake and conversion rates could not be determined for individual animals housed in group pens. As there were no apparent differences among the study replicates or pens, the data were combined for all animals in each group. Percentages of pig carcasses in different classes were compared between the treatment and control groups by the χ^2-test (the Brandt and Snedecor method for the comparison of proportions). Calculations of the direct surplus were performed to evaluate the profitability of production for both groups of fattener pigs studied (descriptive statistics; Table 7). All results are given as mean ± s.d., unless otherwise indicated. P values of <0.05 were regarded statistically significant.

Results

Concentrations of basic nutrients and anti-nutrients in rye and barley samples are summarised in Table 2. Rye grain exceeded barley in starch and crude protein content ($P < 0.05$). The contents of ash, fat and fibre were less in rye grain than in barley ($P < 0.05$). Mean concentrations of alkylresorcinols and pentosans in rye grain were greater ($P < 0.05$) than those in barley. Trypsin-inhibitor activity was less in barley than in rye-cultivar samples ($P < 0.05$).

The mean bodyweight at the outset of the present study was 16.7 ± 2.6 and 17.1 ± 2.6 kg for the control and treatment groups, respectively ($P > 0.05$). Three animals from each group were removed from the study because of health-related problems, mainly diarrhoea, during the initial stages of fattening (i.e. end of starter and beginning of grower phases). There were no significant differences in body mass between the two groups of gilts at weighing following the starter phase of fattening or at the third weighing after the grower phase (Table 3). After the finisher phase, however, the mean weight of control (barley-fed) animals was less ($P < 0.05$) than that of the experimental (rye-fed) group. The mean daily weight gain did not differ ($P > 0.05$) between the groups in the starter and grower phase of fattening, but in the finisher phase the pigs in the experimental groups exhibited significantly ($P < 0.05$) greater growth rates.

The overall daily feed intake was significantly greater in the experimental group; statistically significant differences were observed in the grower and finisher phases. The mean feed to weight gain ratio (feed conversion index) was greater ($P < 0.01$) in the experimental than in the control group only during the grower phase (Table 4). There were no differences ($P > 0.05$) between the two groups of gilts in the back-fat thickness and lean meat content, or percentages of carcasses in different EUROP system classes (Table 5).

Table 2. Concentrations (mean ± s.d.) of basal nutrients and anti-nutrients in rye and barley samples

TUI-trypsin units inhibited. Within rows, means followed by uppercase different letters are significantly different ($P < 0.01$)

Component	Content in grain	
	Barley	Rye
Ash (g/kg)	23.5 ± 0.4A	18.7 ± 0.4B
Crude protein (g/kg)	103.2 ± 6.8A	109.2 ± 3.1B
Fat (g/kg)	22.4 ± 0.4A	14.8 ± 0.6B
Fibre (g/kg)	49.4 ± 2.6A	28.7 ± 0.8B
Starch (g/kg)	629.3 ± 6.1A	648.6 ± 6.8B
Alkylresorcinols (mg/kg)	292.8 ± 5.2A	400.9 ± 4.0B
Pentosans (%)	0.9 ± 0.06A	1.9 ± 0.01B
Trypsin inhibitors (TIU/g)	0.4 ± 0.01A	1.6 ± 0.03B

Table 3. Bodyweights at control weighing and weight gains of gilts during fattening

Within rows, means followed by different lowercase letters are significantly different ($P < 0.05$)

Variable	Control group (barley)	Experimental group (rye)
Liveweights (kg)		
Initial bodyweight	16.7 ± 2.6	17.1 ± 2.6
Bodyweight after starter phase	33.6 ± 4.3	33.9 ± 4.3
Bodyweight after grower phase	59.4 ± 5.6	59.0 ± 6.4
Bodyweight before slaughtering	103.3 ± 14.6a	108.0 ± 9.9b
Weight gain per fattening phase/pig (kg)		
Starter phase (25 days)	16.8 ± 3.7	16.7 ± 4.0
Grower phase (35 days)	25.8 ± 6.6	25.1 ± 6.2
Finisher phase (50 days)	44.0 ± 14.5a	49.1 ± 11.8b
Whole fattening (110 days)	86.7 ± 13.5a	90.8 ± 9.6b
Daily weight gain (g)		
Starter phase (25 days)	731 ± 159	726 ± 173
Grower phase (35 days)	688 ± 195	678 ± 167
Finisher phase (50 days)	880 ± 290a	982 ± 236b
Whole fattening (110 days)	747 ± 218a	783 ± 183b

The average cost of weight gain was significantly greater ($P < 0.01$) during the grower phase but it was significantly lower ($P < 0.05$) during the finisher phase in the experimental than in the control group of pigs (Table 6). Because of the differences in production parameters analysed, the experimental group exceeded controls in the total sale value and estimates of the simplified direct surplus (Table 7).

Table 4. Summary of daily feed intake and feed conversion during the three phases of pig fattening

Within rows, means followed by different uppercase letters are significantly different ($P < 0.01$)

Variable	Control group (barley)	Experimental group (rye)
Net feed intake during fattening phases (kg)		
Starter phase (25 days)	3371	3393
Grower phase (35 days)	5053	5900
Finisher phase (50 days)	7932	8815
Whole fattening period (110 days)	16 355	18 108
Feed intake per pig per fattening phase (kg)		
Starter phase (25 days)	45.5 ± 4.3	45.8 ± 2.9
Grower phase (35 days)	68.3 ± 5.2A	79.7 ± 3.5B
Finisher phase (50 days)	115.0 ± 7.1A	125.9 ± 5.4B
Whole fattening period (110 days)	237.0 ± 6.6A	258.7 ± 5.0B
Daily feed intake per pig (kg)		
Starter phase (25 days)	2.0 ± 0.2	2.0 ± 0.2
Grower phase (35 days)	1.8 ± 0.2A	2.1 ± 0.2B
Finisher phase (50 days)	2.3 ± 0.2A	2.5 ± 0.2B
Whole fattening period (110 days)	2.1 ± 0.2A	2.3 ± 0.2B
Feed intake to gain ratio (kg)		
Starter phase (25 days)	2.7 ± 0.1	2.7 ± 0.1
Grower phase (35 days)	2.6 ± 0.1A	3.2 ± 0.1B
Finisher phase (50 days)	2.6 ± 0.1	2.6 ± 0.1
Whole fattening period (110 days)	2.7 ± 0.2	2.77 ± 0.1

Discussion

Even though rye is a cereal with confirmed health benefits for humans, rye cultivation decreases steadily each year (Aman *et al.* 1997; Slavin *et al.* 1997; Bushuk 2001). In Poland, for example, there was a 50% decline in rye cultivation area between 2000 and 2010 (Central Statistical Office 2011). A narrow range of industrial applications for rye grain is a major limiting factor in rye production. Most other cereals can be used as a raw material in the food industry and any surplus grain can be utilised in farm animal production. However, rye grain is not a primary choice in animal nutrition and so it is rather difficult to sell surplus rye (Sullivan *et al.* 2005).

Table 5. Summary of the slaughter values, EUROP system carcass classifications and mean prices of pig carcasses

Within rows, means followed by different uppercase ($P < 0.01$) and lowercase ($P < 0.05$) letters are significantly different

Variable	Control group (barley)	Experimental group (rye)
Liveweight (kg)	103.3 ± 14.6a	108.0 ± 9.9b
Carcass weight (kg)	76.8 ± 12.5A	82.2 ± 8.9B
Slaughter value (%)	74.1 ± 2.8A	76.1 ± 1.7B
Back fat thickness (mm)	15.7 ± 4.9	16.8 ± 3.8
Loin depth (mm)	58.3 ± 8.6	60.5 ± 7.9
Lean meat content (%)	56.0 ± 4.1	55.9 ± 2.8
% of carcasses in S class	5.6	2.8
% of carcasses in E class	53.5	66.7
% of carcasses in U class	26.8	25.0
% of carcasses in R class	5.6	4.1
% of carcasses in P class	8.5	1.4
Carcass price/1 kg (PLN/$US)[A]	5.1 ± 0.6/ 1.9 ± 0.2a	5.3 ± 0.3/ 2.0 ± 0.1b
Total carcass price (PLN/$US)[A]	399.1 ± 32.2/ 150.6 ± 12.1A	434.8 ± 26.0/ 164.1 ± 9.8B

[A]Average exchange rate (National Bank of Poland): $US 1 = 2.6499 PLN, as of 4 May 2011.

Table 6. The cost of nutrition incurred during pig fattening

Percentage increase/decrease shows the percentage increase or decrease in the treatment group relative to the control group. Within rows, means followed by different uppercase ($P < 0.01$) and lowercase ($P < 0.05$) letters are significantly different

Variable	Control group (barley)	Experimental group (rye)	Percentage (%) increase/decrease
Starter mix price (PLN/$US)[A]	879.0/331.7	871.0/328.7	−0.9%
Starter phase cost	2963.1/1118.2	2955.3/1115.2	−0.3%
Starter phase cost per pig	40.0 ± 2.6/15.1 ± 1.0	39.9 ± 1.7/15.1 ± 0.7	−0.3%
Starter phase cost of 1 kg weight gain	2.4 ± 0.2/0.9 ± 0.07	2.4 ± 0.1/0.9 ± 0.04	+0.4%
Grower mix price (PLN/$US)[A]	797.0/300.8	777.0/293.2	−2.5%
Grower phase cost	4027.2/1519.8	4584.3/1730.0	+13.8%
Grower phase cost per pig	54.4 ± 4.2/20.5 ± 1.6A	62.0 ± 2.7/23.4 ± 1.0B	+13.7%
Grower phase cost of 1 kg weight gain	2.1 ± 0.2/0.8 ± 0.06A	2.5 ± 0.1/0.9 ± 0.05B	+17.1%
Finisher mix price (PLN/$US)[A]	599.0/226.1	572.0/215.9	−4.5%
Finisher phase cost	4751.3/1793.0	5042.2/1902.8	+6.12%
Finisher phase cost per pig	68.7 ± 4.3/26.0 ± 1.6a	72.0 ± 3.1/27.2 ± 1.2b	+4.6%
Finisher phase cost of 1 kg weight gain	1.6 ± 0.1/0.6 ± 0.05a	1.5 ± 0.09/0.5 ± 0.03b	−5.8%
Total cost of fattening (PLN/$US)[A]	11741.6/4431.0	12581.8/4748.0	+7.2%
Total cost of fattening per pig	170.2 ± 5.2/64.2 ± 2.0A	179.7 ± 4.2/67.8 ± 1.6B	+5.6%
Total cost of 1-kg weight gain	1.9 ± 0.1/0.7 ± 0.05	1.9 ± 0.09/0.7 ± 0.03	+0.5%

[A]Average exchange rate (National Bank of Poland): $US 1 = 2.6499 PLN, as of 4 May 2011.

Table 7. Calculation of the simplified direct surplus from pig fattening
Percentage increase is the percentage increase in the treatment group relative to the control group

Variable	Control group (barley)	Experimental group (rye)	Percentage (%) increase
Total sale value (PLN/$US)[A]	29 534.1/11 145.4	32 173.0/12 141.2	+8.9%
Purchase price of piglets (PLN/$US)[A]	16 455.7/6209.9	16 844.3/6356.6	+2.3%
Total costs of feed (PLN/$US)[A]	11 741.6/4431.0	12 581.8/4748.0	+7.2%
Grand total (expenditures) (PLN/$US)[A]	28 197.3/10 640.9	29 426.1/11 104.6	+4.4%
Simplified direct surplus (PLN/$US)[A]	1336.4/504.5	2746.9/1036.6	+105.5%

[A]Average exchange rate (National Bank of Poland): $US 1 = 2.6499 PLN, as of 4 May 2011.

High concentrations of anti-nutrients such as alkylresorcinols, non-starch polysaccharides and trypsin inhibitors are the main reason why rye is not commonly used in animal nutrition. The net content of alkylresorcinols in older rye cultivars frequently exceeds 1000 mg/kg; as a result, a decrease in growth rates, especially in young animals, was observed after feeding dry mixes with high rye content (Wieringa 1967; Sedlet *et al*. 1984). To overcome this undesirable trend, selective cultivation of rye varieties containing lower quantities of alkylresorcinols began in the 1970s (Hoffmann and Wenzel 1977). In the present study, however, concentrations of alkylresorcinols in barley were still lower than those in the rye cv. Visello.

The present chemical analyses also revealed that concentrations of pentosans were lower in barley than in rye grain. Non-starch polysaccharides (NSPs) are long-chain carbohydrates that are not digestible in the gastrointestinal tract of pigs and pentosans are the major class of NSPs in rye. Pentosans increase the viscosity of feedstuff, easily absorb water (they can swell up to 8 times of their initial weight and volume) and hamper the digestion of various nutrients (Boros *et al*. 1993; Bakker *et al*. 1998; Im *et al*. 1999; Boros 2002). Pentosan 'swelling' also causes a false feeling of 'fullness', and decreases appetite and feed intake (Misir and Marquardt 1978). However, no significant effects on growth rates were observed in fattener pigs that received rye-containing diets selected for reduced viscosity, even though the digestibility coefficients for dry matter, crude protein and gross energy were greater in pigs fed low-viscosity mixes (Thacker *et al*. 1999).

The activity of tripsin inhibitors was 4.5-fold greater in the Visello rye cultivar than in barley. Trypsin inhibitors reduce the activity of endogenous proteolytic enzymes and, consequently, lower the feed conversion rate and weight gain of fattener pigs (Puztai 1967). As with other anti-nutrients, the concentration and activity of trypsin inhibitors in old rye cultivars were greater than in other cereals. However, autoclaving the grain in an attempt to inactivate trypsin inhibitors failed to improve the nutritional value of rye-based diets, suggesting that trypsin inhibitors are not the only agents responsible for suboptimal utilisation of rye components (Sosulski *et al*. 1988). Moreover, a comparison of different rye cultivars revealed significant inter-cultivar differences in anti-trypsin activity (Makarska *et al*. 2007).

In the present study, the mean daily weight gain during the finisher phase was greater by ~100 g in the rye-fed gilts than in their counterparts that received a barley-containing mix. These results are in agreement with several earlier reports (Meyer *et al.* 2003, 2012; Hagemann 2004) but others have obtained different results (Nehring *et al*. 1961; Puztai 1967; Wieringa 1967; Sedlet *et al*. 1984). The key determinants of weight gain and, ultimately, carcass weight and composition are the feed intake and conversion rate of the nutrients contained in it, for which the metabolic energy density of the feedstuff is very important. The composition of dry mixes used in the present trial indicates that both the control and experimental diets were isocaloric and isonitrogenous (Table 1). Therefore, daily feed intake appeared to be the most important determinant of the animal growth rate in the present study; the feed intake was significantly greater in the experimental groups during the grower and finisher phases. This observation was in contrast to a previously reported decrease in consumption of rye-supplemented diets by fattener pigs (Misir and Marquardt 1978; Sedlet *et al*. 1984). It is possible that a partial reduction in the anti-nutrient content of the Visello cultivar, in comparison to older rye cultivars, nullified the adverse effects associated with high viscosity and low digestibility of the rye-containing mixes in the present study. Concurrently, relatively high concentrations of monosaccharides in rye could account for an increased feed intake of the grain as pigs prefer a sweet taste (Kennedy and Baldwin 1972; Baldwin 1976; Alert and Frohlich 2006). Monosaccharides are the best source of metabolic energy and are absorbed from the gastrointestinal tract more readily than are lipids (Zhang *et al*. 2004). Rye grain contains relatively low concentrations of lipids and fibre, which can decrease food digestibility and the absorption rates of other carbohydrates, proteins and lipids (Bindelle *et al*. 2008). Hence, both the absolute concentrations and relative proportions of carbohydrates and lipids in the Visello cultivar may be a key factor in determining its nutritional value.

The only end point recorded during fattening that was greater in pigs fed barley-containing mixes was the feed conversion during the grower phase. It is possible that the relatively low content of rye in the starter phase (10%) had no adverse effects on the conversion rate but the ensuing increase in rye content to 25% in the grower mix was too rapid for young gilts. Consequently, they might not be able to cope with the higher concentration of pentosans and elevated anti-trypsin activity. However, the grower phase could have 'primed' the digestive tract of fattener pigs for the final and longest period of fattening. As this is only a speculation, further studies are needed to corroborate such a possibility, especially in light of the fact that several earlier studies did not show an increase in the feed to weight gain ratio in fattener pigs that received rye-based diets (Hooper *et al.* 2002; Meyer *et al.* 2003, 2012; Hagemann 2004).

As a result of the accelerated growth, the mean live and carcass weights of rye-fed pigs were both significantly greater than in the barley-fed group. Similar results were obtained by Meyer *et al.* (2012), although the difference in the slaughter value of animals was less pronounced than that seen in the present study. The analyses of back-fat thickness and loin depth revealed that both of these parameters were also greater in the present experimental group. The greater fat deposition, combined with a deeper loin muscle in the rye-fed pigs, resulted in the similar lean meat content of carcasses in both groups; this result is also in accordance with earlier reports by Meyer *et al*. (2003, 2012) and Hagemann (2004).

Albeit not statistically different from controls, most of carcasses in the experimental group were classified as the E class (55–60% of lean meat content). This class is most desirable because of the high meat content and good overall quality. In the control group, there were a few more carcasses in the highest S class but also more carcasses in lower classes. While the difference in the price between the S and E classes is small, the difference between the E class and the next classes is much larger. Therefore, the average carcass price was greater in rye- than in barley-fed animals, in spite of the similar lean meat content.

The market price of rye-containing mixes was lower but the feed intake was greater and the conversion rate of those mixes was reduced in comparison to barley-based feedstuff used in the present study. Contrary to the results of several previous studies (Meyer *et al*. 2003, 2012; Hagemann 2004), the total cost of pig fattening using rye-containing diets in the present study was greater than that obtained with barley-containing dry mixes. However, the average feeding cost per 1 kg of liveweight gain did not vary between the groups and the total direct surplus was significantly greater in the experimental group.

Conclusions

The overall efficacy of using a modern hybrid rye cultivar for pig fattening was greater than that of using barley, as feeding the dry mixes containing rye grain resulted in enhanced growth rates, better carcass quality and higher prices. The present observations warrant further studies of different rye cultivars to determine their usefulness in intensive pig farming.

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