Effects of Ground Flaxseed in Swine Diets on Pig Performance and on Physical and Sensory Characteristics and Omega-3 Fatty Acid Content of Pork: I. Dietary Level of Flaxseed[1]

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ABSTRACT: Forty-eight barrows and gilts were fed diets containing 0 (CO), 5, 10, or 15% ground flaxseed (FS) for the final 25 d before slaughter. Flaxseed treatments did not affect any production or carcass traits ($P > .10$). No pork processing problems due to lack of firmness were encountered. Amounts (milligrams/gram of tissue) of alpha-linolenic acid (ALA [18:3*n*-3]) and eicosapentaenoic acid (EPA [20:5*n*-3]) increased ($P < .01$) in both backfat layers and ALA increased ($P < .01$) in kidney (leaf) fat after FS. Alpha-linolenic acid and EPA increased ($P < .001$) in the raw belly in response to FS; the effect was maintained throughout processing ($P < .01$) to microwaved bacon. Alpha-linolenic acid and EPA increased ($P < .01$, $P < .05$, respectively) with amount of FS in longissimus thoracis and liver. In the brain, DHA decreased ($P < .05$) with amount of FS. Trained panelists in triangle tests were able to identify bacon from pigs fed 10 and 15% flaxseed. Panelists could not identify various treatments in the loin tests.

Key Words: Flax, Pork, Fatty Acids, Consumers, Linolenic

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Introduction

Because of conflicting reports appearing daily regarding fat in the human diet, opportunities exist for animal scientists to improve the nutritional value of fat that animals produce. Alpha-linolenic acid (**ALA** [18:3*n*-3]) is the precursor fatty acid for the synthesis of eicosapentaenoic acid (**EPA** [20:5*n*-3]) and docosahexaenoic acid (**DHA** [22:6*n*-3]), the 20 and 22 carbon fatty acids in fish oil that elicit beneficial health effects, especially controlling cardiovascular diseases (Goodnight, 1993) and maintaining normal brain growth and development (Leaf, 1993). Flaxseed (*Linum usitatissimum*) is the oilseed richest in ALA, averaging 18% of the total seed weight and consisting of 53% of the flaxseed fatty acids (USDA, 1986; Chow, 1992). The objectives of this study were 1) to determine the effect of feeding three levels (5, 10, or 15%) of ground flaxseed to pigs for 25 d before slaughter on growth and carcass composition, 2) to determine omega-3 fatty acid content of various pork tissues following feeding of flaxseed, and 3) to determine the effects of dietary flaxseed on processing and cooking capabilities and consumer acceptability of pork.

Materials and Methods

Pigs and Diets. Forty-eight pigs were stratified by starting weight into three replications with two barrows and two gilts per treatment in each replication. The four treatments consisted of diets containing 0, 5, 10, or 15% ground flaxseed for the final 25 d before slaughter. Clark 2925 was the flaxseed variety used.

Proximate composition of the ground flaxseed (Clark 2925) is shown in Table 1. Clark 2925 flaxseed contained 100 mg ALA/g. Composition of the finishing diets is shown in Table 2. Percentage of fat in the finishing diets increased from 3.4% in the control diet to 8.4% in the 15% FS diet (Table 2).

Carcass and Product Handling. Pigs were slaughtered at the South Dakota State University Meat

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Table 1. Composition (as-fed basis) of ground flaxseed[a]

Component	Percentage
Dry matter	93.6
Crude protein	26.2
Crude fiber	14.2
Crude fat	37.1
Ash	3.8
Nitrogen-free extract	11.8

[a]Variety Clark 2925.

Table 2. Diet composition (as-fed basis), %

	Diet			
Ingredient	Control	5	10	15
Flaxseed	0	5	10	15
Corn	82.0	79.2	76.4	73.7
Soybean meal	15.4	13.2	11.1	8.9
Mineral and vitamin premix	2.6	2.6	2.5	2.4
Analyses				
Moisture	12.1	12.0	11.6	11.4
Protein	14.2	14.0	14.1	14.1
Fat	3.4	4.9	6.6	8.4

Laboratory. Skins were pulled (Romans et al., 1994) so all backfat thickness measurements were increased .25 cm to equal fat measurements from scalded carcasses. Samples of the longissimus thoracis, outside and middle/inner layers of backfat separately, and belly were taken at the 10th rib location and of leaf (kidney) fat, liver, heart, brain, and eyes (all) were taken within 50 min postmortem, sealed in Nasco WHIRL-PAK bags (Nasco, Fort Atkinson, WI), and stored at −18°C until they were analyzed. After carcasses were chilled at 1°C for approximately 48 h, routine carcass measurements were taken to estimate composition. Carcasses were cut into standard wholesale cuts. Boneless loin (longissimus thoracis) chops (2 cm thick, 100 g) were vacuum-packaged and frozen at −18°C for later taste panel evaluation. An objective test consisting of hanging the bellies over a smoke stick at their midpoint and measuring the distance between the "draped" ends was used to evaluate belly firmness. Bellies were pumped, tumbled, smoked, cooled, and then sampled, and samples were vacuum-packaged and frozen at −18°C until the various analyses were conducted. Bacon samples were frozen for 6 mo and loin samples for 7 mo before taste tests were conducted.

Taste Evaluations. Trained consumer panels (American Meat Science Association, 1978) consisting of volunteers from the professional staff at the university were used to evaluate the bacon and pork chops. The taste series for bacon preceded the series for pork chops by 1 mo. For each product, one introductory session was held for 12 volunteers. For bacon, two triangle tests were given using Hormel Black Label (Austin, MN) vs Flavorite (Super Valu, Eden Prairie, MN). The number of panelists was reduced to six (two men and four women) on the basis of their ability to discriminate between samples on the introductory tests. Two of the panel members had been on other taste panels previously. The training/introductory session covered visual appearance, aroma, flavor, and texture/mouthfeel of bacon. For pork chops, two triangle tests were given based on differences in tenderness and juiciness. The number of panelists was reduced to eight (four men and four women) on the basis of their ability to discriminate between samples on the introductory tests.

Fatty Acid Profile Analysis. All tissues were removed from the −18°C freezer and immersed in liquid nitrogen and then homogenized before sampling. Samples were dried by grinding with anhydrous sodium sulfate in a mortar and pestle. This mix was then placed in a 30-cm × 19-mm o.d. glass column. Total lipids were extracted from all tissues by a single pass of dichloromethane-methanol (9:1 vol/vol). Because of the toxicity of chloroform (Merck & Co., 1989), dichloromethane is the preferred lipid solvent (Maxwell et al., 1980). Methyl esters were prepared (Morrison and Smith, 1964) and analyzed by GLC in a Hewlett-Packard Model 5890 (Hewlett-Packard, Atlanta, GA) gas chromatograph with a flame ionization detector (**FID**). The separation of fatty acids was effected on a 30-m × .25-mm Supelco Model SP 2330 (Supelco, Bellefonte, PA) column. The column was run isothermally at 150°C for 8 min and then raised 3°C per min to 190°C. The FID and injection port temperatures were held at 250°C and 200°C, respectively. Peak areas were calculated automatically on a Hewlett-Packard Model 3393A integrator.

Statistical Analysis. Analysis of variance (SAS, 1985) was used to analyze fatty acid profiles from the various tissues and to calculate least squares means. A completely random design was employed. Experimental unit was the individual pig. Replication × treatment was used as the error term to test treatments. Standard deviations and df are reported in all tables because the number of samples tested was not always equal. Treatment means were compared using the LSD multiple comparison procedure. Chi-square distribution analysis was used for the taste panel triangle tests.

Results and Discussion

Flaxseed (**FS**) treatments did not affect any measured production or carcass traits ($P > .10$), so overall means and SD are presented in Table 3. An objective test consisting of hanging fresh bellies over a smoke stick at their midpoint and measuring the distance between the draped ends showed no firmness

Table 3. Production and carcass characteristics

Trait	Mean	SD
n	48	—
Days on flaxseed diet	25	—
Initial live wt, kg	86	1.0
Final live wt, kg	104	10
ADG, kg	.71	.10
Hot carcass wt, kg	72	3.7
Muscle score[a]	2.6	.21
Last rib fat, cm	2.1	.35
Avg backfat, cm	2.8	.42
USDA grade	.75	.69

[a]1 = thin, 2 = avg, 3 = thick.

differences (P = .74). Firmness variation due to fatness was removed by using average backfat and belly weight as covariates (data not shown). No processing problems due to lack of firmness were encountered. Percentage of total lipid in the various tissues was not affected by dietary treatment (Table 4).

Fatty acid composition of pork fat can be altered through dietary changes in fatty acid composition by feeding cooked soybeans (Romans et al., 1970; Skelley et al., 1975), sunflower seeds (Hartman et al., 1985), sunflower oil (Rhee et al., 1988; Sterling et al., 1994), peanuts (West and Myer, 1987), canola oil (St. John et al., 1987), safflower oil (Larick et al., 1992), fish (sardine) oil (Irie and Sakimoto, 1992), linseed oil (Anderson et al., 1972), and ground flaxseed (Cunnane et al., 1990). Of these workers, Anderson et al. (1972), Irie and Sakimoto (1992), Larick et al. (1992), Rhee et al. (1988), Skelley et al. (1975), St. John et al. (1987), and West and Myer (1987) measured linolenic acid (18:3), but none of these researchers specified either 18:3n-3 (ALA) or 18:3n-6 linolenic acid. Only Cunnane et al. (1990) measured specifically ALA; these workers and Irie and Sakimoto (1992) also measured EPA and DHA.

Table 4. Percentage of total lipid in various tissues

Tissue	Mean	SD	P
n	48	—	—
Backfat, middle/inner layer	84	6.4	.42
Backfat, outer layer	83	7.1	.06
Belly, kill floor	61	9.3	.38
Uncooked bacon[a]	49	6.4	.66
Fried bacon	38	5.3	.95
Microwaved bacon	31	9.9	.39
Longissimus thoracis	3.1	.64	.26
Liver	4.4	1.4	.86
Heart	2.7	.89	.29
Brain	7.7	.63	.39
Eyes	8.1	3.6	.015

[a]Within 1 wk of smoking.

Increased amounts of dietary FS caused ALA and EPA to increase in both backfat layers and in kidney (leaf) fat (Table 5). Alpha linolenic acid and EPA increased in response to amount of dietary FS beginning with the raw belly; the effect on both fatty acids continued throughout processing except for EPA in microwaved bacon (Table 6).

In general, across all treatments, fatty acids decreased as bellies were stored, processed, and cooked (Table 7), except that frying increased the concentration of EPA and DHA. Changes were possibly due in part to overall total lipid losses during processing (Table 4) that were counteracted by the dehydration effects of cooking.

Alpha-linolenic acid and EPA increased with amount of FS in longissimus thoracis and liver lipids (Table 8). The results of measuring the content of ALA, EPA, and DHA in the heart, brain, and eyes are shown in Table 9. Alpha-linolenic acid and EPA increased in the heart with increased amount of FS. In the brain, which contained the highest amount of DHA of all tissues tested, DHA decreased with amount of FS. There was no FS effect on the fatty acid composition of eyes.

After storage of bacon for 6 mo and loins for 7 mo at −18°C, trained panelists in triangle tests were able to identify bacon from pigs fed 10 and 15% FS. Panelists

Table 5. Effects of amount of dietary flaxseed on fatty acid content of backfat and kidney fat

Flaxseed, %	ALA 18:3	EPA 20:5	DHA 22:6
	mg/g of Tissue		
Backfat, outer layer			
0	4.6[a]	.074[a]	.068
5	9.2[b]	.12[b]	.071
10	15[c]	.16[bc]	.095
15	18[c]	.18[c]	.067
SD	4.1	.039	.029
df	45	45	45
P	.001	.003	.20
Backfat, middle/inner layer			
0	10[a]	.090[a]	.13
5	23[b]	.20[b]	.15
10	37[c]	.28[c]	.15
15	53[d]	.38[d]	.14
SD	7.1	.042	.073
df	46	46	44
P	.001	.001	.87
Kidney (leaf) fat			
0	2.1[a]	.014[a]	.022
5	6.9[ab]	.077[b]	.030
10	9.3[bc]	.091[b]	.038
15	13[c]	.14[b]	.027
SD	5.2	.082	.016
df	46	46	46
P	.012	.067	.20

[a,b,c,d]Means within a column within a tissue lacking a common superscript differ as indicated on the line P.

Table 6. Effects of amount of dietary flaxseed on fatty acid content of bellies and bacon

Flaxseed, %	ALA 18:3	EPA 20:5	DHA 22:6
	mg/g of Tissue		
Belly			
0	1.5[a]	.027[a]	.016
5	3.3[b]	.039[b]	.020
10	5.6[c]	.062[c]	.022
15	8.1[d]	.077[d]	.025
SD	1.2	.011	.0084
df	46	46	46
P	.001	.001	.182
Uncooked bacon			
0	1.2[a]	.015[a]	.009
5	2.9[b]	.018[a]	.008
10	4.6[c]	.047[b]	.011
15	6.9[d]	.066[b]	.020
SD	1.4	.022	.0090
df	46	44	43
P	.001	.004	.078
Fried bacon			
0	1.9[a]	.028[a]	.034[a]
5	3.7[b]	.077[b]	.047[b]
10	4.5[c]	.079[b]	.031[a]
15	5.6[c]	.11[c]	.033[a]
SD	1.2	.0061	.0092
df	41	41	41
P	.002	.001	.037
Microwaved bacon			
0	1.4[a]	.011	.0059
5	2.5[ab]	.039	.011
10	3.8[bc]	.046	.011
15	4.7[c]	.058	.010
SD	1.6	.041	.018
df	45	44	39
P	.008	.17	.84

[a,b,c,d]Means within a column within a tissue lacking a common superscript differ as indicated on the line *P*.

Table 7. Effect of processing stage on fatty acid content of bellies and bacon

Item	ALA 18:3	EPA 20:5	DHA 22:6
	mg/g of Tissue		
Belly	4.6[a]	.051[a]	.021[a]
Uncooked bacon	3.9[a]	.038[c]	.012[c]
Fried bacon	4.0[a]	.076[b]	.037[b]
Microwaved bacon	3.1[b]	.037[c]	.0096[d]
SD	1.5	.029	.021
df	213	210	204
P	.010	.002	.002

[a,b,c,d]Means within a column lacking a common superscript differ as indicated on the line *P*.

Table 8. Effect of amount of dietary flaxseed on fatty acid content of longissimus thoracis and liver

Flaxseed, %	ALA 18:3	EPA 20:5	DHA 22:6
	mg/g of Tissue		
Longissimus thoracis			
0	.19[a]	.033[a]	.017
5	.52[b]	.052[b]	.021
10	.75[bc]	.055[b]	.018
15	.87[c]	.031[a]	.015
SD	.33	.018	.006
df	46	46	45
P	.009	.037	.18
Liver			
0	.059[a]	.081[a]	.12
5	.25[b]	.40[b]	.14
10	.41[c]	.73[c]	.13
15	.41[c]	.73[c]	.10
SD	.10	.22	.037
df	20	20	20
P	.013	.022	.41

[a,b,c,d]Means within a column within a tissue lacking a common superscript differ as indicated on line *P*.

Table 9. Effect of amount of dietary flaxseed on fatty acid content of heart, brain, and eyes

Flaxseed, %	ALA 18:3	EPA 20:5	DHA 22:6
	mg/g of Tissue		
Heart			
0	.08[a]	.017[a]	.011
5	.20[b]	.081[b]	.017
10	.32[c]	.11[bc]	.015
15	.41[c]	.13[c]	.011
SD	.067	.032	.0054
df	22	22	22
P	.001	.008	.26
Brain			
0	.030	.0050	.70[a]
5	.024	.0050	.51[b]
10	.030	.0050	.52[b]
15	.024	.0050	.56[b]
SD	.016	.0065	.84
df	23	10	23
P	.80	.93	.025
Eyes			
0	.20	.019	.0081
5	.21	.0029	.0096
10	.16	.0063	.012
15	.13	.0054	.012
SD	.086	.012	.0065
df	23	22	23
P	.45	.28	.68

[a,b,c]Means within a column within a tissue lacking a common superscript differ as indicated on line *P*.

Table 10. Frequency of identifying different samples[a]

Flaxseed	Bacon, percentage correct	Loin, percentage correct
Control vs 5%	50	44
Control vs 10%	68	44
Control vs 15%	67	48
5% vs 10%	60	33
5% vs 15%	75	44
10% vs 15%	67	48

[a]Six (bacon) and eight (loin) member panels, triangle tests, chi-square distribution analysis. Frequencies >50% are significant ($P < .05$).

could not identify various treatments in the loin tests (Table 10). Free response comments were mostly negative for the FS bacon but were more moderate for the FS loin samples (Romans et al., 1990).

Implications

Increasing levels (0, 5, 10, and 15%) of ground flaxseed in a swine diet for the final 25 d before slaughter increased the content of healthful omega-3 fatty acids in bacon and loin chops. The 15% flaxseed diet caused the greatest increase, but consumers were able to identify bacon from the higher levels in triangle tests. Thus, 15% dietary flaxseed is probably the highest level that should be used with finishing hogs.

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