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Effects of finishing diet and pre-slaughter fasting time on meat quality in crossbred pigs

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The effects of the carbohydrate composition of finishing diet (fed from 80 to 107 kg of body weight) and the length of pre-slaughter fasting on pork quality were studied in a 2 × 2 factorial experiment with 80 crossbred pigs. The control finishing diet was based on barley and soybean meal, and the fibrous finishing diet was based on barley, barley fibre, faba beans, and rapeseed cake. These diets contained 465 and 362 g starch and 177 and 250 g dietary fibre per kg, respectively. The fasting times of 25 and 41 h were obtained by giving the pigs their last meal at different times. Longer fasting lowered the glycolytic potential of the *longissimus lumborum* muscle ($P = 0.01$), whereas the finishing diet had no effect. Different muscles responded differently to the treatments. Longer fasting increased the ultimate pH of the *semimembranosus* muscle ($P = 0.02$), but did not affect that of the *longissimus lumborum* and *semispinalis capitis* muscles. The finishing diets did not affect the ultimate pH of the investigated muscles. A diet × fasting time interaction was seen in the lightness of the *semimembranosus* muscle ($P = 0.05$). The fibrous diet resulted in darker meat than the control diet did in pigs that were fasted for 25 h ($P < 0.05$). Longer fasting darkened the meat colour in pigs fed the fibrous diet ($P < 0.05$) but not in those fed the control diet. The meat from the *semispinalis capitis* muscle was darker in pigs fed the fibrous than those fed the control diet ($P = 0.04$). The treatments did not affect the colour of the *longissimus lumborum* muscle. Longer fasting decreased drip loss from the meat of pigs fed the control diet ($P < 0.05$). The eating quality of the pork was not influenced by the finishing diets or the fasting time. The pigs also grew equally fast on both finishing diets. In conclusion, a moderate alteration in the carbohydrate composition of a finishing diet or longer pre-slaughter fasting can have some effects on pork quality in crossbred pigs, but these effects vary in different muscles.

Key-words: Pigs, feeding, fasting, meat quality, glycolytic potential

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Introduction

Colour and water-holding capacity are important attributes of pork quality. Both these quality traits are affected by biochemical processes during the post-slaughter conversion of muscle to meat, where pH is an important factor. The extent of post-mortem pH fall and the ultimate pH of pork measured 24 h *post mortem* are mainly determined by the muscle glycogen content at slaughter (Bendall and Swatland 1988). High muscle glycogen levels result in pork with low ultimate pH, pale colour, and decreased water-holding capacity (Miller et al. 2000, Hamilton et al. 2003). Muscle glycogen stores at slaughter are generally expressed as glycolytic potential. This is a measure of the compounds present in muscles that can be converted to lactic acid and thus contribute to the post-mortem pH decline (Monin and Sellier 1985). The glycolytic potential of muscles can be influenced by several factors like genotype (Monin and Sellier 1985, Enfält et al. 1997), feeding (Rosenvold et al. 2001a, Ruusunen et al. 2007), rearing conditions (Enfält et al. 1997), fasting (Bertol et al. 2005), and pre-slaughter handling practices (Hambrecht et al. 2004).

Dietary manipulation of muscle glycogen deposition has focused primarily on replacing starch-rich cereals in finishing diets mainly with fat-rich protein feedstuffs and to a lesser extent with feedstuffs rich in fibre (Rosenvold et al. 2001a,b, 2002). Generally, these strategic, low-starch finishing diets have contained no cereals and considerably more protein than standard finishing diets that meet the amino acid requirements of finishing pigs. This is not desirable because the feeding of high-protein diets to finishing pigs increases urinary nitrogen excretion and ammonia emission from the slurry (Portejoie et al. 2004). It should therefore be investigated whether it is possible to manipulate muscle glycogen deposition by means of a partial replacement of cereals with fibre-rich feedstuffs while simultaneously using only moderate amounts of protein feedstuffs. In this context, faba beans seem an interesting feedstuff because they contain more protein and fibre but less starch than cereals (Bach Knudsen 1997). In addition, a smaller proportion of legume starch than cereal starch is digested and absorbed as glucose in the small intestine (Wiseman 2006). In our previous studies, increasing amounts of faba beans in diets based on barley and rapeseed meal have also darkened the colour of the *longissimus dorsi* muscle without having any negative effects on the eating quality of pork (Partanen et al. 2003).

A feed withdrawal of 16–24 h prior to slaughter is recommended in practice (Eikelenboom et al. 1991) in order to reduce the volume of stomach content and the risk of microbial contamination. Longer fasting has also been shown to decrease muscle glycolytic potential, increase ultimate pH, darken meat colour, and decrease the risk of PSE (pale, soft, and exudative) meat (Jones et al. 1985, Eikelenboom et al. 1991, Guàrdia et al. 2004). However, fasting that is too long can increase the incidence of DFD (dark, firm, and dry) meat (Eikelenboom et al. 1991, Guàrdia et al. 2005). The magnitude of the fasting effect on meat quality can also depend on other factors like feeding and pre-slaughter handling practices (Leheska et al. 2003, Faucitano et al., 2006). However, the combined effects of dietary carbohydrate composition and pre-slaughter fasting time have scarcely been investigated.

The aim of this study was to investigate the effect of changing the carbohydrate composition of finishing diets by replacing soybean meal and part of the barley with faba beans, barley fibre, and rapeseed cake and the effect of the length of pre-slaughter fasting on the growth performance and carcass and meat quality of crossbred pigs.

Material and methods

Animals, diets, and feeding

Forty gilts and 40 barrows were used, of which 46 were F1 crosses of Finnish Landrace and Finnish Yorkshire, and 34 were back-crosses of these breeds. At a body weight of 23–28 kg, pairs of gilts or barrows were formed and housed in pens of 0.95 m ×

Vol. 16 (2007): 245-258

2.83 m with a concrete floor in the lying area and a metal grate on the dunging alley. Wood shavings were used as bedding material.

The arrangements of the experimental treatments was 2 × 2 factorial, and the investigated factors were finishing diet (control vs. fibrous) and pre-slaughter fasting time (short vs. long). There were 10 pens (10 gilts and 10 barrows) in each treatment. A three-phase feeding regime was used. During the 35-day growing and 21-day early-finishing periods, all the pigs were fed diets based on barley and soybean meal. During the finishing period (from day 56 to slaughter), the pigs were fed either a control diet based on barley and soybean meal or a fibrous diet, which contained barley, barley fibre from a starch-ethanol production, faba beans, and cold-pressed rapeseed cake as the major ingredients. The diets fed during the growing, early-finishing, and finishing periods were formulated to meet or exceed the nutrient requirements of pigs from 25 to 55, from 55 to 80, and from 80 to 110 kg of body weight, respectively (MTT 2004). The ingredients and calculated nutrient compositions of the experimental diets are presented in Table 1. Dietary net energy content was calculated from the ingredients according to Schiemann et al. (1972) by using tabulated values for nutrient contents and their digestibility coefficients (MTT 2004). In the control and fibrous finishing diets, fat provided 4 and 14% and carbohydrates 82 and 73% of net energy, respectively, while the remaining 14% of net energy came from protein. The experimental diets were pelleted.

The pigs were fed according to a restricted feeding scale, in which the daily allowance was increased gradually from 13.0 to 29.8 MJ NE per day. The daily ration was divided into two portions, which were given at 7 am and 3 pm. Water was available *ad libitum*. The pigs were weighed at the beginning of the growing, early-finishing, and finishing periods and then weekly until the mean body weight of pigs housed in the same pen reached 96 kg and the pigs were scheduled for slaughter during the following week. The final weight was measured before loading the pigs for transportation. The different fasting times were obtained by giving one half of the pigs their last meal at 7 am on the delivery day, and another half at 3 pm on the previous day. The experimental protocol was evaluated and approved by the Animal Care Committee of MTT Agrifood Research Finland (Permit SIK10/04, 18.11.2004).

Slaughtering and carcass quality evaluation

The pigs were collected from the fattening unit between 10 am and 2 pm and transported in a lorry ca 130 km to a commercial slaughter house. The pigs were kept overnight in the barn of the slaughterhouse, where no feed was given, but water was available. The pigs were slaughtered the following morning between 6.30 and 10 am. The time between the last meal and stunning averaged 25 ± 0.9 and 41 ± 0.8 h in the short and long fasting, respectively.

The pigs were stunned in groups of three pigs by 88% carbon dioxide for 3 min 25 s, exsanguinated, scalded with steam, cleaned, and eviscerated on a slaughter line that handled 133 pigs h^{-1}. Carcass lean meat content was measured on the warm carcasses ca 35 min after stunning with a Hennessy Grading probe GP4 (Hennessy Grading Systems, Auckland, New Zealand). The first fat depth measurement (S1) was taken at the last rib, 8 cm from the mid line, and the second fat depth (S2) and loin depth (LD) measurements between the 12^{th} and 13^{th} rib, 6 cm from the mid line. Carcass lean percentage was calculated as 56.713 - (0.271 × S1) - (0.620 × S2) + (0.258 × LD). Simultaneously with the fat and lean depth measurements, the GP4 probe measured meat colour. Carcasses with average colour values < 58 were classified as normal meat, with values 58–73 as suspected PSE meat, and with values ≥ 74 as PSE meat.

Glycolytic potential

Twenty four hours after the slaughter, a 2-g sample was taken from the *longissimus lumborum* muscle of one randomly selected pig per pen (from 20 pigs in

Table 1. Ingredients, calculated nutritive value, and analysed composition of the experimental diets.

	Growing diet	Early-finishing diet	Finishing diet	
			Control	Fibrous
Ingredients, %				
Barley	78.95	81.81	87.56	57.86
Barley fibre	-	-	-	12.00
Faba beans	-	-	-	15.00
Soybean meal	17.86	15.34	9.81	-
Rapeseed cake, cold-pressed	-	-	-	12.77
Mineral and vitamin premix[a]	1.30	1.30	1.30	1.30
Calcium carbonate	0.83	0.76	0.71	0.63
Monocalcium phosphate	0.66	0.49	0.37	0.28
L-Lysine HCl	0.26	0.22	0.20	0.12
DL-Methionine	0.05	0.02	-	0.03
L-Threonine	0.08	0.06	0.04	0.01
Calculated nutritive value				
Net energy, MJ kg^{-1}	8.65	8.74	8.74	8.74
Net energy distribution, %				
Protein	17	16	14	14
Fat	5	5	4	13
Carbohydrates	78	79	82	73
Apparent ileal digestible amino acids, g kg^{-1}				
Lysine	8.8	8.0	6.6	6.6
Methionine+cystine	5.2	4.7	4.0	3.9
Threonine	5.3	4.8	3.9	3.9
Calcium, g kg^{-1}	7.5	7.0	6.4	6.4
Digestible phosphorus, g kg^{-1}	3.0	2.6	2.4	2.4
Analysed nutrient contents				
Dry matter, g kg^{-1}	880	878	879	892
Ash, g kg^{-1}	53	50	46	49
Crude protein, g kg^{-1}	182	166	144	155
Crude fat, g kg^{-1}	22	18	15	40
Sugars, g kg^{-1}	38	34	31	36
Starch, g kg^{-1}	409	435	465	361
Total dietary fibre[b], g kg^{-1}	176	175	177	250
Neutral detergent fibre, g kg^{-1}	164	163	161	229
Acid detergent fibre, g kg^{-1}	55	54	52	93
Lignin, g kg^{-1}	9	11	7	16
Hemicellulose, g kg^{-1}	108	109	109	137
Cellulose, g kg^{-1}	47	44	46	77

[a]Per kilogram of feed, the premix contained Ca, 2.3 g; P, 0.8 g; Mg, 0.5 g; NaCl, 3.3 g, Fe, 103 mg; Cu, 22 mg; Zn, 91 mg; Mn, 23 mg; Se, 0.28 mg; I, 0.28 mg; vitamin A, 5170 IU; vitamin D_3, 517 IU; vitamin E, 50 mg; thiamin, 2 mg; riboflavin, 5 mg; pyridoxine, 3 mg; vitamin B_{12} 20 µg; biotin, 0.2 mg; pantothenic acid, 14 mg; niacin, 20 mg; folic acid, 2 mg; and vitamin K, 2 mg.

[b]Total dietary fibre = dry matter - ash - crude protein - ether extract - sugars - starch.

Vol. 16 (2007): 245-258

total), frozen in liquid nitrogen, and stored at -80°C until analysed for glycogen and lactate contents. Glycogen content was analysed as glucose: 10 µl of homogenate (1 g of muscle sample in 10 ml of ice-cold phosphate buffer (pH 7.0)) were hydrolysed in 200 µl of 0.1 M HCl at 100°C for 2 h, after which the pH was adjusted to 6.5–7.5 (Lowry and Passoneau 1973), and glucose was determined via $NADP^+$ reduction with a linked assay involving hexokinase and glucose-6-phosphate dehydrogenase (Glucose (HK) 16-50, Sigma Diagnostics). Lactate concentration was determined from the homogenate via NAD^+ reduction with a linked assay involving lactate dehydrogenase and glutamate pyruvate transaminase (Boehringer-Mannheim no. 139 084). The glycolytic potential (µmol lactate g^{-1}) was calculated according to Monin and Sellier (1985) as follows: 2 × (glycogen + glucose + glucose-6-phosphate) + lactate.

Meat quality measurements

The ultimate pH and meat colour were measured 24 h *post mortem* in the three muscles *longissimus lumborum*, *semimembranosus*, and *semispinalis capitis* from the left side of the carcass. The ultimate pH was measured with a Knick Portamess 752 pH meter and a Mettler Toledo Inlab 427 electrode. Colour measurements (L^* = lightness, a^* = redness, and b^* = yellowness) were taken with a Minolta DP301 device (Minolta Camera Co., Ltd., Japan) from a freshly cut surface. Drip loss was determined from the *longissimus lumborum* muscle by weighing a 100-g sample of meat before and after storage in a sealed plastic bag at 4°C for three days. The weight difference was the drip, and it was expressed as a percentage. Intramuscular fat content of the *longissimus lumborum* muscle between the 4th and 5th lumbar vertebra was determined as crude fat content using a modified Soxhlet extractor (Soxtec 1047 Hydrolysing Unit and Soxtec Avanti Extraction, Foss Tecator).

The eating quality of the pork was evaluated by a trained 4-member panel from the Finnish Meat Research Institute (3–4 days *post mortem*) using samples taken from the *longissimus lumborum* muscle between the 1st and 4th lumbar vertebra. A total of 44 samples of *longissimus lumborum* were sliced into 1.5-cm steaks, grilled until they reached an internal temperature of 68°C (Palux Rotimat), and served as hot as possible to the panellists. Four samples were served during one evaluation (one from each finishing diet and fasting time combination). Panellists rated each stake for tenderness, juiciness, and taste by using a 7-point scale (7 = extremely tender, juicy, or good flavour, and 1 = extremely tough, dry, or bad off-flavour). Overall acceptability was calculated as the sum of the evaluated traits.

Feed analyses

Feed dry matter content was determined by drying at 103°C for 16 h. The ash, crude protein, and crude fat contents were determined according to the AOAC (1990) methods 942.05, 968.06, and 962.09, respectively. Sugar content was determined according to Somogyin (1945), and starch content according to McCleary et al. (1994) using assay format 2 without pullulanase/ß-amylase treatment. Total dietary fibre content was calculated as the following difference: dry matter - ash - crude protein - ether extract - sugars - starch. The neutral and acid detergent fibre (NDF and ADF) contents were determined according to van Soest et al. (1991) and Robertson and van Soest (1981), respectively, and the hemicellulose and cellulose contents were calculated as the differences NDF - ADF and ADF - lignin, respectively.

Statistical analyses

The data were analysed using the MIXED procedure of SAS (SAS® Systems for Windows, release 8.02). The growth performance data were analysed with pen as the experimental unit, and the carcass and meat quality data with pig as the experimental unit. The model applied to the data included the fixed

effects of finishing diet, fasting time, and their interaction and the random effect of block (blocks were based on breed and sex). Meat quality traits (ultimate pH and colour) measured in different muscles were analysed as repeated measurements using an unstructured covariance structure. Because of significant interactions between the muscle and finishing diet and/or fasting time in meat colour measurements, the data were also analysed separately for each muscle. Categorical data were analysed with the chi^2 test.

Results

Diet composition

The analysed composition of the experimental diets is presented in Table 1. The dietary crude protein contents were close to the targeted values. The fibrous finishing diet contained 104 g kg^{-1} less starch, 73 g kg^{-1} more total dietary fibre, and 68 and 41 g kg^{-1} more NDF and ADF, respectively, than the control diet.

Production performance and carcass quality

Before the finishing period, the pigs grew 1024 g d^{-1} and used 2.28 kg of feed per kg of gain. Neither the finishing diets nor the pre-slaughter fasting time had any significant effects on the growth performance of the pigs during the finishing period or total fattening (Table 2).

A total of 14 pigs from seven pens had been slaughtered by mistake immediately after being delivered to the slaughter house and from six of them no carcasses were received for meat quality measurements. These pigs had ca 17 h less fasting time than the other pigs, and they were excluded from the carcass and meat quality data. The investigated treatments did not have any significant effects on carcass weight, carcass yield, or the leanness of carcasses. However, the fibrous finishing diet increased the colour values ($P < 0.05$), which were assessed by a Hennessy GP4 probe and indicated the presence of PSE carcasses.

Glycolytic potential and quality of fresh pork

The fibrous finishing diet tended to lower ($P = 0.08$) the residual muscle glycogen content (30.2 vs. 24.7 μmol lactate g^{-1}), but it did not affect the lactate content or glycolytic potential measured in the *longissimus lumborum* muscle (Table 3). Longer pre-slaughter fasting lowered both the residual glycogen content (31.7 vs. 23.2 μmol lactate g^{-1}, $P = 0.01$) and glycolytic potential (159.1 vs. 137.8 μmol lactate g^{-1}, $P = 0.01$) of the muscle.

There were distinct differences in the frequency of ultimate pH and *L** values in the *longissimus lumborum*, *semimembranosus*, and *semispinalis capitis* muscles (Figures 1 and 2). The ultimate pH values from 5.7 to 5.9 were considered as optimal. Suboptimal ultimate pH values ($pH < 5.7$) were noticeably more frequent in the *longissimus lumborum* (84%) and *semimembranosus* (72%) muscles than in the *semispinalis capitis* (26%) muscle. Elevated ultimate pH values (≥ 6.0) were seen mainly in the *semispinalis capitis* muscle. According to Barton-Gade (1981), carcasses can be considered DFD when the ultimate pH of the *semispinalis capitis* is ≥ 6.5 or the ultimate pH of both the *longissimus dorsi* and *semispinalis capitis* is > 6.1. Carcasses are considered slightly DFD when the ultimate pH value of the *longissimus dorsi* is ≤ 6.1 and that of the *semispinalis capitis* is > 6.1 but not more than 6.5. Based on these criteria, only one pig had DFD meat, and it had been fed the fibrous diet and fasted for 41 h. The proportions of slightly DFD carcasses were 11.1 and 12.5% in the pigs fed the control diet and fasted for 25 and 41 h, respectively, and 6.3 and 18.8% in the pigs fed the fibrous diet and fasted for 25 and 41 h, respectively. Differences between the treatments were not significant. The colour of the *longissimus lumborum* was optimal (*L** 40–54) in 80% of the carcasses, while pale meat was seen more often in the *semispinalis capitis* and *semimembranosus* muscles. In the latter

Vol. 16 (2007): 245-258

Table 2. Effects of finishing diet and pre-slaughter fasting length on growth performance and carcass quality of fattening pigs.

Finishing diet	Control		Fibrous			Probability		
Fasting time	25 h	41 h	25 h	41 h	SEM	Diet	Fasting	Diet × fasting
No. of pens	10	10	10	10				
Body weight, kg								
Initial	26.1	26.0	25.7	24.6	0.7	0.18	0.33	0.14
Start of early-finishing	80.6	79.8	79.5	79.5	1.2	0.50	0.70	0.73
Final	105.7	105.1	106.8	106.1	1.1	0.24	0.45	0.91
Days on finishing diet	25.9	26.2	28.0	27.5	1.8	0.13	0.96	0.72
Body weight gain, g d^{-1}								
Growing+early-finishing*	1025	1017	1017	1039	24	0.67	0.69	0.37
Finishing	980	958	986	971	38	0.76	0.55	0.91
Overall	1008	1000	1007	1018	25	0.54	0.92	0.46
Kg feed per kg gain								
Growing+early-finishing*	2.28	2.28	2.29	2.25	0.04	0.88	0.54	0.52
Finishing	3.21^{a}	3.47^{b}	3.17^{a}	3.29^{ab}	0.09	0.23	0.04	0.44
Overall	2.57	2.63	2.58	2.58	0.05	0.52	0.38	0.35
No. of carcasses	18	16	16	16				
Carcass weight, kg	77.1	76.5	77.6	76.3	1.1	0.88	0.34	0.65
Carcass yield, %	73.1	73.2	73.0	72.3	0.4	0.15	0.38	0.19
Hennessy GP								
Last rib fat depth, mm	10.9	11.7	11.7	10.8	0.7	0.96	0.97	0.09
Fat depth betw. 12^{th}&13^{th} rib, mm	10.8	10.9	12.1	10.9	0.9	0.23	0.29	0.20
Loin depth, mm	53.5	52.8	51.4	51.4	1.7	0.18	0.76	0.77
Lean percentage	60.8	60.2	59.3	60.1	0.9	0.11	0.89	0.14
Colour value	43.3^{ab}	41.6^{a}	47.8^{ab}	49.5^{b}	3.0	0.01	0.99	0.50

*Lengths of growing and early-finishing periods were 35 and 21 days respectively.

[ab]Means with different superscripts differ significantly ($P < 0.05$).

two muscles, *L** values were within the optimal range only in 40 and 23% of carcasses, respectively.

There was a diet × fasting time interaction ($P = 0.05$) in the average ultimate pH of the investigated three muscles (Table 3). The combination of fibrous finishing diet and 41 h fasting resulted in a higher ultimate pH than the other three treatments ($P < 0.05$). The effects of the finishing diets and the fasting time on meat colour (*L**, *a**, *b**) were not significant. However, there were significant interactions between the muscle, finishing diet, and fasting time in the lightness (*L**) and yellowness (*b**) of pork, indicating that different muscles responded differently to the investigated treatments. Therefore, the data were analysed separately for each muscle as well. The finishing diet and pre-slaughter fasting time did not have any significant effects on the ultimate pH or colour of the *longissimus lumborum* muscle. Longer fasting decreased drip loss in pigs fed the control diet ($P = 0.05$). Fasting increased the ultimate pH of the *semimembranosus* muscle (5.59 vs. 5.67; $P = 0.02$). There was a diet × fasting time interaction in the lightness of the *semimembranosus* muscle ($P = 0.05$). In pigs fed the fibrous finishing diet, the meat was lighter in pigs fasted for 41 instead of 25 h ($P < 0.05$), while the difference observed after the different fasting times

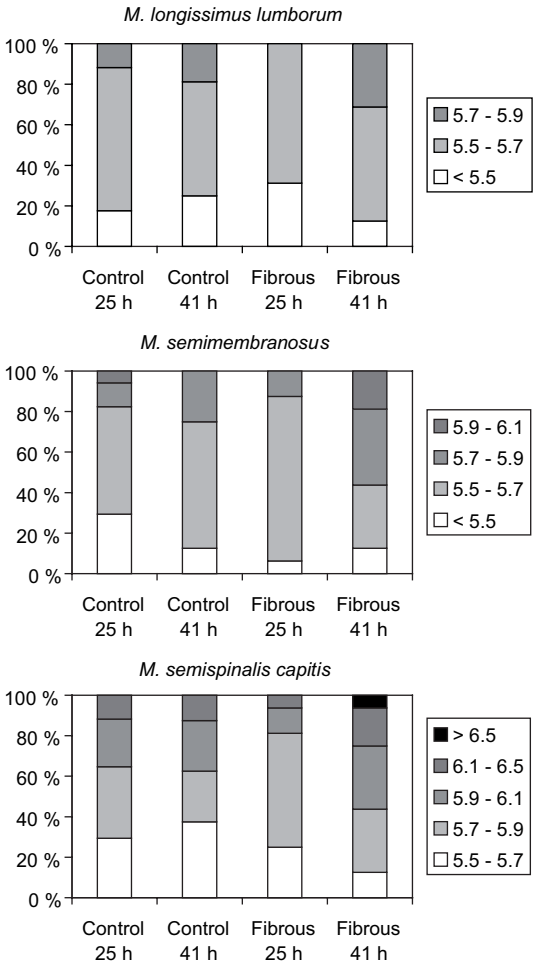

Figure 1. Effects of finishing diet (control vs. fibrous) and pre-slaughter fasting time (25 vs. 41 h) on the frequencies of ultimate pH values in the *longissimus lumborum, semimembranosus*, and *semispinalis capitis* muscles.

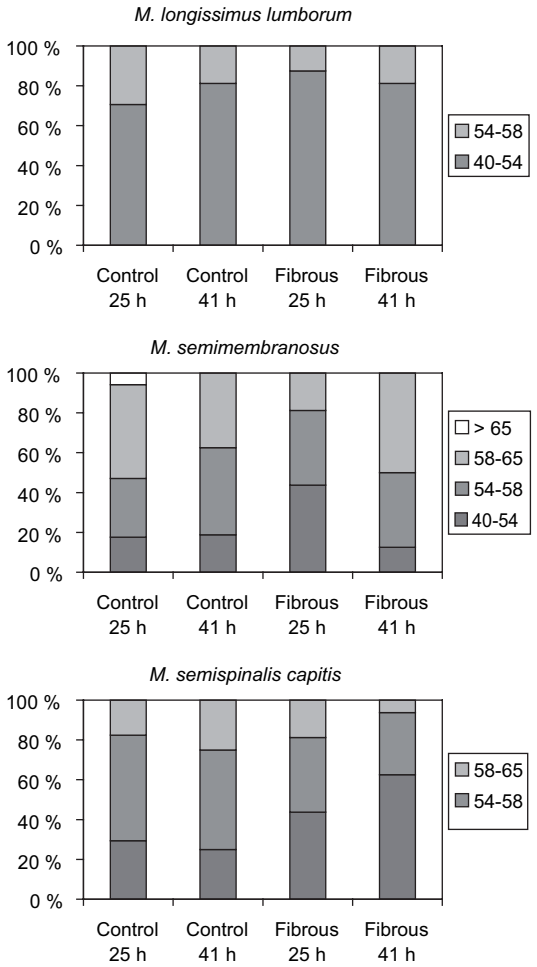

Figure 2. Effects of finishing diet (control vs. fibrous) and pre-slaughter fasting time (25 vs. 41 h) on the frequency of lightness (L^*) values in the *longissimus lumborum*, *semimembranosus*, and *semispinalis capitis* muscles.

was not significant in pigs fed the control diet. In pigs fasted for 25 h, the fibrous diet resulted in darker meat than the control diet ($P < 0.05$). The ultimate pH of the *semispinalis capitis* muscle was not affected by the investigated treatments, but the control finishing diet resulted in lighter (56.0 vs. 54.2; $P = 0.04$) and more yellowish meat colour (6.3 vs. 5.3; $P = 0.02$) than the fibrous finishing diet did.

Intramuscular fat and pork eating quality

Neither the finishing diets nor pre-slaughter fasting had any significant effects on the intramuscular fat content or eating quality (taste, juiciness, and tenderness) of pork as determined in the *longissimus lumborum* muscle (Table 4).

Vol. 16 (2007): 245-258

Table 3. Effects of finishing diet and pre-slaughter fasting time on glycolytic potential of the *longissimus lumborum* muscle and on the quality traits of pork in the *longissimus lumborum, semimembranosus,* and *semispinalis capitis* muscles.

Finishing diet	Control diet		Fibrous diet			Probability		
Fasting time	25 h	41 h	25 h	41 h	SEM	Diet	Fasting	Diet × fasting
No. of samples	9	9	9	8				
Glycogen, μmol g^{-1}	35.9^{b}	24.5^{a}	27.5^{ab}	21.8^{a}	3.2	0.08	0.01	0.36
Lactic acid, μmol lactate g^{-1}	94.8	93.6	96.6	89.4	2.5	0.62	0.09	0.21
Glycolytic potential, μmol lactate g^{-1}	166.6^{b}	142.6^{ab}	151.6^{ab}	133.0^{a}	8.5	0.14	0.01	0.74
No. of samples per muscle	17	16	16	16				
Average in three muscles								
Ultimate pH	5.66^{a}	5.68^{a}	5.65^{a}	5.78^{b}	0.03	0.11	0.01	0.05
*L**	54.8	54.5	53.7	53.6	0.6	0.07	0.68	0.77
*a**	7.3	7.0	7.3	7.2	0.4	0.77	0.52	0.71
*b**	4.5	4.5	4.2	4.3	0.2	0.26	0.92	0.74
Longissimus lumborum								
Ultimate pH	5.57	5.57	5.54	5.62	0.03	0.68	0.16	0.13
*L**	51.0	50.1	51.1	50.3	0.1	0.89	0.24	0.95
*a**	5.8	5.9	6.4	6.3	0.4	0.12	0.67	0.81
*b**	2.8	3.0	3.6	3.0	0.3	0.18	0.54	0.18
Drip loss, %	4.3^{b}	3.1^{a}	3.8^{ab}	3.7^{ab}	0.3	0.93	0.05	0.09
Semimembranosus								
Ultimate pH	5.59^{a}	5.63^{ab}	5.60^{a}	5.71^{b}	0.03	0.17	0.02	0.29
*L**	57.7^{b}	56.8^{ab}	54.7^{a}	57.5^{b}	0.9	0.21	0.28	0.05
*a**	5.4	4.8	5.7	5.4	0.3	0.25	0.17	0.68
*b**	4.4	4.0	3.7	4.4	0.3	0.75	0.58	0.08
Semispinalis capitis								
Ultimate pH	5.82	5.84	5.81	5.99	0.06	0.27	0.08	0.16
*L**	55.8^{ab}	56.3^{b}	55.0^{ab}	53.4^{a}	0.9	0.04	0.52	0.24
*a**	10.5	10.0	9.8	9.7	0.6	0.41	0.64	0.65
*b**	6.3^{b}	6.2^{ab}	5.2^{a}	5.5^{ab}	0.4	0.02	0.75	0.60

^{ab}Means with different superscripts differ significantly ($P < 0.05$).

Table 4. Effects of finishing diet and pre-slaughter fasting time on the intramuscular fat content and eating quality of pork in the *longissimus lumborum* muscle.

Finishing diet	Control diet		Fibrous diet			Probability		
Fasting time	25 h	41 h	25 h	41 h	SEM	Diet	Fasting	Diet × fasting
No. of samples	6	4	5	5				
Intramuscular fat, %	1.4	1.4	1.8	1.9	0.3	0.24	0.92	0.90
Tenderness	4.7	4.4	4.7	4.7	0.3	0.72	0.56	0.64
Juiciness	4.8	4.6	4.9	4.8	0.2	0.56	0.52	0.97
Taste	4.9	4.9	4.9	4.9	0.1	0.82	0.94	0.33
Acceptability^{a}	14.5	13.8	14.5	14.4	0.6	0.64	0.56	0.63

^{a}Sum of tenderness, juiciness and taste scores.

Discussion

Diets for finishing pigs generally contain from ca 85 to over 90% cereals or maize. Starch is the major energy-yielding constituent in both of these crops and can represent 47–69% of dry matter (Bach Knudsen 1997). Consequently, the starch content of finishing diets ranges from 400 to 550 g kg^{-1}. In this study, the replacement of one third of barley and all soybean meal with faba beans, barley fibre, and cold-pressed rapeseed cake lowered the starch content of the finishing diets from 465 to 361 g kg^{-1}. Pure starch consists predominantly of α-glucan in the form of amylose and amylopectin, which can be present in various proportions in starch granules. Legumes contain 30–40% amylose and 60–70% amylopectin in starch, while cereals contain 25–30% amylose and 70–75% amylopectin. Raw starches high in amylopectin are digested more quickly than those high in amylose (Thorne et al. 1983). According to Wiseman (2006), most cereal starch is digested and absorbed as glucose in the small intestine of pigs, while some legume starch escapes ileal enzymatic digestion and is subjected to microbial fermentation in the large intestine. Therefore, it is relevant to assume that the replacement of barley with faba beans did not only limit the starch intake but also altered the site and extent of starch digestion in pigs fed the fibrous finishing diet. Legume proteins and antinutritive factors may also reduce the availability of starch for digestion (Thorne et al. 1983). The total dietary fibre, hemicellulose, and cellulose contents were naturally greater in the fibrous than in the control finishing diet.

The control and fibrous finishing diets were formulated to provide equal amounts of net energy and apparent ileal digestible amino acids per kg. Therefore the choice of finishing diet was not expected to and did not affect the growth performance or carcass lean percentage of the pigs. Similarly, Rosenvold et al. (2001a) reported no significant effects on body weight gain or feed conversion ratio when finishing pigs were fed muscle-glycogen-reducing diets containing rapeseed cake, sugar beet pulp, and/or grass meal as the major ingredients. However, the INURA diet (main ingredients: rapeseed cake and inulin) has improved body weight gain compared to a standard finishing diet (Rosenvold et al. 2001a, 2002). In the study of Rosenvold et al. (2001b), several low-starch but high-fibre and high-protein diets resulted in reduced feed intake and growth performance of finishing pigs.

The two fasting times, 25 and 41 h from the last meal to slaughter, were obtained by altering the length of on-farm fasting while treating the pigs in a similar manner during loading, transportation, and lairage. The 16-h difference in on-farm fasting had no effect on carcass weight or carcass yield. This is contrary to findings in several earlier studies in which longer fasting has been reported to reduce gut fill and viscera weight and consequently increase carcass yield (Leheska et al. 2003, Bidner et al. 2004). Generally, carcass yield has increased when fasting time has exceeded 20 h, and both fasting times in this study were longer.

Based on the colour measurements taken in the slaughter line with a Hennessy GP4, none of the carcasses had clearly PSE meat (colour values ≥ 74). The average colour values were higher in carcasses of pigs fed the fibrous instead of the control finishing diet ($P = 0.01$), but fasting time did not affect colour values. According to Guàrdia et al. (2004), the minimum risk of PSE condition is achieved when on-farm fasting time is between 18 and 22 h. Similarly, Eikelenboom et al. (1991) recommended an on-farm fasting period of 16–24 h to reduce the incidence of PSE meat.

The glycolytic potential is an estimate of the glycogen content present in the muscle at slaughter (Monin and Sellier 1985). It is generally determined from samples taken after exsanguination. However, when pigs are slaughtered in a commercial slaughter house, like in this study, the sampling of carcasses can be difficult due to high slaughter speed. According to Maribo et al. (1999), the glycolytic potential on the *longissimus dorsi* muscle was similar when determined 4 or 30 h after slaughter. Therefore, the glycolytic potential was determined from muscle samples taken one day after the slaughter.

The glycolytic potential of the *longissimus lumborum* muscle ranged from 97 to 196 µmol lactate g^{-1}. The fibrous finishing diet did not manage to

Vol. 16 (2007): 245-258

lower the muscle glycolytic potential. It is likely that the change in the carbohydrate composition of the finishing diet was not sufficiently large to significantly affect the muscle glycolytic potential. Rosenvold et al. (2001b) fed slaughter pigs different diets with low starch but high fibre, fat, and protein contents, which managed to lower the muscle glycogen content during the three-week finishing period.

When pigs are fasted before slaughter, they use muscle glycogen stores to get energy. Pre-slaughter fasting has been shown to deplete muscle glycogen reserves in pigs, but the magnitude of the effect seems to depend on various factors like the length of fasting, transportation, and lairage conditions (Leheska et al. 2003). In this study, fasting decreased both the residual glycogen content and the glycolytic potential of the *longissimus lumborum*, which is in accordance with the results of Leheska et al. (2003) and Bertol et al. (2005).

In this study, finishing diet did not affect the average ultimate pH of the investigated three muscles but the ultimate pH was increased by longer fasting. The combination of fibrous finishing diet and 41 h fasting resulted in the highest ultimate pH values. In individual muscles, increasing fasting time from 25 to 41 h increased the ultimate pH of the *semimembranosus* muscle and tended to increase that of the *semispinalis capitis* muscle, while the *longissimus lumborum* remained unaffected. Other studies have also shown that increased feed withdrawal decreases muscle glycolytic potential and consequently increases the ultimate pH and darkness of meat (Jones et al. 1985, Eikelenboom et al. 1991).

The rate at which the muscle pH and glycogen content decline during the conversion of muscle to meat has significant impact on the development of fresh meat quality attributes (Scheffler and Guarrard 2007). In this study, we were not able to measure these changes in the slaughterhouse. Normally, the pH declines gradually from 7.4 in living muscle to roughly 5.6–5.7 within 6–8 h *post mortem*, and the ultimate pH at 24 h is about 5.3–5.7. Some pigs exhibit rapid glycolysis which produces heat and slows carcass chilling. This results in rapid pH decline to less than 6.0 during the first hour after slaughter but the ultimate pH is ca 5.3–5.7. In contrast, extended pH decline proceeds at normal rate but continues to low ultimate pH of 5.3–5.5 (acid meat). The combination of high temperature at low pH or abnormally low ultimate pH results in paler colour and reduced water holding capacity. In the study of Eikelenboom et al. (1991), drip loss was decreased after 24 h of feed withdrawal before delivery, while 16 h of feed withdrawal did not affect drip loss. In this study, 41 h fasting reduced drip loss from meat in pigs that were the control diet.

Although the fibrous finishing diet did not affect the muscle glycolytic potential and ultimate pH, it darkened the colour of the *semispinalis capitis* muscle, and it darkened the colour of the *semimembranosus* in pigs that were fasted for 25 h. In the study of Partanen et al. (2003), barley-based diets that contained faba beans and rapeseed cake darkened the colour of the *longissimus dorsi* muscle. Diets containing high amounts of rapeseed products have also been reported to result in darker and redder meat (Dransfield et al. 1985). Rosenvold et al. (2001b) found that a low starch diet with rapeseed cake and peas increased the ultimate pH of pork but did not affect its colour. Previously, Rosenvold et al. (2001a,b) had reported that decreased muscle glycogen content improves the water-holding capacity of different muscles. In this study, however, drip loss was not influenced by the finishing diets.

Prolonged fasting can result in increased incidence of DFD meat that has high ultimate pH (≥ 6.0) and poor microbiological stability (Eikelenboom et al. 1991, Guàrdia et al. 2005). In this study, the combination of the fibrous finishing diet and 41 h of fasting resulted in DFD in one pig, while the share of slightly DFD pigs did not differ between the treatments.

The quality scoring of cooked meat samples did not show any significant differences in the tenderness, juiciness, and taste or the overall acceptability of cooked loin samples resulting from the different finishing diets or pre-slaughter fasting times. In addition, the number of scored meat samples per treatment was small. According to Støier et al. (2006), meat from pigs fed a strategic, low-carbohydrate finishing diet exhibited taste differences in cooked

meat patties that were made from minced shoulder clod and blade roll. The meat patties from pigs fed the control diet had more bitter/burnt flavours and those from pigs fed the strategic finishing feed had more sour flavours. In the study of Partanen et al. (2003), the eating quality of pork from pigs fed diets containing faba beans and rapeseed meal did not differ from that of pigs fed barley and soybean meal based diet.

Conclusions

Changing the carbohydrate composition of a finishing diet by replacing soybean meal and some barley with fibrous feed ingredients like faba beans, barley fibre, and cold-pressed rapeseed cake has little impact on the muscle glycolytic potential and the ultimate pH of fresh pork, but it can darken meat colour in some muscles. Increasing pre-slaughter fasting is a more effective means of manipulating muscle glycolytic potential, and it also increases the ultimate pH of fresh pork, but it has little impact on meat colour. Longer fasting can also reduce drip loss from meat in pigs that are fed a high-starch diet based on barley and soybean meal. Neither a fibrous finishing diet nor pre-slaughter fasting seem to affect the eating quality of pork. Furthermore, moderate changes in the carbohydrate composition of finishing diet do not affect the production performance of pigs.

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Vol. 16 (2007): 245-258

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SELOSTUS

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Tutkimuksen tavoitteena oli selvittää 2 × 2 faktorikokeessa, miten loppukasvatusrehun hiilihydraattikoostumus ja teurastusta edeltävän paaston pituus vaikuttavat sianlihan laatuun. Lihasikojen kasvatuskokeessa 80 maatiais- ja yorkshirerotujen risteytyssikaa jaettiin pareittain, sukupuolet erikseen neljään koekäsittelyyn. Kontrollina olleessa ohra-soijarouhepohjaisessa loppukasvatusrehussa oli tärkkelystä 465 g/kg ja kuitua 177 g/kg. Kuitupitoisessa, ohraa, ohrakuitua, härkäpapua ja kylmäpuristettua rypsiä sisältäneessä loppukasvatusrehussa oli tärkkelystä 361 g/kg ja kuitua 250 g/kg. Loppukasvatusrehuja syötettiin 80 kilon elopainosta alkaen teurastukseen saakka eli noin neljä viikkoa. Teurastusta edeltäneet 25:n ja 41 tunnin paastot saatiin aikaan muuttamalla viimeisen rehuannoksen antamisajankohtaa. Kuljetus ja odotusaika teurastamossa olivat kaikilla sioilla samanlaiset.

Siat kasvoivat kontrolliruokinnalla ja kuitupitoisella ruokinnalla yhtä nopeasti. Loppukasvatusrehu ja paaston pituus eivät vaikuttaneet ruhopainoon eivätkä lihaprosenttiin. Paaston pidentäminen pienensi ulkofileestä (*M. longissimus lumborum*) mitattua lihaksen glykolyyttistä potentiaalia, mutta ruokinta ei vaikuttanut siihen. Vaikka ruokinta ja paasto eivät muuttaneet ulkofileen loppu-pH-arvoa (24 tuntia teurastuksesta) tai väriä, pidempi paasto vähensi kudosnesteiden valumaa kontrollirehua syöneiden sikojen lihasta. Loppukasvatuksen ruokinta ei vaikuttanut sisäpaistin (*M. semimembranosus*) loppu-pH-arvoon, mutta pidempi paasto nosti sitä. Sisäpaistin värissä oli ruokinnan ja paaston välillä yhdysvaikutus. Kuitupitoinen rehu tummensi sisäpaistin väriä 25 tuntia paastonneilla sioilla, ja pidempi paasto tummensi kuitupitoista rehua syöneiden sikojen sisäpaistin väriä. Vaikka ruokinta ei vaikuttanut niskapaistin (*M. semispinalis capitis*) loppu-pH-arvoon, kuitupitoinen rehu tummensi sen väriä. Sen sijaan paaston pituudella ei ollut vaikutusta niskapaistin pH-arvoon eikä väriin. Loppukasvatuksen ruokinta ja paaston pituus eivät myöskään vaikuttaneet ulkofileestä määritettyyn lihan syöntilaatuun. Tulosten perusteella maltillinen loppukasvatusrehun tärkkelyspitoisuuden alentaminen ja kuitupitoisuuden lisääminen ja pitempi teurastusta edeltävä paasto voivat jossain määrin vaikuttaa tuoreen sianlihan laatuun, mutta vaikutukset ovat erilaisia eri lihaksissa.