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Chia (Salvia hispanica L.) seed as an n-3 fatty acid source for finishing pigs: Effects on fatty acid composition and fat stability of the meat and internal fat, growth performance, and meat sensory characteristics

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Chia (*Salvia hispanica* L.) seed as an n-3 fatty acid source for finishing pigs: Effects on fatty acid composition and fat stability of the meat and internal fat, growth performance, and meat sensory characteristics[1]

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ABSTRACT: Coronary heart disease is caused by arteriosclerosis, which is triggered by an unbalanced fatty acid profile in the body. Today, Western diets are typically low in n-3 fatty acids and high in SFA and n-6 fatty acids; consequently, healthier foods are needed. Chia seed (*Salvia hispanica* L.), which contains the greatest known plant source of n-3 α-linolenic acid, was fed at the rate of 10 and 20% to finishing pigs, with the goal to determine if this new crop would increase the n-3 content of the meat as has been reported for other n-3 fatty acid-rich crops. The effects of chia on fatty acid composition of the meat, internal fats, growth performance, and meat sensory characteristics were determined. Productive performance was unaffected by dietary treatment. Chia seed modified the fatty acid composition of the meat fat, but not of the internal fat. Significantly ($P < 0.05$) less palmitic, stearic, and arachidic acids were found with both chia treatments. This is different than trials in which flaxseed, another plant based source of ω-3 fatty acid, has been fed. Alpha-linolenic acid content increased with increasing chia content of the diet; however, only the effect of the 20% ration was significantly ($P < 0.05$) different from that of the control. Chia seed increased panel member preferences for aroma and flavor of the meat. This study tends to show that chia seems to be a viable feed that can produce healthier pork for human consumption.

Key words: α-linolenic, chia, n-3, pork, *Salvia hispanica*

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INTRODUCTION

Cardiovascular disease (**CVD**) is the main cause of death worldwide, accounting for 10 to 30% of all deaths. Although CVD has been primarily a problem in developed countries, it is becoming a growing concern in developing countries and has become the main cause of death in many of them. The main form of CVD is coronary heart disease (**CHD**), which makes up more than one-half of all CVD events (World Health Organization, 2005).

Coronary heart disease is caused by arteriosclerosis, which is triggered by an unbalanced fatty acid profile in the body (World Health Organization, 2005). In particular, SFA and polyunsaturated n-6 fatty acids have a close relationship with CHD (Simopoulos, 2004). Clinical and epidemiological studies have indicated that dietary n-3 fatty acids, including α-linolenic (an essential fatty acid) and its metabolites eicosapentaenoic and docosahexaenoic acid, reduce the risk of suffering CHD (de Lorgeril et al., 1994, 1996). The problem is that Western diets are typically low in n-3 fatty acids and high in SFA and n-6 fatty acids (Simopoulos, 2004).

Agricultural changes that took place over the last 100 yr have dramatically diminished the number of species cultivated that are rich in n-3 fatty acids and low in n-6 fatty acids. Because these crops are typically used for feeding domestic animals, they produce animal products having the same lipidic characteristics as the food consumed (Simopoulos, 1998; Chilliard et al., 2001). One caveat to this statement is that diet influences products from nonruminant food-producing animals much more readily than from ruminant animals. The shortage of n-3 fatty acids in the diet points

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to the need to produce foods for humans and feed for domestic animals that will provide consumers with food lipidic profiles similar to those under which the human genome evolved (O'Keefe and Cordain, 2004).

The purpose of the present study was to feed chia seed (*Salvia hispanica* L.), a relatively new crop that is gaining increased recognition as a good source of n-3 α-linolenic acid, to finishing pigs and determine if the fatty acid composition of the meat and internal fat can be improved as has been found with other n-3 sources, without negatively affecting meat sensory characteristics or growth performance.

MATERIALS AND METHODS

The trial was conducted at a commercial facility that follows generally accepted procedures for the raising of pigs in Argentina as set forth by the Argentine Government office of SENASA, Servicio Nacional de Sanidad Animal, Secretaria de Agricultura y Ganaderia.

Animals and Diets

The feeding trial was conducted at a private pork rearing facility located in Ranchos, province of Buenos Aires, Argentina. Eighteen hybrid (Degesa Jsr., Burgos, Spain) pigs were selected from a commercial herd made up of 1 breed, then randomly distributed into 3 groups of 6 and housed in typical confinement pens. The selection process included categorizing the animals equally by sex, age, and BW to ensure that the test animals were as uniform as possible at the beginning of the trial.

Three diets ($\mathbf{T_1}$, $\mathbf{T_2}$, and $\mathbf{T_3}$) containing 0, 10, and 20% whole chia seed, respectively, were fed. Nutrient composition of the diets is shown in Table 1. Water and food were provided ad libitum. Each ration was weighed at the start of the trial and at the end, with average consumption calculated by dividing the difference in BW by the number of animals in each pen. Body weights were recorded initially, at d 32, and at d 63, just before the animals were sent to a commercial slaughter house located in General Belgrano, province of Buenos Aires, Argentina.

The animals were processed following commercial slaughterhouse practices established by the government of Argentina. Immediately after slaughter, internal and muscle adipose samples were obtained from each of the 18 animals for laboratory analysis. Perirenal adipose tissue was chosen to provide internal adipose samples, whereas a slice taken across the width of the LM at the 10th rib provided the subcutaneous adipose samples. Selection of adipose sampling locations followed procedures used in other trials designed to examine fatty acid composition as affected by diet (Enser et al., 1998; Coates and Ayerza, 2004). All samples were individually packed in plastic bags, transferred to a freezer maintained at −22°C, and frozen. Two days after sampling the samples were transferred to a cooler containing artificial ice, then transported by vehicle (1 h travel time) to the laboratory where they were analyzed.

Table 1. Nutrient composition of the pig diets

Item	Control	10% chia	20% chia
Ingredient			
Corn, %	69.93	68.54	62.36
Soybean pellets (42% CP), %	27.07	18.37	14.54
Chia seed,[1] %	—	10	20
Vitamin/mineral mix,[2] %	3.1	3.1	3.1
Calculated nutrient value			
ME, kcal/kg	3,202	3,230	3,200
NE, kcal/kg	2,363	2,446	2,466
CP, %	16.5	15	15
Lipids, %	3.14	6.19	9.16
Linoleic acid, %	1.49	2.02	2.49
α-Linolenic acid, %	0.07	2.0	4.04
Linoleic:α-linolenic ratio	21.29	1.01	0.62
Starch, %	44.38	47.47	47.7
Total sugar, %	3.56	2.84	2.41
Cellulose, %	3.54	5.05	6.84
Ash, %	5.05	5.18	5.39
Total P, %	0.59	0.64	0.7
Available P, %	0.33	0.32	0.32
Calcium, %	0.86	0.92	0.97
Sodium, %	0.12	0.14	0.15
Lysine, %	0.98	1.17	1.5
Methionine, %	0.3	0.26	0.26
Methionine + cystine, %	0.65	0.69	0.79
Arginine, %	1.21	1.8	2.53
Threonine, %	0.68	0.87	1.13
Tryptophan, %	0.19	0.27	0.38
Xanthophyll, mg/kg	15.38	15.08	13.72
Water, %	12.32	11.41	10.54

[1]Chia Farms Inc., Sonoita, AZ.

[2]Vetifarma S.A., La Plata, Argentina: calcium, 13 g/kg; phosphorous, 10 g/kg; sodium chloride, 3 g/kg; lysine, 1,020 g/kg; vitamin A, 9,000,000 IU; vitamin D_3, 1,800,000 IU; vitamin E, 15 g/kg; vitamin K_3, 0.48 g/kg; vitamin B_1, 0.942 g/kg; vitamin B_2, 3.12 g/kg; vitamin B_6, 1.83 g/kg; vitamin B_{12}, 20 g/kg; nicotinic acid, 19.41 g/kg; pantothenic acid, 9.45 g/kg; biotin, 49.8 g/kg; folic acid, 0.3 g/kg; selenium, 0.228 g/kg; choline, 162 g/kg; iodine, 0.39 g/kg; cobalt, 0.50 g/kg; copper, 165 g/kg; zinc, 117 g/kg; iron, 100 g/kg; magnesium, 48.24 g/kg; and organic chromium, 0.2 g/kg.

Laboratory Analysis

Lipids were extracted from the samples according to the method described by Folch et al. (1957). Total lipids were then converted to fatty acid methyl esters using the ISO 5509 method (ISO 5509, 2000). Fatty acid methyl esters were separated and quantified by an automated gas chromatograph (model Agilent 6890, GC, Agilent Technologies Inc., Santa Clara, CA), equipped with a flame ionization detector and a 30 m × 0.53 mm capillary column (model HP-FFAP, Hewlett Packard Co., Wilmington, DE).

Sensory Evaluation

A limited sensory evaluation was conducted to determine whether or not the chia negatively affected the meat. Three animals, 1 from each treatment, were

Table 2. Body weight, BW gain, and feed conversion among treatments

	Day							
	1	32		63		1 to 63		
Item	BW, kg	BW, kg	ADG, kg	BW, kg	ADG, kg	BW gain, kg	ADG, kg	Feed conversion ratio[1]
Diet, % chia								
0	75.3[a]	93.5[a]	0.586[a]	114.3[a]	0.672[a]	39[a]	0.629[a]	4.64
10	76[a]	94.8[a]	0.608[a]	115[a]	0.651[a]	39[a]	0.629[a]	4.57
20	75.2[a]	92.3[a]	0.554[a]	118.7[a]	0.849[a]	43.5[a]	0.702[a]	4.15
LSD[2]	6.846	6.901	0.146	6.893	0.211	8.147	0.131	n/a

[a]In a column, means with the same letter are not statistically different ($P > 0.05$) according to Duncan's multiple range test.
[1]kg of feed/kg of BW gain over the test period.
[2]LSD for $P < 0.05$.

randomly selected when hanging in the slaughterhouse. These animals were apportioned by hand into commercial cuts, and the right loin (LM) was removed for sensory analyses. The samples were refrigerated for 2 d at 4°C, then roasted in a commercial oven at 175°C without the addition of any spices or salt.

Thirty-four untrained adult panelists (16 females and 18 males and 29 to 67 yr of age, from the cities of General Belgrano and Buenos Aires, Argentina) were chosen for the sensory test. These people regularly consumed pork as part of their diet. The panelists received 3 plates, 1 at a time, with each plate containing a rectangular piece of meat cut from 1 of the treatments. The plates were marked with a code corresponding to one diet. Panelists sat 1 m apart at a table and received plates in random order. Each panelist had a sheet of paper containing 3 labeled squares (1 for each sample) to fill in using category scales for aroma and flavor. For scoring and analyses, aroma and flavor were assigned a number from 1 to 9 (9 = like very much, 1 = dislike very much). Cold tap water was provided for the panelists to rinse their mouths between samples.

Statistical Analysis

The experimental design for the feeding trial was completely randomized and consisted of 3 treatments and 6 replications. Each variable was compared by ANOVA. When the F-value was significant ($P < 0.05$), means were separated using Duncan's new multiple range test (Cohort Stat, 2006).

RESULTS

Productive Performance

Productive performance was unaffected by dietary treatment. Body weight and BW gain were not significantly ($P < 0.05$) different among treatments throughout the trial (Table 2). Feed conversion, calculated on a per pen basis, was similar among treatments, but decreased with increasing chia content of the diet.

Fatty Acid Composition

Results Within Adipose Types—Meat. Fatty acid composition of the subcutaneous adipose tissue is shown in Table 3. The SFA (sum of myristic, palmitic, stearic, and arachidic) content was less in the subcutaneous adipose tissue of both chia diets than the control diet. The difference was significant ($P < 0.05$) for each fatty acid individually except in the case of arachidic acid for T_3. No significant ($P < 0.05$) difference was detected between chia diets.

Monounsaturated oleic acid composed the greatest percentage of fatty acid in all treatments. The order was $T_2 > T_3 > T_1$, with significant ($P < 0.05$) differences between each treatment found. Gadoleic acid, a minor component of the MUFA detected, was significantly ($P < 0.05$) less in the T_1 subcutaneous adipose tissue than in that of the chia treatments, which showed no significant ($P < 0.05$) difference between them.

Linoleic acid, an n-6 PUFA, was significantly ($P < 0.05$) greater in the subcutaneous adipose tissue of the animals fed either chia diet than in the animals fed the control diet. No significant ($P < 0.05$) difference was detected between chia diets.

Alpha-linolenic acid, an n-3 PUFA, showed a relationship among treatments of $T_3 > T_2 > T_1$. However, only T_3 was significantly ($P < 0.05$) greater compared with the control diet.

Results Within Adipose Types—Perirenal. Fatty acid composition of the perirenal adipose tissue is shown in Table 3. None of the fatty acids showed significant ($P < 0.05$) differences among treatments.

Results Between Adipose Types. A comparison between the fatty acid contents of the 2 adipose tissues within diets is presented in Table 3. Adding chia seed to the pig diets modified the fatty acid relationship between the adipose types for the 4 SFA measured. Significantly ($P < 0.05$) less palmitic, stearic (the 2 major saturated components), and arachidic acids were found in the subcutaneous adipose tissue with both chia treatments. There was more ($P < 0.05$) myristic acid in the subcutaneous adipose tissue, vs. the perire-

Table 3. Fatty acid composition of subcutaneous and perirenal pork adipose tissues among treatments and between adipose tissue types

		Fatty acid							
Diet, % chia	Fat type	14:0	16:0	18:0	18:1	18:2	18:3	20:0	20:1
		% of total fatty acids							
0	Meat	1.91[a]	32.22[a]	15.22[a]	41.4[c]	1.19[b]	0.09[b]	0.23[a]	0.58[b]
10	Meat	1.52[b]	24.82[b]	11.35[b]	50.12[a]	5.17[a]	0.21[ab]	0.16[b]	0.69[a]
20	Meat	1.55[b]	25.63[b]	11.97[b]	47.27[b]	5.76[a]	0.39[a]	0.19[ab]	0.73[a]
	LSD[1]	0.146	1.438	1.219	2.006	1.472	0.235	0.038	0.089
0	Internal	1.48[a]	27.9[a]	17[a]	38.2[a]	10.18[a]	0.53[a]	0.22[a]	0.52[a]
10	Internal	1.49[a]	27.9[a]	16.73[a]	36.92[a]	11.37[a]	0.68[a]	0.25[a]	0.54[a]
20	Internal	1.51[a]	27.9[a]	17.45[a]	35.9[a]	10.18[a]	0.97[a]	0.26[a]	0.52[a]
	LSD	0.090	1.303	1.649	2.946	2.389	0.459	0.053	0.092
0	Meat	1.91[a]	32.21[a]	15.22[a]	41.4[a]	1.19[b]	0.09[b]	0.23[a]	0.58[a]
	Internal	1.48[b]	27.9[b]	17[a]	38.2[b]	10.18[a]	0.53[a]	0.22[a]	0.52[a]
	LSD	0.086	1.552	1.809	1.913	2.298	0.094	0.056	0.068
10	Meat	1.52[a]	24.82[b]	11.35[b]	50.12[a]	5.17[b]	0.21[b]	0.16[b]	0.69[a]
	Internal	1.49[a]	27.93[a]	16.73[a]	36.92[b]	11.37[a]	0.68[a]	0.25[a]	0.54[b]
	LSD	0.091	1.293	1.222	3.154	2.099	0.266	0.039	0.105
20	Meat	1.55[a]	25.63[b]	11.97[b]	47.27[a]	5.76[b]	0.39[a]	0.19[b]	0.73[a]
	Internal	1.51[a]	27.97[a]	17.45[a]	35.9[b]	11.5[a]	0.97[a]	0.26[a]	0.52[b]
	LSD	0.181	1.447	1.459	2.687	1.794	0.598	0.049	0.105

[a–c]Means within a column with different superscripts are significantly different ($P < 0.05$) according to Duncan's multiple range test.
[1]LSD for $P < 0.05$.

nal tissue, with the control diet. Adding chia to the diet produced no change in the oleic (the largest percentage of total fatty acid in both adipose types) relationship between adipose types. Compared with the control, individual fatty acid changes within adipose tissues had similar behavior for both chia diets and showed a similar change in magnitude and significance ($P < 0.05$). The exception was α-linolenic acid. No significant ($P > 0.05$) difference was found between adipose types for T_3, whereas T_1 and T_2 showed significantly ($P < 0.05$) greater content in the perirenal tissue.

Sensory Evaluation

Adding chia seed to the pig diet increased ($P < 0.05$) panel member preferences for aroma and flavor of the cooked meat. However, the aroma and flavor ratings were significantly ($P < 0.05$) different only for the T_2 meat compared with the control (Table 4).

DISCUSSION

Productive Performance

The absence of significant differences in BW and BW gain among treatments indicates that chia was not inappropriate for finishing pigs because it did not alter performance compared with the typical corn-soybean-based diet used by commercial pork rearing facilities in Argentina. These results agree with other studies that reported chia seed as being a useful dietary ingredient for nonruminants such as poultry (hens and broilers) and rats, as well as ruminants (dairy cows); (Ayerza and Coates, 1999, 2000, 2001, 2002a,b, 2005; Ayerza et al., 2002; Azcona et al., 2008).

The feed efficiency of the 3 treatments was less compared with those reported for other trials using animals of similar BW (Mason et al., 2005). The poorer feed conversion could be related to the protein content of the diet. A low growth rate and poor feed conversion for pigs fed relatively low protein diets, such as fed herein, have been reported (Kerr et al., 1995; Woods et al., 2004; Teye et al., 2006). The feed conversions, however, are normal for commercial farms in the region and arise because ration protein contents are being limited by increasing prices of source feeds (D. Sanchez Margariños, technical advisor at the farm, General Belgrano, Argentina, personal communication).

Fats and Fatty Acids

Diets play an important role in the fatty acid composition of pork. The level of energy, protein-lipid-carbohydrate ratios, and fatty acid composition of the

Table 4. Sensory results among treatments

% chia	Aroma	Flavor
0	6.48[b]	6.72[b]
10	7.12[a]	7.36[a]
20	6.55[ab]	6.97[ab]
LSD[1]	0.598	0.605

[a,b]Means in a column with different superscripts are different ($P < 0.05$) according to Duncan's multiple range test.
[1]LSD for $P < 0.05$.

feed (diet) all influence fatty acid composition of the animal tissues. Location of fat deposition also affects composition. Hence, location of fat depot interacts with diet, and this determines the fatty acid composition of tissues of pigs (Warnants, 1999) and other animals (Coates and Ayerza, 2004).

Addition of 10 and 20% chia seed to the diet of finishing pigs affected the fatty acid composition of the subcutaneous tissue, but not the perirenal tissue, indicating a resistance of this tissue to modification of its fatty acid composition. Tissue deposition differences among dietary fatty acids in pork have been reported (Howe, 1998; Øverland et al., 2005). In the case of α-linolenic acid-enriched diets, Cherian and Sim (1995) found that adding 0, 10, 17.5, and 25% ground flaxseed to pig diets brought about changes in the fatty acid composition of muscle, meat fat, heart, and liver tissues, but not brain tissue. Warnants et al. (1996), when feeding flax to pigs, found the rate of incorporation of linoleic and α-linolenic acids to be greater in the outer backfat layer than the inner layer, and the rate of incorporation of both fatty acids in meat fat to be much less than in backfat.

Increasing the amount of chia seed fed from 10 to 20% did not have any significant effect on the fatty acid composition of the subcutaneous adipose tissue. This indicates that the difference in chia amounts fed was less than that needed to produce a change in meat composition.

A significant finding in this study was the effect chia had in terms of reducing the palmitic and total SFA contents. Dietary SFA, especially palmitic acid, are independent risk factors associated with CHD. Their effects in terms of increasing blood low-density lipoprotein concentrations are more important than those of dietary cholesterol (American Heart Association, 1988). The reduction in SFA content found in the pork trial has also been reported for eggs, broiler dark and white meat, and rat blood when feeding chia (Ayerza and Coates, 1999, 2000, 2005; Neely, 1999; Ayerza et al., 2002; Azcona et al., 2008).

Other research, however, in which pigs were fed diets rich in α-linolenic acid obtained by adding flax seed/oil have found no change in palmitic acid, total SFA contents, or both (Rey et al., 2001; Hoz et al., 2003; Kouba et al., 2003; Nuerenberg et al., 2005). Studies in which different α-linolenic acid dietary sources were directly compared showed chia-enriched diets to reduce total saturated or palmitic acid contents, or both, unlike flaxseed-enriched diets (Ayerza and Coates, 2001; Azcona et al., 2008). Thus various trials suggest that a reduction in palmitic and SFA content is feed-dependent. The reduction in palmitic and total SFA content, up to 23% found herein, indicates an additional health advantage for this n-3-enriched pork compared with that produced when feeding flax seed.

The greater linoleic (an n-6 PUFA) content found with both chia diets is in agreement with studies of other nonruminants in which this fatty acid increased, when the level of chia seed fed increased (Ayerza and Coates, 2000; Ayerza et al., 2002). The linoleic acid increase has also been reported for meat and fat tissues when feeding different levels of flaxseed to growing-fattening pigs (Cherian and Sim, 1995; Nuerenberg et al., 2005).

The 20% chia diet dramatically increased (333%) the n-3 α-linolenic acid content of the subcutaneous adipose tissue. The lack of difference between T_2 and T_3 suggests that a 10% increase in dietary chia for pigs slaughtered after 63 d is not enough to produce significant changes in the α-linolenic acid content of subcutaneous adipose tissue. Variations in α-linolenic acid deposition brought about by increasing the amount of flaxseed in the diet, time on feed, and the n-6:n-3 ratio have been reported for muscle and plasma tissues of growing-finishing pigs (Kouba et al., 2003).

Sensory Evaluation

The greater scores for aroma and flavor for meat from the chia diets compared with that of pigs fed the control diet agrees with other sensory tests performed on animal products, such as eggs and dark and white poultry meat, when chia-enriched diets were fed (Ayerza and Coates, 1999, 2001, 2002a; Ayerza et al., 2002). One of the problems identified for commercialization of animal products enriched in n-3 fatty acids has been the fishy flavor they presented (Marshall et al., 1994; Scheideler et al., 1997). This flavor/taste problem has been attributed to low oxidative stability of PUFA (Bryhni et al., 2002). In several cases, adding increased amounts of antioxidants to pork diets has improved the flavor/taste and diminished the fishy taint (Howe, 1998; Hoz et al., 2007). Chia seed is different from other n-3 fatty acid sources because it contains several compounds having antioxidant capacity. The absence of fishy taints in animal products produced when diets containing up to 30% chia seeds were fed could be attributed to the quality and quantity of these antioxidant compounds as has been reported by Taga et al. (1984) and Castro-Martínez et al. (1986). As the addition of artificial substances to animal feeds has been a concern expressed by growing numbers of health-conscious consumers, the results found herein could represent a significant commercial advantage for this n-3 rich oilseed.

Conclusions

In summary, the most significant findings in this trial were the effects chia had in terms of reducing the palmitic acid and total SFA contents and increasing the n-3 α-linolenic acid contents of the meat without negatively affecting animal production or meat taste. Omega-3-enriched animal products could help consumers better meet health recommendations without having to change dietary habits. However, more research is needed to determine the optimal amount of chia that can be fed to improve the fatty acid profile of pork.

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