Alteration of the Fatty Acid Profile of Pork by Dietary Manipulation

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ABSTRACT : This work was undertaken to study the effect of dietary fat source on the fatty acid profile of pork, and to evaluate the effect of inclusion of vitamin E in pig diets on lipid oxidation of pork tissue and processed pork products. Fifty-six pigs were allocated to four treatments, that included two dietary fat sources and two levels of vitamin E inclusion. Dietary fat was derived from either tallow, a source of saturated fatty acids (SFA), or from a mixture of soybean and linseed oils, which contain polyunsaturated fatty acids (PUFA). Vitamin E was included at either 0% or 0.011% of the diet. Growth and carcass characteristics were not affected by the dietary treatments. Dietary fat source affected the fatty acid profile of the longissimus muscle and subcutaneous fat tissue, with the PUFA diet resulting in significantly more polyunsaturated fatty acids in the tissues, and more favourable ratios of SFA to PUFA and C18:2 to C18:3 in terms of human health considerations. Lipid oxidation was significantly greater in tissues and processed products from PUFA-fed pigs. Inclusion of vitamin E in the diets, however, reduced the extent of lipid oxidation in the meat and meat products. Dietary manipulation of the fatty acid profile of pigs is an effective means of altering the fat composition of pork in order to provide human consumers with a healthy product. Vitamin E is effective as an antioxidant agent, particularly where processed products are concerned.
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Key Words : Pork, Fatty Acid Profile, Linseed Oil, Soybean Oil, Vitamin E, Lipid Oxidation

INTRODUCTION

The benefits of polyunsaturated fat acids (PUFAs) for human health, particularly for protection against cardiovascular and related diseases, have been reviewed in numerous reports (Hoz et al., 2003; Nguyen et al., 2003; Wood et al., 2003), and increased intake of long-chain n-3 and n-6 PUFAs is now commonly recommended (Kouba et al., 2003). Because meat is seen as a primary source of dietary fat, especially saturated fat, there is much interest in manipulating its fatty acid composition (Wood et al., 2003). The fatty acid profile of monogastric meat animal species is relatively easy to alter. Dietary fatty acids are absorbed directly and unchanged from the intestine of non-ruminant species (Ellis et al., 1999; Enser et al., 2000), and deposited in both muscle and fatty tissues, making pork an excellent delivery system for fat of a healthy composition for human consumption.

In New Zealand, pigs have traditionally been fed cereal-based diets supplemented with protein and fat from animal sources. In pigs, there is a strong correlation between the fat profiles of the dietary fat source and adipose tissue in the carcass (Nguyen et al., 2003); hence pork from New Zealand production systems tends to be high in saturated fatty acids. Alternative fat sources are available, however, and can be included in pig diets in order to alter the fatty acid profile. Fish oils are rich in the healthy, long-chain eicosapentaenoic (C20:5n-3) and docosahexaenoic (C22:6n-3) acids, although their addition with the use of fish byproducts and oils can have adverse effects on flavour and acceptability of pork (Jaturasitha et al., 2002; Sheard et al., 2000) and can result in soft fat (Irie and Sakimoto, 1992; Leskanich et al., 1997). Similar healthy fat profiles can be obtained with the use of oilseed products, with a decreased risk of adverse flavour effects. Soybean oil is a source of linoleic acid (C18:2n-6; Wood et al., 2003) and linseed oil provides linolenic acid (C18:3n-3; Specht-Overholt et al., 1997). These oils are essential in the diet as they cannot be synthesized by mammalian tissues. Furthermore, these compounds are the "parent fatty acids" of the n-6 and n-3 families (Nguyen et al., 2003) and are the precursors to longer chain fatty acids found in fish oils.

While increasing PUFAs in pig diets can direct the fat profile towards a more favourable composition, the increased level of unsaturation, regardless of the dietary source, causes a decreased oxidative stability in the resultant pork products (Sheard et al., 2000; Kouba et al., 2003). As a result, rancidity-related off odours and flavours may occur (Rhee et al., 1988; Jensen et al., 1998) and shelf life may be compromised (Sandström et al., 2000). Protection against lipid oxidation, however, can be provided by the supra-nutritional supplementation of pig diets with vitamin E (α-tocopherol; Jensen et al., 1997; Hoz et al., 2003). Supplementation increases muscle concentration of this powerful antioxidant that disrupts the oxidation chain reaction extremely effectively since α-tocopherol reacts with damaging peroxyl radicals nearly 10^4 times faster than the rate at which the propagation reaction occurs (Morrissey et al., 1998).

The objectives of this study were: to study the effect of dietary fat source on the fatty acid profile of pork from pigs fed tallow or a combination of soybean and linseed oils, and

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Table 1. Diet composition (as-fed basis)[1]

Item	Diet			
	SFA[2]	SFA+ Vit E	PUFA[3]	PUFA+ Vit E
Ingredient (%)				
Barley	60.0	60.0	60.0	60.0
Soybean meal	12.0	12.0	12.0	12.0
Broll[4]	10.0	10.0	10.0	10.0
Blood meal	5.0	5.0	5.0	5.0
Meat and bone meal	5.0	5.0	5.0	5.0
Tallow	6.0	6.0	-	-
Soybean oil	-	-	4.0	4.0
Linseed oil	-	-	2.0	2.0
Vitamin E	-	0.011	-	0.011
Lysine	0.05	0.05	0.05	0.05
Methionine	0.03	0.03	0.03	0.03
Salt	0.15	0.15	0.15	0.15
Dicalcium phosphate	1.5	1.5	1.5	1.5
Premix[5]	0.25	0.25	0.25	0.25
Calculated composition[6]				
DE (MJ/kg)	14.55	14.55	14.55	14.55
Lysine (g/kg)	10.72	10.72	10.72	10.72
Analysed composition fatty acid composition (mg/g)				
C12:0, lauric	1.70	1.54	1.87	1.71
C14:0, myristic	1.93	2.07	-	-
C16:0, palmitic	22.76	19.67	12.31	12.81
C16:1, palmitoleic	2.95	3.23	-	-
C18:0, stearic	13.62	13.06	3.96	3.61
C18:1, oleic	30.63	28.43	19.09	18.96
C18:2, linoleic	15.39	14.93	37.04	39.30
C18:3, linolenic	1.91	2.20	15.96	14.10

[1] Diets fed for 30 days starting at BW 57.0±2.5 kg and finishing at an average slaughter weight 88.1±5.9 kg.
[2] Saturated fatty acid.
[3] Polyunsaturated fatty acid.
[4] A mixture of wheat milling by-products including wheat bran, husk, and flour.
[5] Provided the following per kg diet: 10,000 IU Vitamin A, 2,000 IU Vitamin D3, 50 mg Vitamin E, 2 mg Vitamin K, 1 mg Vitamin B1, 2.5 mg Vitamin B2, 2 mg Vitamin B6, 10 μg Vitamin B12, 10 mg calcium pantothenate, 15 mg niacin, 10 μg biotin, 0.5 mg folic acid, 100 mg choline, 100 mg iron, 45 mg manganese, 0.5 mg cobalt, 0.3 mg selenium, 120 mg zinc, 25 mg copper, 1 mg iodine.
[6] Based on: P. C. H. Morel, J. Pluske, G. Pearson and P. J. Moughan. 1999. A Standard Nutrient Matrix for New Zealand Feedstuffs. Massey University, Palmerston North, New Zealand.

to evaluate the effect of the inclusion of vitamin E in pig diets on lipid oxidation of pork tissue and pork products.

MATERIALS AND METHODS

Animal management

A total of 56 pigs were included in this experiment conducted over two consecutive runs, each of 28 pigs. Each run of 28 pigs consisted of 14 intact males and 14 females. The pigs were housed in individual pens at the Massey University Pig Biology Unit and fed twice daily, with water available at all times. Feed refusals were measured daily, and all animals were weighed weekly. Feed allowances were adjusted weekly to maintain provision at 0.11-0.115×$BW^{0.75}$.

Table 2. Ingredient composition of American-style sausages

Ingredient	%
Lean	84.57
Fat	13.00
Salt	1.625
Sodium tripolyphosphate	0.25
White pepper	0.097
Nutmeg	0.094
Sage	0.035
Coriander	0.074
Monosodium glutamate	0.06
Water	0.195

Dietary treatment

The pigs were randomly allocated across four dietary treatments (Table 1) consisting of a factorial arrangement with two types of dietary fat (saturated (SFA) or polyunsaturated (PUFA)), and two levels of vitamin E supplementation (0% or 0.011% of diet; Lutavit E50; BASF, Auckland, New Zealand). Tallow, a source of saturated fatty acids, is typically included in New Zealand pig diets and was the primary fat source in the SFA diets. A mixture of soybean and linseed oils were the main lipid contributors to the polyunsaturated profile of the PUFA diets. The diets were formulated to meet or exceed the National Research Council (1998) nutrient recommendations. Dietary treatment began at an average liveweight of 57.0 kg±2.5 (SD) kg and was continued for 30±2.8 days to an average slaughter weight of 88.1±5.9 kg.

Carcass and meat processing

Slaughter and carcass dressing were conducted at a commercial abattoir. Following overnight chilling, each carcass was weighed with the back bone, head, feet, kidneys, and kidney fat removed. The left side of each carcass was then transported to Massey University for further dissection and analysis. The forelimb, shoulder, rib back (longissimus muscle between the third and tenth ribs), and loin back (longissimus muscle from the tenth rib to the pelvic bone) were then removed from each side. Fat thickness over the longissimus muscle was measured with a ruler at the 10th rib. Fat was then dissected from all cuts except the rib back. Samples of longissimus muscle and subcutaneous fat (both layers) for chemical analyses were removed with a knife from the P2 location (65 mm lateral to the midline of the spine at the last rib), placed in individual bags, and frozen (-30°C) prior to further analysis.

At two days post-slaughter, the dissected fat from the loin back and the lean from the forelimb and shoulder were minced and mixed with spices to make American-style sausages according to the proportions presented in Table 2.

Table 3. Effect of dietary lipid type and vitamin E supplementation on animal growth performance and lipid content of tissues and processed products

	Dietary lipid			Vitamin E			SEM
	SFA[1]	PUFA[2]	p	0%	0.011%	p	
N	25	26		24	27		
ADG (kg/d)	1.09	1.05	0.43	1.09	1.05	0.36	0.030
ADFI (kg/day)	2.61	2.58	0.34	2.60	2.60	0.85	0.02
Feed:gain	2.44	2.51	0.49	2.45	2.51	0.49	0.06
Carcass weight (kg)	68.8	67.8	0.39	68.5	68.2	0.77	0.79
Backfat thickness (mm)	11.8	11.8	0.96	11.6	12.0	0.51	0.36
Intramuscular lipid (%)	0.97	0.99	0.81	0.94	1.01	0.38	0.40
Lipid in backfat (%)	78.6	78.7	0.81	78.5	78.8	0.77	0.32
Lipid in bacon (%)	23.4	23.6	0.52	23.9	23.0	0.51	0.05
Lipid in sausage (%)	15.1	14.7	0.86	14.7	15.1	0.58	0.75

[1] Saturated fatty acid. [2] Polyunsaturated fatty acid.

A bacon product was prepared from the rib-backs, and injected (Fomaco Ross, Read Food Equipment Ltd., Christchurch, NZ) to contain 1.8% salt and 0.18% commercial brine mix.

Chemical analyses

Prior to analysis, samples of longissimus muscle, subcutaneous fat, and one sausage and one bacon slice from each carcass were lyophilized. Fat content of the freeze dried tissues was determined by extraction with petroleum ether (60-80°C).

To characterize the fatty acid profile of the pig diets and the carcass tissues, freeze dried samples of each were ground in a coffee grinder to a particle size of approximately 1 mm^3. Fat was extracted from the feed, subcutaneous fat, sausage, and bacon samples with petroleum ether (60-80°C boiling fraction) in a Soxtec apparatus (FOSS Tecator, Auckland, NZ). Fatty acids in the freeze dried longissimus muscle tissue and in the fat extracted from the other samples were converted to fatty acid methyl esters (FAMES) by heating the samples to 70°C with a 2 ml toluene and 3 ml methanolic-HCL mixture for two hours according to the method of Sukhija and Palmquist (1988). The fatty acid methyl esters were analysed by gas liquid chromatography (Shimidazu GCA8,) using a 3.5 m packed column containing 15% EGGS-X on chromosorb W. The carrier gas was N_2 with a flame ionization detector. The fatty acids were quantified using pentadecanoic acid as an internal standard.

Prior to analysis of thiobarbituric acid reactive substances (TBARS), fat was extracted from freeze dried samples of subcutaneous fat, sausage, and bacon using petroleum ether (40-60°C boiling fraction), with the addition of 24 mg butyl hydroxytoluene as an antioxidant. TBARS were measured directly from the longissimus muscle samples without first extracting the fat. The oxidized lipids were estimated by the method of Inoue et al. (1998) using acid conditions, and the colour was extracted with a butanol-pyridine mixture. An Allen correction was used to compensate for any non-specific colour formation.

Statistical analysis

Due to poor growth performance, one animal was removed from the study during feeding. Four animals were excluded from growth performance analyses due to the condemnation of portions of their carcass, but were included in the fatty acid and TBARS analyses. Growth performance, carcass characteristic and fatty acid data were analysed with SAS (SAS Institute Inc., 1990) using a general linear model that included the fixed effects: run, sex, dietary fat type, and vitamin supplementation, and the fat type×vitamin interaction. In all cases, the interaction between fat type and vitamin content was non-significant. The TBARS data were log transformed and analysed with a general linear model that include the fixed effects: dietary fat type, vitamin supplementation, and product, and their interactions. Animal within dietary fat type and vitamin supplementation was fitted as random effect in the TBARS model.

RESULTS AND DISCUSSION

Neither dietary fat nor the vitamin E level had a statistically significant effect on growth performance, carcass characteristics, or fat content of the various tissues and pork products (Table 3). Bee et al. (2002) compared soy oil and tallow, and Kouba et al. (2003) used fat blends of tallow and soybean compared to a diet that also included crushed linseed, and both groups reported no effect of dietary fat source on growth performance and carcass characteristics. Waylan et al. (2002) reported a lack of effect of vitamin E supplementation on pig growth performance and concluded the vitamin E status of the pigs prior to commencement of the experimental treatments was sufficient to meet normal growth requirements, hence no additional effect of supplementation was observed.

While the inclusion of vitamin E in the diets had no effect on the fatty acid profile of the longissimus muscle

Table 4. Effect of dietary lipid type and vitamin E supplementation on fatty acid composition of the longissimus muscle

	Dietary lipid			Vitamin E			SEM
	SFA[1]	PUFA[2]	p	0%	0.011%	p	
N	27	28		27	28		
Fatty acid, mg/g fresh sample							
C14:0, myristic	0.19	0.23	<0.01	0.20	0.22	0.10	0.010
C16:0, palmitic	2.41	2.56	0.39	2.44	2.53	0.55	0.122
C16:1, palmitoleic	0.55	0.48	0.16	0.52	0.51	0.87	0.036
C18:0, stearic	1.32	1.43	0.24	1.34	1.41	0.41	0.063
C18:1, oleic	4.60	4.30	0.43	4.34	4.55	0.37	0.210
C18:2, linoleic	1.24	2.02	<0.01	1.62	1.64	0.66	0.044
C18:3, linolenic	0.09	0.32	<0.01	0.20	0.22	0.42	0.013
Total SFA	3.93	4.22	0.27	3.97	4.17	0.45	0.187
Total MUFA[3]	5.15	4.77	0.36	4.86	5.06	0.60	0.280
Total PUFA	1.67	2.70	<0.01	2.18	2.19	0.94	0.059
PUFA:SFA	0.44	0.66	<0.01	0.57	0.54	0.25	0.019
C18:2:C18:3	18.2	6.5	<0.01	14.1	10.6	0.19	1.830

[1] Saturated fatty acid. [2] Polyunsaturated fatty acid. [3] Monounsaturated fatty acid.

Table 5. Effect of dietary lipid type and vitamin E supplementation on fatty acid composition of subcutaneous fat tissue

	Dietary lipid			Vitamin E			SEM
	SFA[1]	PUFA[2]	p	0%	0.011%	p	
N	27	28		27	28		
Fatty acid (mg/g fresh sample)							
C14:0, myristic	13.68	12.59	<0.01	13.07	13.20	0.72	0.277
C16:0, palmitic	213.08	206.63	0.29	207.10	212.61	0.38	4.362
C16:1, palmitoleic	38.97	31.13	<0.01	33.53	36.57	0.18	1.550
C18:0, stearic	106.86	102.92	0.42	105.29	104.49	0.89	3.326
C18:1, oleic	415.31	354.88	<0.01	381.84	388.35	0.47	6.204
C18:2, linoleic	69.57	145.42	<0.01	108.64	106.35	0.60	3.259
C18:3, linolenic	13.12	51.46	<0.01	32.38	32.19	0.91	1.537
Total SFA	333.63	322.14	0.25	325.47	330.31	0.62	6.964
Total MUFA[3]	454.28	386.01	<0.01	415.37	424.92	0.35	7.038
Total PUFA	82.68	196.88	<0.01	141.02	138.54	0.69	4.673
PUFA:SFA	0.229	0.613	<0.01	0.441	0.422	0.26	0.004
C18:2:C18:3	5.592	2.880	<0.01	4.33	4.14	0.45	0.167

[1] Saturated fatty acid. [2] Polyunsaturated fatty acid. [3] Monounsaturated fatty acid.

(Table 4), the effect of dietary fat source was significant. Longissimus muscle of pigs fed the PUFA diet contained significantly more linoleic (C18:2) and linolenic (C18:3) acids, and had a greater total PUFA content than meat from pigs fed the SFA diet (Table 4). According to Wood et al. (2003), the risk of cancer and coronary heart disease is reduced where PUFA:SFA in the diet is greater than 0.4, and the C18:2 to C18:3 ratio is less than 4.0. While the SFA diet was near the desired PUFA to SFA ratio minimum, the PUFA diet resulted in pork that was well above the minimum 0.4 level (SFA diet 0.44, PUFA diet 0.66, $p<0.01$). Concomitantly, the ratio of C18:2 to C18:3 achieved with the PUFA diet in the longissimus muscle tissue was slightly above the upper limit of 4.0; however, the SFA treatment resulted in a ratio that exceeded the desired maximum by more than 4.5 times (SFA diet 18.2, PUFA diet 6.5, $p<0.01$). As such, it can be concluded that inclusion of the linseed/soy oil mix can be relied upon to effectively achieve a "healthy" level of fat saturation, although some refinement of the combination is required to reach the desired balance of linoleic and linolenic acids in the longissimus muscle.

Vitamin E supplementation had no effect on fatty acid composition of the subcutaneous fat, a finding also reported by Bosi et al. (2000) who examined the effect of sunflower oil and vitamin E on the quality and fatty acid profile of Parma ham. As expected, based on the fatty acid profile of the SFA and PUFA feeds, pigs fed the SFA diet had significantly greater amounts of myristic (C14:0), palmitoleic (C16:1), and oleic (C18:1) acids in the subcutaneous fat tissue. Conversely, the PUFA diet resulted in significantly more of the polyunsaturated linoleic (C18:2) and linolenic (C18:3) acids. These changes represent a greater effect of dietary manipulation on subcutaneous fat tissue than on the longissimus muscle. This can be explained by the fact that the percentage of intramuscular fat in the longissimus muscle is constant in the finisher phase whereas the percentage of back fat is increasing

Table 6. Effect of dietary lipid type and vitamin E supplementation on lipid oxidation (mg MDA[1]/kg fat) in longissimus muscle, subcutaneous fat, bacon, and sausage

	Dietary lipid				Vitamin E			Product
	SFA	PUFA	SEM (log10)	p	0%	0.011%	SEM (log10)	
N	27	28			27	28		56
Main effect mean	2.45 (0.39)[4]	4.68 (0.67)	0.046	-	3.63 (0.56)	3.16 (0.50)	0.046	-
Product								
Longissimus muscle	2.04 (0.31)	1.95 (0.29)	0.065	0.90	2.00 (0.30)	1.95 (0.29)	0.065	2.00 (0.24)[c]
Subcutaneous fat	1.17 (0.07)	2.51 (0.40)	0.065	<0.01	1.66 (0.22)	1.78 (0.25)	0.065	1.74 (0.30)[c]
Bacon	6.31 (0.80)	15.85 (1.20)	0.065	<0.01	12.30 (1.09)	8.13 (0.91)	0.065	10.00 (1.00)[a]
Sausage	2.40 (0.38)	6.31 (0.80)	0.065	<0.01	4.37 (0.64)	3.55 (0.55)	0.065	3.89 (0.59)[b]
P main effect	<0.01				0.05			<0.01
p interaction with product	<0.01				0.37			-

[1] Malondialdehyde.
[2] Saturated fatty acid.
[3] Polyunsaturated fatty acid.
[4] Numbers in parenthesis are log transformed means.
[a, b, c] Product means followed by different letters are significantly different (p<.05); SEM (log10) = 0.045.

(D'Souza et al., 2000). Thus allowing for a greater effect of the dietary manipulation in the subcutaneous back fat tissue. Five of seven fatty acids in the subcutaneous fat showed a significant effect of the dietary treatment (Table 5), while only three were significantly affected in the longissimus muscle. Enser et al. (2000) reported similar findings with 15 significant changes across 17 fatty acids in fat, versus 9 differences in the longissimus muscle. Furthermore, as compared to the longissimus muscle, larger treatment differences for individual fatty acid were also recorded in the subcutaneous fat, likely due to differences in the pattern of their deposition of particular fatty acids between tissues (Enser et al., 2000; He et al., 2005) and/or the varying rate of maturation of the fat depots, the subcutaneous depot maturing earlier than the intramuscular.

Only the PUFA diet resulted in a favourable ratio of polyunsaturated to saturated fatty acid (0.61 with target >0.4) in the subcutaneous fat tissue. Likewise for the ratio of linoleic to linolenic acids, the PUFA treatment resulted in subcutaneous fat that fell well below the desired maximum (2.8 with target <4.0). These favourable ratios (Table 5) are of particular importance where fat is consumed as part of a processed product such as sausage, or is included in skin-on cuts or those with minimal fat trimming prior to preparation and consumption. While consumers are demanding lean cuts of whole muscle pork products, processed products routinely contain much higher levels of fat. To that end, Romans et al. (1995) discussed that by enriching the fat that remains in pork, an already nutritious product will provide even further benefit to consumers.

A significant interaction was observed between dietary lipid source and the various pork products evaluated for lipid oxidation (Table 6). While the PUFA diet resulted in increased lipid oxidation compared to the SFA treatment in the subcutaneous fat tissue and the processed bacon and sausage products, there was no significant change in the longissimus muscle, a tissue with a relatively low fat content (~1%). Overall, lipid oxidation was significantly increased with use of the PUFA diet, a result also reported by Kouba et al. (2003) who assessed lipid oxidation in pork muscle after feeding a diet high in linolenic acid. As expected, due to its powerful antioxidant capacity (Morrissey et al., 1998), the overall effect of vitamin E supplementation was a significant reduction in the extent of lipid oxidation (Table 6), a result also reported by Jensen et al. (1997) and Hoz et al. (2003).

Comparing the degree of oxidation across the pork products, there was no significant difference between the longissimus muscle and subcutaneous fat tissues. The processed products, however, showed a significant increase in oxidation (Table 6), with the greatest effect observed in the bacon product which contained the highest level of added salt, a pro-oxidant compound (Lee et al., 1997). Comparing pork chops, liver, bacon, and sausage, Sheard et al. (2000) also reported the greatest lipid oxidation in bacon. In the current work, however, the degree to which lipid oxidation occurred would not have limited acceptability of the longissimus muscle, the subcutaneous fat, or the sausage. Gray and Pearson (1987) reviewed the relationship between TBARS values and sensory scores associated with rancidity summarizing thresholds, below which off-odours and flavours were not detected, at 0.5-1.0 and 0.6-2.0 mg malondialdehyde (MDA)/kg product where evaluation was conducted with trained and inexperienced taste panels, respectively. Longissimus samples, with their low fat content were, at 0.02 mg MDA/kg product, well below the thresholds. The PUFA treatment resulted in the greatest increase in oxidation in the fat and sausage samples and brought the TBARS values near, but still under, the cut-off point (1.98 and 0.93 mg MDA/kg product, respectively). The bacon samples were in excess of the threshold, as was also observed by Sheard et al. (2000), with TBARS values ranging from 1.48 to 3.74 mg MDA/kg product.

IMPLICATIONS

The fatty acid profile of pork tissue and pork products can be altered by manipulation of the dietary treatment of pigs without risk of detrimental effects on growth performance or carcass characteristics. A diet rich in polyunsaturated fatty acids significantly increases linoleic and linolenic acid content in both the longissimus muscle and subcutaneous fat, and concomitantly, increases polyunsaturated to saturated fatty acid ratio and decreases linoleic to linolenic ratio to near or within target ranges for the reduction of risk associated with human disease. The polyunsaturated fatty acid dietary treatment, however, results in significantly greater degree of lipid oxidation in fat tissue, bacon, and sausage, although lipid oxidation in longissimus muscle tissue is not affected by dietary fat source. To further protect against lipid oxidation, addition of vitamin E is recommended where processed products are to be manufactured.

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