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Growth performance, carcass and pork quality of finisher pigs fed oat-based diets containing different levels of β -glucans¹

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ABSTRACT: A study was undertaken to investigate the growth performance and carcass and meat quality of pigs (BW = 52 to 108 kg) fed oat-based (*Avena sativa* L.) diets containing four levels of mixed-linkage (1 → 3), (1 → 4)- β -D-glucans. One hundred sixty pigs—80 barrows and 80 gilts (average starting BW = 52.7 kg)—were allocated to one of five diets: a wheat-barley-based control diet and four experimental diets. The groats of Marion, a covered oat, and OT789, a hullless oat, were used to formulate four isonitrogenous and isocaloric diets to achieve 4.1, 3.3, 2.1, or 1.6% total β -glucans (as fed). Growth performance (daily gain and gain to feed ratio) was not affected ($P > 0.05$) by the different levels of β -glucans. Carcass yield, although lower ($P \leq 0.05$) for pigs fed the control diet, was similar ($P > 0.05$) for pigs fed any of the experimental diets. Cutout yields were also alike ($P > 0.05$) across the five diets. β -glucan content had no effect ($P > 0.05$) on the longissimus muscle area, or, by and large, on the proportions of commercial cuts; the only exceptions were a commercial picnic from pigs fed the 2.1% diet lower ($P < 0.05$) relative to all other diets and a lower ($P < 0.5$) commercial

loin from pigs fed diets 4.1 or 3.3% relative to the control diet. Furthermore, the relative proportions of total lean, total bone, and total dissectable fat in the four lean cuts (picnic, butt, loin, and ham) were not different ($P > 0.05$) among the five diets. For pigs fed 4.1% β -glucans, the proportion of lean in each of the four major cuts was lower ($P < 0.05$). No differences ($P > 0.05$) associated with the level of β -glucans were detected for either the initial or ultimate pH mean values, the subjective assessment of color or structure of the longissimus muscle, or the instrumentally measured color (L value). Similarly, drip loss was not influenced ($P > 0.05$) by the level of β -glucans in the diets. Soluble protein did differ ($P < 0.05$) among the high- to low- β -glucans diets. No differences ($P > 0.05$) associated with diets were found for fat hardness and shear values of grilled pork chops. Chemical fat of the longissimus muscle from pigs fed 4.1, 3.3, or 2.1% β -glucans was lower ($P < 0.05$) compared to pigs fed the control or 1.6% β -glucans diets. In summary, no evidence of detrimental effect of β -glucans in oat-based diets, particularly at levels below 4%, was detected, lending support for the inclusion of oat into finisher diets.

Key Words: Carcasses, β -glucans, Oats, Pigs, Pork, Quality

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Introduction

Oat products have been shown to have important hypocholesterolemic properties in humans (Beer et al., 1995). The mixed-linkage (1 → 3), (1 → 4)- β -D-glucans have been proposed as the component responsible for this cholesterol-lowering effect. Because of this medicinal property, there has been an impetus to develop oat cultivars that contain high levels of β -glucans. How-

ever, since strict quality requirements are imposed by food companies before oat can be used in their manufacturing processes, there is a need for alternatives in the event that they cannot be used for human consumption; one alternative is as an ingredient in diets for monogastric animals such as pigs.

Bach Knudsen et al. (1993) showed that β -glucans in oat-based diets impacted several gastrointestinal events, resulting in lower digestibilities of protein and fat in the small intestine of young pigs. Others (Newman et al., 1980; Graham et al., 1989) also showed a detrimental effect of β -glucans on digestibility, feed efficiency, and subsequent growth in young pigs. Pettersson and Lindberg (1997) demonstrated an age-related improvement of the ileal and total digestibility of dietary components and energy. Then, if correct, diets containing a high level of β -glucans could be fed to older pigs.

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Pigs fed diets containing only oats had lower ADG (Friend et al., 1988; 1989), less favorable characteristics, and a change in the proportions of the primal cuts (Madsen et al., 1990; Just, 1995; van Barneveld et al., 1998). Madsen et al. (1990) observed a deterioration in the quality of backfat at levels of substitution exceeding 50%. Brand and van der Merwe (1996), however, showed minimal effects on carcass characteristics.

As there is a scarcity of information on the effect of β -glucans on the carcass and pork quality of pigs, this study was undertaken to investigate the growth performance and carcass and meat quality of pigs (BW = 52 to 108 kg) fed oat-based diets containing different levels of β -glucans.

Material and Methods

One hundred sixty pigs (80 barrows and 80 gilts) were allocated by sex and weight to one of five dietary treatments, starting at 52.7 (\pm 3.3) kg. All animals used in this study were raised and slaughtered at the Lacombe Research Centre (Lacombe, Alberta, Canada) in accordance with the principles and guidelines set out by the Canadian Council of Animal Care (CCAC, 1993).

Pigs were housed at the Lacombe Research Centre swine unit. The treatment unit consisted of a pen of either four barrows or four gilts, with four pens of barrows and four pens of gilts per treatment. The feeding trial was conducted in four blocks (four separate research rooms), with one pen of barrows and one pen of gilts per treatment in each block. Individual blocks started and finished on different dates over a 3.5-mo period.

Diets were formulated to meet the National Academy of Sciences—National Research Council (NRC, 1998) requirements. The control diet was based on wheat, barley, peas, soybean meal, and vitamin and mineral supplements (Table 1). Two oat genotypes, Marion (covered oat) and OT789 (hulless oat), were used in the formulation of four experimental diets to achieve four levels of total β -glucans (4.1, 3.3, 2.1, and 1.6% on an as fed basis). Prior to diet formulation and preparation, Marion was mechanically dehulled and produced groats containing 15.0% CP and 14.1 MJ/kg of DE, whereas the CP and DE content of OT789 was 14.7% CP, and 13.6 MJ/kg of DE, respectively. The total β -glucan content of Marion groats and OT789 was determined using the flow injection method of Jorgensen (1988) and were 5.94 and 4.68% by weight, respectively. All diets were formulated to be isocaloric and isonitrogenous (Table 1). They were supplemented with lysine and, in the case of the control diet, with L-threonine. Diets were pelleted and pigs had ad libitum access to the diets and water. Water was available from automatic water nipple in each pen.

The pigs completed the experiment when they reached a final weight of 108 \pm 5 kg; they were then shipped to the Lacombe Research Centre abattoir where they were slaughtered under typical commercial

procedures. Slaughter weight was recorded immediately prior to electrical stunning with a head to shoulder electrode (400 V, 60 Hz). Thereafter, carcasses were dressed to Canadian commercial specifications (Fortin et al., 2003). A Hennessy grading probe (HGP; Hennessy Grading Systems, Auckland, N.Z.) was used to obtain fat and muscle thickness measurements at the Canadian grading site (7 cm off the midline between the 3rd and 4th last ribs). After washing, carcass sides were chilled at 1°C, with an air velocity of 1 m/s for approximately 24 h. Firmness of the subcutaneous fat above the 2nd thoracic vertebra of the right side was measured at this time using the Bristol fat hardness meter (AFRC Inst. Food Res., Bristol, U.K.). The meter, calibrated to provide measurements over a range of 0 to 1,000, has a spring-loaded probe that is placed against the fat surface and a simple measurement is made of the retraction of the probe against the resistance of the calibrated spring. Low meter readings (420 to 829) correspond very slightly to soft fat, whereas high meter readings (830 to 969) correspond to slightly very hard fat (Sather et al., 1995).

The left side of each carcass was fabricated into the shoulder (picnic and butt), loin, ham, and belly. The picnic, butt, loin, and ham were dissected into bone, lean, and fat depots—body cavity, subcutaneous and intermuscular fat—whereas the belly was reduced to a squared, skinless, and trimmed bacon piece and side ribs (Fortin et al., 2003). Per Canadian pork carcass grading regulations, dissected yield was calculated as the sum of the lean in the picnic, butt, loin, and ham plus the weight of the bacon piece and side ribs expressed as a proportion of cold side weight. Loin eye area at the 12th rib was determined using image analysis of acetate tracings.

Measurements of pH and temperature 45 min poststunning and pH 2 d postmortem were made with a Hanna Instruments model 9025 pH/temperature meter (Laval, Canada) fitted with a temperature probe and a Mettler-Toledo spear-type electrode (Calgary, Canada) by insertion into the longissimus muscle between the 10th and 11th ribs through the exposed surface of the split carcass. The anterior portion of the longissimus muscle from the 3rd to the 12th rib was collected during cutout and meat quality determinations were conducted.

A 20-mm-thick chop, cut from the 12th-rib end, was weighed onto an absorbent pad in a styrofoam retail display tray and overwrapped with oxygen-permeable film (Goodyear Canada Ltd., Toronto, Canada). After storage for 48 h at 4°C, the chop was blotted dry on paper towel and reweighed. Drip loss was calculated as the difference in initial and final weights and expressed as a proportion of initial weight (Murray et al., 2001). The chop was held overnight at 1°C and then trimmed of all external fat, connective tissue, and fascia. The subjective color and structure were evaluated as a consensus of three experienced panelists according to the Agriculture Canada Pork Quality Standards

Table 1. Ingredients and chemical composition of the control and experimental diets fed to finisher pigs

Item	Diets ^a				
	Control	4.1	3.3	2.1	1.6
Major ingredients, % as fed					
Oats		70.6 ^b	70.7 ^c	35.2 ^b	35.1 ^c
Wheat	45.5	19.4	16.6	35.1	34.5
Barley	20.3				
Peas	20.2			19.9	20.1
Soybean meal (48%)	7.6	5.9	7.1	4.9	4.8
Lysine·HCl	0.06	0.21	0.21	0.08	0.11
L-Threonine	0.025				
Vitamin and mineral premix ^d	0.54	0.47	0.47	0.47	0.47
Chemical composition, analyzed (as fed)					
Dry matter, %	89.9	87.1	88.2	89.4	89.4
Crude Protein, %	16.6	15.9	15.8	15.9	16.5
Ether extract, %	4.6	3.1	4.9	4.3	5.3
Ash, %	4	3.9	4.1	4.3	3.8
Lysine, %	0.6	0.73	0.67	0.67	0.68
Methionine, %	0.32	0.34	0.2	0.27	0.26
Threonine, %	0.48	0.57	0.57	0.65	0.49
β -glucan, % ^e	0.8	4.1	3.3	2.1	1.6
DE, MJ/kg	14.7	14.2	14.7	14.6	15

^aThe experimental diets are denoted by their β -glucan content.

^bMarion groats.

^cOT789.

^dThe vitamin and mineral premix supplied the following per kilogram of diet (approximately): vitamin A, 8,000 IU; vitamin E, 100 IU; vitamin D, 1,000 IU; vitamin K, 0.1 mg; vitamin B₁₂, 20 μ g; niacin, 80 mg; biotin, 1.6 mg; thiamine, 3.7 mg; choline, 1,323 mg; riboflavin, 5.5 mg; pantothenate, 23.2 mg; Mg, 2.03 g; K, 7.1 mg; Fe, 235 mg; Zn, 184 mg; Mn, 100 mg; Cu, 28.6 mg; Se, 0.045 mg; I, 1.1 mg.

^eCalculated from analyzed values of Marion groats and OT789.

(Agriculture Canada, 1984) as described by Murray and Johnson (1990). Color was rated on a five-point scale, ranging from 1 = extremely pale to 5 = extremely dark. Structure was also evaluated on five-point scale, ranging from 1 = extremely soft, exudative, and dough-like, usually with an open and grainy texture, to 5 = extremely firm, dry, and sticky, with a closed and grainless texture.

A second chop of 35-mm thickness was fabricated from the 11th-rib end of the longissimus muscle, and the fresh surface was allowed to bloom for 20 min prior to measuring the objective color (CIE reflectance coordinates L* a* b*; CIE, 1978) with a Minolta CR-300 color reflectance meter (light source: CIE illuminant C; aperture: 8 mm diameter; Minolta Canada, Inc., Mississauga, ON, Canada) calibrated with a white calibration plate (CR-A43). Marbling was assessed by an experienced panelist on the same chop on which color was measured using a scale from 100 = devoid to 1,100 = very abundant (AMSA, 1990). This second chop was then cooked on a grill (Garland grill model ED30B, Condon Barr Food Equipment Ltd., Edmonton, AB, Canada) to an internal temperature of 40°C, turned, and cooked to a final temperature of 72°C. Further cooking was arrested by cooling the chop in an ice bath. The chop was held overnight at 4°C, and then two cores, 19 mm in diameter, were removed parallel to the muscle fibers. Each core was sheared once at right angles to the fibers in a Warner-Bratzler shear cell (50-kg load

cell operated at a crosshead speed of 200 mm/min). The maximal force required to shear the cores was recorded using an Instron model 4301 Materials Testing System (Burlington, ON, Canada; Aalhus et al., 1998).

The remainder of the longissimus muscle was ground and analyzed for moisture, fat, and protein (AOAC, 1997). Moisture was determined gravimetrically by drying at 105°C for 24 h. Petroleum ether fat extractions were conducted for 10 min on the resultant dried product using a Tecator Soxtec Extraction System (Tecator, AB, Hoganas, Sweden). The dried product was also used to determine protein content using a Leco FP-2000 nitrogen analyzer (Leco Instruments Ltd., Mississauga, ON, Canada). A subsample of the freshly ground product was frozen and stored at -25°C for subsequent determination of soluble protein according to the method of Barton Gade (1984), except that the result was expressed as milligrams of per gram of lean muscle instead of optical density (Murray et al., 1989).

Data were analyzed using the GLM procedure of the SAS (SAS Inst., Inc., Cary, NC). Level of β -glucans and sex were used in a 5 \times 2 factorial in a randomized complete block arrangement with four replications. Interaction effects ($P > 0.05$) were removed from the model. Pen was the experimental unit for the growth performance data, whereas the individual carcass was the experimental unit for the carcass and meat quality parameters. For color and structure scores, the data were first transformed using the angular transforma-

Table 2. Growth performance of finisher pigs fed oat-based diets containing different levels of β -glucans^a

Item	Diet ^b						Sex		
	Control	4.1	3.3	2.1	1.6	SEM ^c	Gilts	Barrows	SEM ^d
Number of animals	29	30	29	29	31		75	73	
Age at start, d	95.3	93.7	95.6	95.6	94.4	1.13	96.7	93.2	0.71**
Weight at start, kg	52.8	52.4	52.8	53.3	52.2	0.64	52.4	53	0.40*
Final age, d	155.3	155.3	157	158.7	157.2	1.97	161.5	152	1.24**
Final weight, kg	107.5	107.9	107.6	107.4	107.2	0.89	107.4	108.9	0.56*
Days on experiment	59.9	61.3	61.1	63.4	62.4	1.63	64.5	58.8	1.03**
Weight gain, kg	54.6	55.1	54.3	54.2	54.9	1.03	54.8	55.7	0.66*
Daily gain, kg/d	0.92	0.91	0.88	0.86	0.88	0.019	0.86	0.95	0.011**
Gain:feed ratio	0.41	0.4	0.42	0.4	0.42	0.009	0.42	0.39	0.004**

^aLeast squares means.

^bThe experimental diets are denoted by their β -glucan content.

^c $P > 0.05$.

^d** $P \leq 0.01$, * $P > 0.05$.

tion $2\arcsin(\%)^{1/2}$ (Puri and Mullen, 1980). Warm carcass weight was added to the model as a covariate in the analysis of the following carcass traits: cutout yield, HGP measurements, loin eye area, and cutout data. Fat hardness measurements were analyzed using HGP fat thickness as a covariate since Wood et al. (1989) have shown that backfat thickness can affect fat quality. Significant differences between least squares means were tested by Duncans' multiple range test (Steel and Torrie, 1980).

Results and Discussion

The five diets were formulated to be isocaloric and isonitrogenous. Analysis confirmed that the CP contents of the diets were within a one percent unit of each other and DE differed by less than 0.8 MJ/kg. The CP content of all diets met the National Academy of Sciences—National Research Council (NRC, 1998) requirements for pigs between 50 to 80 kg of BW, but exceeded the requirements for pigs between 80 to 120 kg of BW by approximately 3%. The dietary amino acid content met the requirement for lysine, but was slightly high for threonine and methionine (NRC, 1998). Twelve animals had to be removed due to bleeding ulcers (control diet: two barrows, one gilt; diet 4.1: two barrows; diet 3.3: two gilts and one barrow; diet 2.1: one gilt and two barrows; diet 1.6: one gilt). Necropsies revealed stomach ulceration in all cases. At time of slaughter, stomach examination revealed only occasional irritations near the esophagus.

For numerous growth performance, carcass and pork quality traits, sex was found to be significant (Tables 2 to 5). However, as no interaction between sex and diet was detected ($P < 0.05$), and since the objective of the study was to investigate the effect of different levels of β -glucans in oat-based diets, the results for gilts and barrows are only presented in a tabular format.

The growth performance of neither the barrows nor gilts was affected by the level of β -glucans in the diets (Table 2). Total weight gain did not differ ($P > 0.05$)

between the diets. This was expected as pigs started on the experimental diets at about the same weight (52 to 53 kg) and were slaughtered at the same weight (107 to 108 kg). Daily gains were similar ($P > 0.05$) among pigs fed the high or low β -glucan diets. More importantly however, daily gains on the experimental diets were similar ($P > 0.05$) to those of pigs fed the control diet. Gain:feed ratio was not affected ($P > 0.05$) by the different level of β -glucans in the diets. These findings, similar to those of Morris and Burrows (1986) and the more recent findings by Brand and van der Merwe (1996), would then suggest that β -glucans in oat-based diets have no detrimental effect on the growth performance of finisher pigs.

Carcass measurements are shown in Table 3. Carcass yield (dressing percentage) of pigs on the control diet was lower ($P < 0.05$) than that of pigs on any of the four experimental diets. However, no differences ($P > 0.05$) associated with the high to low β -glucan diets were observed. Friend et al. (1989) and Brand and van der Merwe (1996) also observed no difference in carcass yield for pigs fed different levels of oat and corn. The HGP measures fat thickness and muscle depth at the designated grade site (7 cm off the midline between the 3rd and 4th last ribs), and the measurements are used to predict carcass lean yield. The estimated yield is then used to derive an index that is used for payment to the producers. For all diets, control and high to low β -glucans, no difference in fat thickness and muscle depth was observed ($P > 0.05$). Brand and van der Merwe (1996) reported similar findings in pigs fed various levels of hulless oat to grower-finisher pigs. Carcass lean yields established by cut out were also similar ($P > 0.05$) across the five diets. Loin eye area is an important characteristic to the packer. Larger loin eyes are particularly valued for export markets. β -glucans content of the diets had no affect ($P > 0.05$) on loin eye area measured at the 12th rib (Table 3).

The proportions of commercial cuts, by and large, were not altered ($P > 0.05$) by the level of β -glucans in the diets; the only exceptions were a commercial picnic

Table 3. Carcass measurements of finisher pigs fed oat-based diets containing different levels of β-glucans^a

Item	Diets ^b						Sex ^c		
	Control	4.1	3.3	2.1	1.6	SEM	Gilts	Barrows	SEM
Slaughter weight, kg	107.9	107.5	106.1	107.1	106.8	0.86	107.1	108.2	0.55*
Warm carcass, kg	87.6	89.5	88.9	88.2	88.1	0.76	88.3	89.3	0.45*
Dressing, % ^d	81.9 ^x	83.1 ^y	82.6 ^y	82.5 ^y	82.5 ^y	0.22	82.5	82.4	0.12*
HGP fat, mm	18.5	20.8	19.5	19.7	19	0.56	17.8	21.2	0.34**
HGP muscle, mm	51.7	50.4	50.4	49.9	51.2	0.85	50.7	50.7	0.54*
Cutout yield, % ^e	59	57.6	58.1	58.8	59	0.54	59.9	57.3	0.32**
Longissimus muscle area, cm ²	40.04	38.98	38.2	39.77	39.12	0.68	40.23	38.25	0.43**

^aLeast squares means. HGP = Hennessy Grading Probe (Hennessy Grading Systems, Auckland, N.Z.).

^bThe experimental diets are denoted by their β-glucan content.

^c***P* ≤ 0.01, **P* > 0.05.

^dWeight of warm carcass weight expressed as a percentage of slaughter weight.

^eSum of the lean in the picnic, butt, loin, and ham plus the weight of the bacon piece and side ribs expressed as a proportion of cold side weight.

^{x,y}For the dietary treatments, least squares means within a row lacking a common superscript letter differ (*P* < 0.05); if no superscript letter, the least squares means do not differ (*P* > 0.05).

from pigs fed the 2.1 diet lower (*P* < 0.05) relative to all other diets and a lower (*P* < 0.5) commercial loin from pigs fed diets 4.1 or 3.3 relative to the control diet (Table 4). Each of the four lean cuts (picnic, butt, loin, and ham) were dissected into lean, bone, and the three fat depots: body cavity fat, subcutaneous fat and skin, and intermuscular or seam fat. The sum of the three fat depots equals total dissectible fat. The relative proportions of total lean, total bone, and total dissectible fat in the four lean cuts, and the proportions of the

three fat depots were not different (*P* > 0.05) among the five diets (Table 4). However, within each cut, the proportion of lean was altered (*P* < 0.05) by the experimental diets; particularly at the high the level of β-glucans (4.1%). For pigs fed the high level of β-glucans (diet 4.1), the proportion of lean in each of the four major cuts (picnic, butt, loin, and ham) was lower (*P* < 0.05) than for pigs fed the control diet: 66.5 vs. 68.6, 60.3 vs. 63.6, 53.2 vs. 55.6, and 68.6 vs. 70.9%, respectively. Relative to the pigs fed the control diet, the proportion

Table 4. Carcass yield measurements of finished pigs fed oat-based diets containing different levels of β-glucans^a

	Diets ^b						Sex ^c		
	Control	4.1	3.3	2.1	1.6	SEM	Gilts	Barrows	SEM
Commercial cuts ^d									
Picnic	10.1 ^x	9.8 ^x	9.8 ^x	8.8 ^y	9.9 ^x	0.11	9.6	9.3	0.22*
Butt	8.8	9.1	8.9	9.1	9.0	0.13	8.9	8.8	0.11*
Loin	22.6 ^x	21.9 ^y	21.9 ^y	22.2 ^{xy}	22.4 ^{xy}	0.23	22.6	21.7	0.12**
Ham	23.5	23.5	23.9	23.7	23.4	0.38	23.6	23.4	0.23*
Belly	11.5	11.6	11.6	11.5	11.5	0.15	11.4	11.7	0.09**
Four cuts (picnic, butt, loin, ham) ^e									
Total lean	62.8	61.1	62.0	63.0	62.9	0.70	64.3	60.4	0.42**
Total bone	9.3	9.0	9.3	9.1	9.1	0.13	9.3	9.1	0.07*
Total dissectible fat	29.8	30.7	30.7	29.9	29.9	0.75	28.4	32.4	0.45**
Body cavity fat	0.57	0.59	0.58	0.55	0.65	0.03	0.53	0.64	0.02**
Intermuscular fat	5.3	5.0	4.9	4.8	4.8	0.31	4.8	5.2	0.18*
Skin and subcutaneous fat	23.9	25.1	25.2	24.5	24.3	0.56	23.1	26.5	0.33**
Lean									
Picnic ^f	68.6 ^x	66.5 ^y	67.0 ^y	68.2 ^x	68.4 ^x	0.57	69.5	66.0	0.32**
Butt ^f	63.6 ^x	60.3 ^y	62.0 ^x	62.0 ^x	62.3 ^x	0.71	64.2	59.7	0.41**
Loin ^f	55.6 ^x	53.2 ^y	54.3 ^{xy}	55.1 ^x	55.1 ^x	0.70	56.4	52.1	0.65**
Ham ^f	70.9 ^x	68.6 ^y	69.2 ^{xy}	70.2 ^x	70.2 ^x	0.61	71.3	68.3	0.35**

^aLeast squares means.

^bThe experimental diets are denoted by their β-glucan content.

^c***P* ≤ 0.01, **P* > 0.05.

^dPercentage of weight of side cut.

^ePercentage of weight of four cuts.

^fPercentage of weight of respective cut.

^{x,y}For the dietary treatments, least squares means within a row lacking a common superscript letter differ at (*P* < 0.05); if no superscript letter, the least squares means do not differ (*P* > 0.05).

Table 5. Quality measurements and chemical composition of the longissimus thoracis in finisher pigs fed oat-based diets containing different levels of β -glucans^a

Item	Diets ^b						Sex ^c		
	Control	4.1	3.3	2.1	1.6	SEM	Gilts	Barrows	SEM
Quality measurements									
Initial pH	6.16	6.15	6.18	6.15	6.16	0.03	6.17	6.15	0.01 ^{NS}
Initial temperature, °C	40.6	40.7	40.6	40.6	40.6	0.1	40.6	40.6	0.06 ^{NS}
Ultimate pH	5.5	5.5	5.51	5.5	5.48	0.01	5.49	5.5	0.01 ^{NS}
Fat hardness	774	768	768	779	769	10.8	745	798	6.4 ^{**}
Marbling	350 ^x	283 ^{xy}	324 ^x	321 ^x	352 ^x	13.8	319	333	9.0 ^{NS}
Shear, kg	5.4	5.31	5.85	5.69	5.52	0.23	5.59	5.52	0.15 ^{NS}
L* value	54.94	53.57	53.88	54.51	54.12	0.69	53.99	53.61	0.44 ^{NS}
Color score	2.7	2.7	2.9	2.8	2.6	0.08	2.7	2.8	0.05 ^{NS}
Structure score	2.6	2.6	2.9	2.8	2.6	0.09	2.7	2.7	0.06 ^{NS}
Drip loss, % of longissimus	6.71	6.14	6.19	6.46	6.38	0.4	5.8	6.5	0.23 [*]
Soluble protein, mg/g	201.8 ^x	191.4 ^y	206.1 ^x	204.7 ^x	191.7 ^y	4.08	201.3	196.9	2.56 ^{NS}
Chemical composition									
Moisture, %	74.81	74.74	74.76	74.66	74.57	0.12	74.88	74.53	0.08 ^{**}
Crude protein, N \times 6.25 ^d	22.26 ^x	22.60 ^y	22.46 ^{xy}	22.56 ^y	22.33 ^x	0.1	22.37	22.51	0.05 ^{**}
Ether extract ^d	1.91 ^x	1.53 ^y	1.56 ^y	1.66 ^y	1.96 ^x	0.09	1.57	1.88	0.07 ^{**}

^aLeast squares means.

^bThe experimental diets are denoted by their β -glucan content.

^c** $P \leq 0.01$, * $P \leq 0.05$, ^{NS} $P > 0.05$.

^dPercent on a wet basis.

^{x,y}For the dietary treatments, least squares means within a row lacking a common superscript letter differ ($P < 0.05$); if no superscript letter, the least squares means do not differ ($P > 0.05$).

of lean in each of the four cuts from pigs fed diet 2.1 or 1.6 did not differ ($P < 0.05$).

Muscle color and structural properties are highly variable and important attributes of pork meat. The capacity of the meat to hold or to bind water has implications for shrink losses during chilling and cooking and important implications for further processing of pork products. During the conversion of muscle to meat, the rate and extent of biochemical activity in the pork musculature following slaughter has a direct impact on the color and structural characteristics of the pork. A rapid rate of glycolysis, and therefore, a rapid pH decline in the first hour postmortem, such that the pH falls below 6.0 within that time frame and while the temperature of the muscle is still high, generally results in the production of PSE pork (Murray, 1995). If muscle glycogen reserves are low at time of slaughter, then the pH of the muscle may never fall below 6.0 and DFD pork is the result. In this experiment, muscle pH was monitored at 45 min poststunning to determine the rate of glycolysis, and was measured again 48 h postmortem to determine the extent of glycolysis. No differences ($P > 0.05$) were found in either initial or ultimate pH mean values among the dietary treatments (Table 5), and the mean pH values were all within the range associated with pork of normal color and structure. No differences ($P > 0.05$) associated with the level of β -glucans in the diet were detected in the subjective assessment of color or structure of the pork loins, nor were there any differences ($P > 0.05$) in the instrumentally measured color (L value). Similarly, drip loss, a measure of the water-holding properties of lean, was not influenced ($P > 0.05$) by the level of β -glucans in the diets. However, there

was a statistical significant effect of diets ($P < 0.05$) on the soluble protein of the longissimus muscle, an indicator of the potential value of pork for forming the emulsions and gels required in the processing of pork (Murray, 1995). For pigs fed diets 4.1 or 1.6, soluble protein was the lower than for pigs fed diets 3.3 or 2.6: 191.4 and 191.7 vs. 206.1 and 204.7 mg/g, respectively. For pigs fed the control diet, the level of soluble protein was 201.8 mg/g. Although significant ($P < 0.05$), it is debatable whether these differences are of practical significance (A.C. Murray, personal communication).

Fat hardness was not affected ($P > 0.05$) by the β -glucan content of the diets (Table 5). This is contrary to the findings of Madsen et al. (1990), who reported low iodine values for backfat in pigs (20 to 100 kg of BW) fed diets containing more than 50% hullless oat. The quality of the subcutaneous fat of hog carcasses is largely a function of the degree of saturation of the fatty acids—the higher the level of polyunsaturated fatty acids, the softer the fat (Madsen et al., 1990). The amount of fat and the ratio of unsaturated to saturated fat in the diet have a major impact on quality of the carcass fat (Wood et al., 1989). If the pork carcass fat is too soft, it creates difficulties in the processing of cuts, makes the bellies undesirable for production of bacon, and can be problematic in the manufacture of sausage (NPPC, 2000).

Increased concerns regarding animal fat in the diet have consumers demanding minimal visual fat, yet marbling has long been associated with eating quality. Although marbling accounts for a small portion of the variation associated with any one palatability characteristic, it is nevertheless positively associated, albeit

to a small extent, with juiciness and flavor intensity but has a somewhat inconsistent effect on tenderness (Hodgson et al., 1991; Jeremiah, 1998). A more recent study, showed that consumers judged highly marbled pork chops as being more tender, juicy, and flavorful than low marbled chops (Brewer, 2001). However, in that study, all chops, irrespective of the level of marbling, were found to have satisfactory attributes. In our experiment, marbling scores assigned to loins from pigs fed the high β -glucans diet (4.1%) were lower ($P < 0.05$) than those for loins from pigs fed the other diets; experimental and control (Table 5). However, the magnitude of the difference in marbling scores observed in this experiment would not be expected to impact significantly the overall palatability of the loin. Shear values, which are widely used as an objective measure of tenderness, support this statement since no differences ($P > 0.05$) were found in shear values of grilled pork chops from pigs fed any of the five diets. Chemical fat of the loin muscle, a measure of the intramuscular fat content, showed a parallel with the marbling scores in that loins from pigs fed the high β -glucans diet (4.1%) also had the lowest ($P < 0.05$) chemical fat content (Table 5). This could be a reflection of the lower fat content of diet 1 (Table 1). Friend et al. (1988) demonstrated a similar parallel between the loin fat content and the fat content of the diets. Although statistically significant ($P < 0.05$), the importance of the magnitude (in the order of 0.30 percent unit) of the difference in the protein content of the loin from pigs fed the various diets is questionable.

Our results on growth performance and carcass and pork quality of pigs fed oat-based diets containing high to low levels of β -glucans generally confirm the suggestion by Pettersson and Lindberg (1997) that diets containing high level of β -glucans can be fed to older pigs (BW = 52 to 108 kg). As for younger pigs, Bach Knudsen et al. (1993) have shown that oat diets varying widely in β -glucans content (2.0 to 5.7%) impacted several events in the gastrointestinal tract. They postulated that as a result of the cell walls trapping nutrients, the digestibility of protein and fat in the small intestine was reduced, whereas the digestibility of starch was not affected. They also observed low digestibility for β -glucans. Li et al. (1996), utilizing the improvement in the ileal digestibilities of CP and energy associated with the supplementation of β -glucanase enzyme to a hullless barley-based diet fed to weaning pigs (7.3 kg of BW) as indirect evidence, also concluded that β -glucans were problematic for young pigs. However, Pettersson and Lindberg (1997), who investigated the effect of various levels of β -glucans in barley-based diets fed to pigs (37 to 89 kg of BW) showed a significant age related improvement of the ileal and total gastrointestinal tract digestibilities of dietary components and energy. Fadel et al. (1989) also reported improved digestibility values for β -glucans in older pigs. Although no digestibility trial was conducted in the present study, in a series of studies, Friend et al. (1988, 1989) also provided support for the inclusion of hullless oat in the diet of finisher pigs.

It would then appear that the lack of major detrimental effect of β -glucans in oat-based diets could have resulted from an improvement in the digestibility of β -glucans associated with age.

Implications

Oat products have been shown to have important medicinal properties in humans. Mixed-linkage (1 \rightarrow 3), (1 \rightarrow 4)- β -D-glucans have been proposed as the active components in oats. Because of the high quality requirements demanded by the food industry, alternative uses have to be developed in order to encourage the production of oats in cases when the oats produced do not meet those requirements. One such alternative is to use oat as a feedstuffs for pigs. However, β -glucans are known to interfere with digestion and absorption, particularly in young pigs. Four oat-based diets containing different levels of β -glucans (4.1, 3.3, 2.1, and 1.6%) were fed to finisher pigs (52 to 107 kg of BW). Their growth performance and carcass and pork quality were compared to that of pigs fed a standard wheat-barley-based diet. No evidence of serious dilatory effect of the β -glucans was detected, providing support for the inclusion of oat into finisher pig diets.

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