Chia Seed (*Salvia hispanica* L.) as an ω-3 Fatty Acid Source for Broilers: Influence on Fatty Acid Composition, Cholesterol and Fat Content of White and Dark Meats, Growth Performance, and Sensory Characteristics

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ABSTRACT Five thousand four hundred, 1-d-old, male, Ross 308, broiler chicks were fed for 49 d to compare diets containing 10 and 20% chia (*Salvia hispanica* L.) seed to a control diet. Cholesterol content, total fat content, and fatty acid composition of white and dark meats were determined at the end of the trial. A taste panel assessed meat flavor and preference. Cholesterol content was not significantly different among treatments; however, the 10% chia diet produced a lower fat content in the dark meat than did the control diet. Palmitic fatty acid content was less in both meat types when chia was fed, with differences being significant ($P < 0.05$), except for the white meat and the 20% chia diet. α-Linolenic fatty acid was significantly higher ($P < 0.05$) in the white and dark meats with the chia diets. Chia significantly lowered the saturated fatty acid content as well as the saturated:polyunsaturated fatty acid and ω-6:ω-3 ratios of the white and dark meats compared to the control diet. No significant differences in flavor or preference ratings were detected among diets. Body weight and feed conversion were significantly lower with the chia diets than with the control, with weight reductions up to 6.2% recorded with the 20% chia diet.

(*Key words*: chia, omega-3, broiler, meat flavor, saturated fatty acid)

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INTRODUCTION

Changes in human diets over the past 100 to 150 yr, particularly in terms of dietary fat intake and its effect on human health, have become a major interest in nutrition research (Simopoulos, 1998; Lichtenstein, 1999). Epidemiological and scientific evidence has shown a strong relationship among total fat intake and composition and a number of diseases, including coronary heart disease (CHD), cancer, diabetes, and depression (Okuyama et al., 1997; Henning and Watkins, 1998; Leaf and Kang, 1998; Katan, 2000).

The single largest killer of American males and females is CHD, causing one of every five deaths. The economic cost of CHD in the United States is projected to be $299 billion for 2001 (American Heart Association, 2001). Clinical data strongly support a relationship between CHD and dietary intake of cholesterol and saturated fatty acids (SFA) (American Heart Association, 1991), whereas epidemiological and controlled experiments have demonstrated an inverse relationship between CHD and consumption of foods rich in ω-3 fatty acids (Bang et al., 1980; Kromhout et al., 1985; Kinsella et al., 1990; Ferretti and Flanagan, 1996; Lorgeril et al., 1996; Pauletto et al., 1996; Leaf and Kang, 1998; Iso et al., 2001).

Although early studies used fish and fish oil as the source of long-chain ω-3 fatty acids, recent studies have used vegetable oil or seeds containing α-linolenic fatty acid (Lorgeril et al., 1994; Loria and Padgett, 1997; Hu et al., 1999; Li et al., 1999; Mantzioris et al., 2000). α-Linolenic acid is an ω-3 fatty acid that is converted to long-chain ω-3 fatty acids by desaturation and elongation with Δ6 and Δ5 enzymes and, hence, can be substituted for fish oils (Simopoulos, 1998, 1999).

There is growing consensus that dietary habits adopted by Western societies over the past 100 yr have contributed to the increased risk of not only CHD, but also hypertension, diabetes, and cancer (Leaf and Weber, 1987). During the last century, the emergence of processed foods, grain-fattened livestock, and hydrogenated vegetable fats has reduced the intake of ω-3 fatty acids while increasing the intake of ω-6 fatty acids and saturated fats (Leaf and Weber, 1987; Simopoulos 1998).

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Abbreviation Key: CHD = coronary heart disease; DHA = docosahexanoic acid; EPA = eicosapentaenoic acid; MUFA = monounsaturated fatty acid; PUFA = polyunsaturated fatty acid; SFA = saturated fatty acid; T0 = control diet; T1 = 10% chia; T2 = 20% chia.

Attempts to return to a balanced fatty acid diet have led to increased consumption of fish and fish products; however, there have been major changes in the types of fish consumed. For example, in the past 100 yr consumption of fatty fish in the UK has dropped from 137 to 22 g per capita per week (Summers, 2001). Another problem is that world fish stocks are in decline because of overfishing and pollution of waterways.

A partial solution may be found in aquaculture. The nutritional value of farmed fish, however, depends upon what they are fed. For example, ω-3 fatty acid levels can be extremely low because fish cannot form these fatty acids de novo and can only elongate and desaturate short chain ω-3 fatty acids (Wahlqvist, 1999). Hence, the benefits of eating more fish may be minimal, depending upon what they have been fed.

Despite scientific evidence as to the health benefits of an enriched ω-3 fatty acid diet, eating habits are still far from meeting nutritional recommendations (United States Department of Agriculture, 1997; British Nutrition Foundation, 1999). Seasonal availability, affordability, and consumer preference have all been reported to limit fish consumption. For many people, increasing the intake of oil-rich fish is not a readily accepted means of ingesting ω-3 fatty acids, and hence for these populations, fish and fish products can be excluded as a significant ω-3 source (Hargis and Van Elswyk, 1993; Buttriss, 1999).

In those cases in which less than optimal dietary intake of ω-3 fatty acids occurs because of decreased acceptability or accessibility of fish products, diets could be improved by consuming more popular, and perhaps less expensive, poultry products. Ayerza and Coates (1999, 2000, 2001a) used chia (*Salvia hispanica L.*) seed in laying hen diets to produce eggs having a high ω-3 fatty acid content, a reduced SFA content, and a lower ω-6:ω-3 ratio without imparting off-flavors. Because of the success of these trials, a subsequent trial was conducted to determine the effects that feeding chia to broilers would have on white and dark meat cholesterol, fat content, and fatty acid composition, as well as on broiler weight gain and mortality. The results are reported herein.

MATERIALS AND METHODS

Five thousand four hundred, 1-d-old, male, Ross 308, broiler chicks were distributed randomly among 36 pens (each 5 × 3 m) in a commercial poultry facility located in Cañuelas, Province of Buenos Aires, Argentina. Sunflower husks were used as litter. Three diets, containing 0, 10, and 20% whole chia seed, were selected for the test. Nutrient composition of the diets and chia seed are shown in Table 1. Each diet (treatment) was replicated 12 times, with each replicate comprising one pen of 150 birds.

After random allocation to the pens, a typical starter diet was offered for 14 d to all of the birds. On Day 14, the birds that were to be fed the control diet (T0) were changed to the 0% chia diet, and the remainder were placed on the 10% chia diet. On Day 21, feeding of the 20% chia diet commenced for those birds selected to receive this diet. The feeding trial then lasted 49 d with feed and water provided ad libitum.

Mortality, bird weight, and feed consumption for each pen were recorded on Days 14, 21, 28, 35, 42, and 49. On Day 49, six birds from each treatment were randomly selected, killed, processed, and eviscerated in a local commercial slaughterhouse. After evisceration, the birds were apportioned by hand into commercial cuts. Left side breasts (white meat) and legs (dark meat), both with the skin on, were placed in plastics bags and refrigerated (4 to 6 C) during transport to the laboratory. At the laboratory, the samples were frozen at –18 C until they were analyzed.

Laboratory Analyses

Cholesterol content, fat content, and fatty acid composition were determined for the white and dark meat samples by the following procedure. Each sample was defrosted and then ground. Total lipids were extracted according to the method of Folch et al. (1957), and lipid content was determined gravimetrically. Total lipids were converted to fatty acid methyl esters with the IRAM 5-560II method (Instituto Argentino de Racionalizacion de Materiales, 1982), which is equivalent to ISO 5508 (1990). Fatty acid methyl esters were separated and quantified by an automated gas chromathograph (Model 6890, GC)[2] equipped with flame ionization detectors and a 30 m × 530 um i.d. capillary column (Model HP-FFAP).[2] Hewlett Packard Chem Station[2] was used to integrate peak areas.

Cholesterol was extracted according to the method of the Association of Official Analytical Chemists procedure 941.09 (1990). The same equipment and procedures that were used for the fatty acids were used to quantify cholesterol levels, except that the column (Model HP-1 methyl siloxane)[2] was different.

Sensory Evaluation

After completion of the analyses of the meat samples, a second trial was begun to determine meat acceptance and flavor. Forty, 1-d-old, male, Pita broiler chicks were obtained from a local commercial hatchery and were distributed randomly between two pens in a commercial poultry facility in El Carril, Province of Salta, Argentina. After an initial period that allowed the birds to adjust to their surroundings, they were placed on a 0 or 10% chia seed diet, as used in the main trial. The feeding period lasted 64 d, with feed and water provided ad libitum. Wood shavings were used as litter.

Four birds, two from each treatment, were randomly selected at the end of the feeding period, killed by exsanguination, processed, and eviscerated according to standard procedures in a commercial slaughterhouse in Argentina. After the birds were eviscerated, they were ap-

[2]Hewlett Packard Co., Wilmington, DE.

TABLE 1. Nutrient composition of the broiler diets

Ingredient	Starter diet (0 to 14 d)	Control (14 to 49 d)	10% chia (14 to 49 d)	20% chia (21 to 49 d)
Calculated nutrient				
ME, kcal/kg	3,050	3,000	3,000	3,000
Crude fiber, %	2.96	3.19	5.2	7.27
Xanthophyll, mg	14	13.02	11.19	9.01
Methionine, %	0.58	0.55	0.55	0.55
Methionine + cystine, %	0.91	0.89	0.89	0.9 0
Lysine, %	1.29	1.25	1.24	1.25
Threonine, %	0.87	0.85	0.85	0.89
Tryptophan, %	0.28	0.29	0.28	0.28
Arginine, %	1.52	1.53	1.57	1.69
Glycine, %	1.04	1.07	1	0.99
Histidine, %	0.56	0.56	0.57	0.6
Isoleucine, %	0.76	0.74	0.75	0.8
Leucine, %	1.73	1.7	1.68	1.72
Valine, %	0.95	0.94	0.97	1.04
Calcium, %	1.1	1	1	1
Total P, %	0.71	0.73	0.56	0.43
Available P, %	0.55	0.47	0.47	0.47
Ca:P ratio	1.55	1.38	1.79	2.32
Sodium, %	0.2	0.2	0.2	0.2
Potassium, %	0.82	0.9	0.85	0.83
Chloride, %	0.24	0.23	0.23	0.22
Magnesium, %	0.3	0.31	0.27	0.23
Choline, mg	1329	1316	1233	1221
ω-6:ω:3 ratio	5.94	10.78	0.93	0.59
Analyzed nutrient				
Crude protein, %	20.8	21	21.26	22.36
Lipids, %	4.35	5.56	8.16	10
Myristic, % of total lipids	2.19	0.19	0.08	0.02
Palmitic, % of total lipids	20.55	17.35	12.51	10.41
Palmitoleic, % of total lipids	3.76	0.73	0.4	0.25
Stearic, % of total lipids	4.34	4.11	3.55	3.29
Oleic, % of total lipids	37.64	37.2	23.44	17.71
Linoleic, % of total lipids	26.12	36.98	29	25.39
Linolenic, % of total lipids	4.4	3.43	31.03	42.93
Ration ingredients				
Corn, %	61.49	70.71	65.82	59.6
Soybeans, %	7.8	12	11.85	–
Soybean pellets (43% CP), %	22.55	1.8	1.25	6.2
Gluten meal (60% CP), %	–	3.1	–	3
Sunflower pellets, %	–	1	–	–
Limestone, %	0.6	0.425	1.05	1.45
Meat meal (40% CP), %	1.8	3.15	1.9	–
Blood meal spray, %	–	–	2	2
Bone meal, %	–	0.35	–	–
Poultry viscera oil, %	–	0.5	–	0.8
Feather/blood meal, %	–	2.8	2.8	2.75
Vscera meal, %	–	1.5	2	2
Fish protein (60% CP), %	4.3	1.5	–	1
Alimet (liquid methionine), %	0.21	0.12	0.2	0.17
Pigments, %	–	0.048	0.132	0.072
Calcium phosphate, %	0.25	–	–	–
Vitamin/mineral mix, %	1	1	1	1
Chia seed, %	–	–	10	20

portioned by hand into commercial cuts with the skin on. Left side breasts (white meat) and legs (dark meat) were refrigerated for 12 h. The samples were then cooked on a commercial rotary roaster before being placed in four serving containers.

Ten untrained adult panelists from Salta, Province of Salta, Argentina, were chosen for the sensory test. Each panelist received two sets of two plates. Each plate contained a piece of meat from the control or meat from the 10% chia diet, which had been randomly selected from the serving containers. Each plate was marked with a code corresponding to the diet and type of meat. Panelists sat 1 m apart at a table and received each set of two plates in a random order. Each panelist had a sheet of paper containing four labeled squares (one for each sample) to fill in with the following evaluation criteria.

Acceptance. Like very much, like moderately, neither like nor dislike, dislike moderately, or dislike very much.

Flavor. High intensity, intense, low intensity, very low intensity, or normal.

For scoring and analyses, each classification was assigned a number from one to five. Cold tap water was provided for panelists to rinse their mouths between samples.

TABLE 2. Effect of different levels of chia seeds on performance of broilers

	Day						
Diet	7	14	21	28	35	42	49
Mortality (%)							
Control		0.12[a]	0.24[a]	0.42[a]	0.42[a]	1.81[a]	1.53[a]
10% chia		0.12[a]	0.18[a]	0.48[a]	0.30[a]	2.83[a]	1.88[a]
20% chia		0.24[a]	0.30[a]	0.48[a]	0.30[a]	2.47[a]	1.37[a]
CR[1]		0.27	0.34	0.47	0.5	1.27	1.37
Body weight (kg)							
Control	0.14[a]	0.35[a]	0.67[a]	1.24[a]	1.78[a]	2.37[a]	3.18[a]
10% chia	0.14[a]	0.35[a]	0.66[a]	1.23[ab]	1.68[b]	2.22[b]	3.02[b]
20% chia	0.14[a]	0.35[a]	0.66[a]	1.22[b]	1.70[b]	2.22[b]	2.98[b]
CR	0	0	0	0.02	0	0	0
Feed conversion ratio							
Control		1.54[a]	1.63[a]	1.65[b]	1.76[b]	1.94[b]	1.96[b]
10% chia		1.53[a]	1.63[a]	1.66[ab]	1.90[a]	2.08[a]	2.10[a]
20% chia		1.53[a]	1.63[a]	1.67[a]	1.90[a]	2.09[a]	2.12[a]
CR		0	0	0.02	0	0.1	0

[a,b]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[1]Critical range for mean separation.

Statistical Analyses

The feeding trial was set up in a randomized block design with 12 replications. The experimental unit was one pen of 150 birds. For the sensory trial, each serving container represented a treatment-meat combination of 10 replications (10 untrained adult panelists). Each variable was compared using the generalized linear model analysis of variance technique to assess treatment differences. When the F-value was significant ($P < 0.05$), differences in means were analyzed for significance using Duncan's multiple-range test (SAS, 1988).

RESULTS

Productive Performance

Mortality, body weight, and feed conversion values are presented in Table 2. Mortality was not significantly ($P < 0.05$) different among treatments, but body weight and feed conversion were.

At the end of the trial, broiler weight was significantly ($P < 0.05$) lower with the chia diets, but differences between the 10 and 20% chia diets were not significant ($P > 0.05$) (Table 2). Decreases in body weight were first detected on Day 28 for 20% chia (T2), and on Day 35 for 10% chia (T1). The decreases in body weight at the end of the trial were 5 and 6.2% for broilers fed T1 and T2, respectively, compared with broilers fed the control diet.

Feed conversion was significantly ($P < 0.05$) poorer when chia was added to the diet from Day 28 onward with the 20% chia diet and from Day 35 onward with the 10% chia diet compared to the control diet. The effect of chia on feed conversion appeared to have stabilized from Day 35 onward. No significant ($P > 0.05$) differences were detected in feed conversion between chia diets throughout the trial.

Cholesterol and Total Lipids

Results Within Meat Types. Cholesterol and fat contents of the white and dark meats are presented in Table 3. No significant ($P > 0.05$) differences among treatments were detected except with the fat content of the dark meat. The 10% chia diet produced a lower fat content than did the control diet.

Results Between Meat Types. The comparison of cholesterol and fat contents in the dark and white meats for each diet is presented in Table 4. Significantly ($P < 0.05$) less fat was found in the white meat than in the dark meat for all treatments. Cholesterol content was not significantly ($P > 0.05$) different between meats for any of the treatments.

Fatty Acid Composition

Results Within Meat Types. Fatty acid compositions of the white and dark meats are shown in Table 3. Palmitic fatty acid content was less in both types of meat when chia was fed. The difference was significant ($P < 0.05$) for all treatments except for the dark meat and T2 diet.

Monounsaturated fatty acids (MUFA) comprised the greatest percentage of fatty acids for both meat types (Table 5), with oleic being the predominant constituent. White meat produced by broilers fed chia had significantly lower ($P < 0.05$) MUFA levels (palmitoleic and oleic) compared with the control diet, with no significant difference between chia diets detected. No significant ($P > 0.05$) differences among treatments were detected for the dark meat.

Linoleic acid, an ω-6, polyunsaturated fatty acid (PUFA), was significantly ($P < 0.05$) higher in the dark meat of the broilers fed the 10% chia diet than for the birds fed the control diet (Table 3). No significant differences were detected between chia diets or between the 20% chia diet and the control diet. Arachidonic acid, a

TABLE 3. Fatty acid composition, fat content, and cholesterol content of white and dark broiler meats—comparison among treatments

Diet[1]	Cholesterol	Lipids	Miristic	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Linolenic	Arachiadonic
	(mg/100 g)	(%)	(% of total fatty acids)							
T_{0-w}	50.73[a]	8.99[a]	0.57[a]	26.03[a]	9.48[a]	4.75[a]	39.18[a]	15.09[a]	0.93[b]	0.12[b]
T_{1-w}	53.53[a]	9.11[a]	0.50[a]	21.50[b]	7.41[b]	4.32[a]	34.95[b]	19.98[a]	7.66[a]	0.12[b]
T_{2-w}	50.37[a]	6.50[a]	0.48[a]	20.68[b]	7.27[b]	4.70[a]	34.62[b]	17.65[a]	8.85[a]	0.36[a]
CR[2]	7.71	3.4	0.1	3.59	1.23	0.95	2.43	5.0	1.63	0.12
T_{0-d}	55.30[a]	19.03[a]	0.68[a]	30.5[a]	8.92[a]	5.68[a]	34.41[a]	10.44[b]	0.58[b]	<0.01
T_{1-d}	56.63[a]	13.26[b]	0.64[a]	26.58[b]	6.91[a]	5.22[a]	34.13[a]	14.68[a]	4.61[a]	<0.01
T_{2-d}	54.00[a]	16.13[ab]	0.62[a]	27.43[ab]	7.44[a]	5.64[a]	33.07[a]	12.93[ab]	5.72[a]	<0.01
CR	9.13	5.28	0.11	3.58	2.31	0.65	3.94	2.86	1.42	

[a,b]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[1]T_{0-w} white meat from 0% chia diet; T_{1-w} white meat from 10% chia diet; T_{2-w} white meat from 20% chia diet; T_{0-d} dark meat from 0% chia diet; T_{1-d} dark meat from 10% chia diet; T_{2-d} dark meat from 20% chia diet.

[2]Critical range for mean separation.

long-chain, ω-6 PUFA, was significantly higher ($P < 0.05$) in the white meat obtained from the broilers fed the T2 diet compared with the 10% chia and control diets. No differences were detected in the dark meat for any diet.

α-Linolenic fatty acid, an ω-3 PUFA, was significantly higher ($P < 0.05$) in the white and dark meats of the broilers fed chia, compared to the control diet (Table 3). Although, ω-3 α-linolenic fatty acid levels increased with level of chia in the diet, differences between the chia diets were not significant ($P < 0.05$).

Addition of chia to the diet significantly ($P < 0.05$) increased the ω-3 content of both meats (Table 5). It also significantly ($P < 0.05$) lowered the SFA content as well as the SFA:PUFA and ω-6:ω-3 ratios of the white and dark meats compared to the control diet. As the chia percentage in the diets increased, the ω-6:ω-3 ratio improved but not significantly ($P < 0.05$).

Results Between Meat Types. A comparison between the fatty acid contents of the white and dark meats within diets is presented in Table 4. Significantly ($P < 0.05$) less myristic and palmitic acids were found in the white meat than in the dark meat for both chia treatments; there was less stearic acid found in the white versus the dark meat from the control diet.

Oleic acid was significantly higher ($P < 0.05$) in the white meat than in dark meat with the control diet. No significant difference ($P < 0.05$) was detected between meat types for the chia diets. Arachidonic acid was significantly higher ($P < 0.05$) in the white meat than in the dark for the broilers fed the T2 diet.

The ω-6 and ω-3 PUFA contents of the white meat were significantly greater ($P < 0.05$) than those of the dark meat for the broilers fed chia (Table 6). No significant difference ($P > 0.05$) was found between meat types with the control diet.

The white meat had a significantly ($P < 0.05$) lower SFA content than the dark meat for all treatments. The SFA:PUFA ratio was significantly lower ($P < 0.05$) in the white meat than the dark meat with both chia diets, as was the ω-6:ω-3 ratio for the 10% chia diet. Neither ratio was significantly ($P > 0.05$) different by meat type for broilers fed the control diet.

Sensory Evaluation

No significant difference ($P > 0.05$) between the control and 10% chia treatment was detected for acceptance or flavor for either type of meat (Table 7).

DISCUSSION

Productive Performance

Lack of a significant ($P < 0.05$) difference in mortality between treatments (Table 2) is in agreement with trials

TABLE 4. Fatty acid composition, fat content, and cholesterol content of white and dark broiler meats—comparison of meat types

Diet[1]	Cholesterol	Lipids	Miristic	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Linolenic	Arachiadonic
	(mg/100 g)	(%)	(% of total fatty acids)							
T_{0-d}	55.30[a]	19.03[a]	0.68[a]	30.50[a]	8.92[a]	5.68[a]	34.42[b]	10.44[a]	0.58[a]	0.10[a]
T_{0-w}	50.73[a]	8.99[b]	0.57[a]	26.03[a]	9.48[a]	4.75[b]	39.18[a]	15.09[a]	0.93[a]	0.12[a]
CR[2]	8.58	4.87	0.13	4.2	0.65	0.86	3.68	4.96	0.43	0.45
T_{1-d}	56.63[a]	13.26[a]	0.64[a]	26.58[a]	6.91[a]	5.22[a]	34.13[a]	14.68[b]	4.61[b]	0.10[a]
T_{1-w}	53.53[a]	9.11[b]	0.50[b]	21.50[b]	7.41[a]	4.32[b]	34.96[a]	19.98[a]	7.65[a]	0.12[a]
CR	9.36	3.84	0.09	2.7	2.87	0.85	2.24	2.97	1.71	0.04
T_{2-d}	54.00[a]	16.13[a]	0.62[a]	27.43[a]	7.44[a]	5.63[a]	33.07[a]	12.93[b]	5.72[b]	0.10[b]
T_{2-w}	50.37[a]	6.50[b]	0.48[b]	20.68[b]	7.27[a]	4.70[b]	34.62[a]	17.65[a]	8.85[a]	0.36[a]
CR	7.21	4.51	0.1	3.66	1.25	0.72	3.66	4.02	1.97	0.14

[a,b]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[1]T_{0w} white meat from 0% chia diet; T_{1-w} white meat from 10% chia diet; T_{2-w} white meat from 20% chia diet; T_{0-d} dark meat from 0% chia diet; T_{1-d} dark meat from 10% chia diet; T_{2-d} dark meat from 20% chia diet.

[2]Critical range for mean separation.

TABLE 5. Total saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), ω-6, and ω-3 fatty acids and their ratios in white and dark broiler meats—comparison among treatments

Diet[1]	SFA	MUFA	PUFA	ω-6	ω-3	SFA:PUFA	ω-6:ω-3
	(% of total fatty acids)						
T_{0-w}	31.35[a]	48.66[a]	16.26[b]	15.33[a]	0.93[b]	2.42[a]	20.01[a]
T_{1-w}	26.32[b]	42.36[b]	27.87[a]	20.22[a]	7.65[a]	0.97[b]	2.67[b]
T_{2-w}	25.87[b]	41.88[b]	27.22[a]	18.37[a]	8.85[a]	0.97[b]	2.19[b]
CR[2]	4.17	2.67	5.47	4.98	1.63	1.32	7.02
T_{0-d}	36.86[a]	43.34[a]	11.22[b]	10.64[b]	0.58[b]	3.36[a]	18.84[a]
T_{1-d}	32.44[b]	41.05[a]	19.49[a]	14.88[a]	4.61[a]	1.74[b]	3.36[b]
T_{2-d}	33.69[b]	40.50[a]	18.85[a]	13.13[ab]	5.72[a]	1.89[b]	2.31[b]
CR	4.18	4.79	4.16	2.86	1.42	0.75	2.19

[a,b]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[1]T_{0-w} white meat from 0% chia diet; T_{1-w} white meat from 10% chia diet; T_{2-w} white meat from 20% chia diet; T_{0-d} dark meat from 0% chia diet; T_{1-d} dark meat from 10% chia diet; T_{2-d} dark meat from 20% chia diet.

[2]Critical range for mean separation.

in which broilers were fed redfish meal or redfish oil to increase the ω-3 content of the meat (Hulan et al., 1988, 1989). Mortality for the chia trial, however, was lower than the 7.1 and 13.1% obtained in the two redfish experiments, respectively. The mortality recorded in the chia trial is considered normal for commercial broiler production facilities in this region of Argentina (D. Nuñez, 2001, Rasic Hnos S.A, Las Acacias 1076, La Union, Argentina, personal communication).

The reduced body weight (Table 2) and decreased feed conversion efficiency (Table 2) with the chia diets agrees with observations made by others when ω-3 rich sources were added to broiler diets. It could be noted, however, that a lesser negative effect was observed with chia as compared to flaxseed and other sources of dietary ω-3 fatty acids. Hrdinka et al. (1996) reported 15, 16, 15.3, and 17.3% reductions in body weight in broilers fed 15% full-fat flaxseed, 15% full-fat flaxseed plus mixed tocopherol, 15% full-fat flaxseed plus canthaxanthin, and 15% full-fat flaxseed plus mixed tocopherol and canthaxanthin, respectively. Hulan et al. (1988) reported less reduction in body weight with fish products in diets; 7, 7.5, 12.3, or 11.4% reduction was observed in broilers fed 8, 12, 15, or 30% redfish meal, respectively, and a reduction of 9.3% was observed with 4.2% redfish oil.

In another study (Ayerza and Coates, 2001b), significantly ($P < 0.05$) greater detrimental effects on body weight were found with laying hens fed flaxseed-enriched diets than hens fed chia-enriched diets. Flaxseed in the diet has been strongly questioned because several of its constituents interfere with development in people and animals, which is due mainly to the presence of toxic cianoglicosides (limarin) and vitamin B6 antagonistic factors (Oomah et al., 1992; Chadha et al., 1995; Vetter, 2000). Numerous publications have shown the negative effect that the antinutritional factors in flax have on developing layers and broilers (Kung and Kummerow, 1950; Homer and Schaible, 1980; Bell, 1989; Lee et al., 1991; Ajuyah et al., 1993; Bhatty, 1993; Bond et al., 1997; Novak and Scheideler, 1998). None of the toxic factors of flax have been found in chia seeds or oil (Bushway et al., 1981, 1984; Ting et al., 1990; Weber et al., 1991; Lin et al., 1994). Thus, the difference in body weight reduction reported by others when broilers were fed flaxseed and when broilers were fed chia, as reported herein, could be related to one or more of the antinutritional factors in flaxseed.

TABLE 6. Total saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), ω-6, and ω-3 fatty acids of white and dark broiler meats—comparison of meat types

Diet[1]	SFA	MUFA	PUFA	ω-6	ω-3	SFA:PUFA	ω-6:ω-3
	(% of total fatty acids)						
T_{0-d}	36.86[a]	43.34[b]	11.22[a]	10.64[a]	0.58[a]	3.36[a]	18.84[a]
T_{0-w}	31.35[b]	48.66[a]	16.26[a]	15.33[a]	0.93[a]	2.42[a]	20.01[a]
CR[2]	5.04	3.95	5.41	4.99	0.43	1.7	8.92
T_{1-d}	32.44[a]	41.05[a]	19.49[b]	14.88[b]	4.61[b]	1.74[a]	3.36[a]
T_{1-w}	26.32[b]	42.36[a]	27.87[a]	20.22[a]	7.65[a]	0.97[b]	2.67[b]
CR	3.33	4.45	4.56	3	1.71	0.5	0.6
T_{2-d}	33.69[a]	40.50[a]	18.85[b]	13.13[b]	5.72[b]	1.89[a]	2.31[a]
T_{2-w}	25.87[b]	41.88[a]	27.22[a]	18.37[a]	8.85[a]	0.96[b]	2.19[a]
CR	3.95	3.07	4.51	3.91	1.97	0.54	0.75

[a,b]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[1]T_{0-w} white meat from 0% chia diet; T_{1-w} white meat from 10% chia diet; T_{2-w} white meat from 20% chia diet; T_{0-d} dark meat from 0% chia diet; T_{1-d} dark meat from 10% chia diet; T_{2-d} dark meat from 20% chia diet.

[2]Critical range for mean separation.

TABLE 7. Flavor and preference ratings for dark and white meats of broilers fed control and 10% chia diets

Meat type	Diet	Acceptance	Flavor
White	Control	4.4[a]	2.9[a]
	10% chia	4.2[a]	2.1[a]
	CR[1]	0.94	1.12
Dark	Control	4.6[a]	3.3[a]
	10% chia	4.5[a]	4.0[a]
	CR	0.73	1.17

[a]Means within a column and group without a common superscript differ significantly ($P < 0.05$) according to Duncan's multiple-range test.

[2]Critical range for mean separation..

The decrease in body weight found with chia might have resulted from the presence of the polysaccharide mucilaginous gel that is tightly bound to the seed (Lin et al., 1994). The gum could form a physical barrier to fat extraction from the seed, yielding net lower metabolizable energy for broilers fed chia than for birds fed the control diet. This finding is supported by the visual determination of whole chia seeds found in the manure of the birds fed chia. Substitution of ground chia for whole chia seeds could decrease this effect.

The combination of reduced weight gain with similar feed intakes for broilers fed chia, compared to the birds fed the control diet, resulted in significantly ($P < 0.05$) lower feed conversion for the chia diets. The 7 and 8% lower feed conversion efficiencies observed with 10 and 20% chia diets, however, were not as dramatic as the 32, 36, 32, and 36% reductions reported when broilers were fed 15% full-fat flaxseed, 15% full-fat flaxseed plus mixed tocopherol, 15% full-fat flaxseed plus canthaxanthin, and 15% full-fat flaxseed plus mixed tocopherol and canthaxanthin, respectively (Hrdinka et al., 1996).

Total Lipids

Although the chia diets had higher fat content than the control diet, the white and dark meats did not contain significantly ($P < 0.05$) higher fat contents than meats from the broilers fed the control diet. Chickens synthesize more body lipids when the energetic density or the calorie/protein ratio of the feed increases, irrespective of energy source. Hence, increased incorporation of fat in the diet will not modify the adiposity of chickens when the calorie/protein ratio remains constant (Lessire et al., 1996). This was the case for the chia experiment.

Although the results of the chia trial are in concordance with trials that fed other ω-3 sources in that an increased lipid content compared to the control was not detected (Hulan et al., 1989; Ratanayake et al., 1989; Crespo and Esteve-Garcia, 2001), fat content of the meat samples for all treatments (control, 10% chia, and 20% chia) in the chia trial were much higher. This difference occurred because the objective was to analyze meat samples representing portions normally consumed, that is meat with skin. Hence, all of the samples had approximately 15 to 30 times more fat for white and dark meats alone than were reported by Hulan et al. (1989) and Ratanayake et al. (1989).

SFA

A significant finding was the effect chia had on the palmitic content of both types of meat. The decreased palmitic levels were opposite the increased contents that have been reported when broilers were fed redfish-meal-enriched diets (Ratanayake et al., 1989) or menhaden-oil-enriched diets (Miller and Robisch, 1969). The presence of SFA in bird tissues depends on their presence in the diet, their oxidation rate, and their synthesis in the liver (Nir et al., 1988). Because inhibition of fatty acid synthesis in the liver is greater during digestion of unsaturated fats than saturated fats (Sim and Qi, 1995), the discrepancies between ω-3-enriched poultry tests in terms of palmitic acid content could be at least partially attributed to different degrees of lipogenesis reduction brought about by the different PUFA contents of the diets. The lack of a significant difference ($P < 0.05$) among chia diets in meat palmitic acid content indicated decreased conversion efficiency with increased concentration of chia in the diet. The myristic and palmitic contents of the white meat were lower than those of the dark meat. The ratio between the dark and white meats increased as chia content increased. Myristic ratio increased from 1.19 (T0) to 1.28 (T1) or 1.29 (T2), and palmitic ratio increased from 1.17 (T0), to 1.24 (T1) or 1.33 (T2). The increasing ratios indicate a decrease in conversion for the white meat compared to the dark. The reason for this finding may be related to variability in lipid manipulation between tissues, as has been demonstrated for poultry and other animals (Sheehy et al., 1993; Cha and Jones 1996; Surai and Sparks, 2000).

A factor that could influence the fatty acid composition of the white meat lipid classes, but which was less significant in the dark meat, is antioxidants. Ajuyah et al. (1993) reported on the effect adding antioxidants to the diet had on SFA content of chicken meat. Significantly ($P < 0.05$) lower palmitic fatty acid level of the triglyceride fraction was found for white meat of broilers fed 15% full-fat flaxseed plus mixed tocopherol than with 15% full-fat flaxseed. On the other hand, the dark meat did not have significantly ($P < 0.05$) different levels of palmitic fatty acid. This pattern was repeated when other natural antioxidants (canthaxanthin or canthaxanthin plus tocopherol) were used; however, the extent of the influence depended upon the mixture.

Chia contains relatively high quantities of chlorogenic acid, caffeic acid, and flavonol glycosides, all of which have demonstrated strong antioxidant activity (Taga et al., 1984). Thus the significantly ($P < 0.05$) lower percentage of myristic and palmitic fatty acids found in the white meat compared to the dark meat when broilers were fed chia, combined with the lack of a significant ($P < 0.05$) difference with the broilers fed the control diet, could be related to the antioxidant compounds in the chia seeds affecting the two types of meat differently.

Another significant finding with the chia was its effect on SFA. The chia affected not only the quantity but also the composition of the SFA content of both types of tissues. As the percentage of chia increased, the fatty acid profile improved as evidenced by the change in the relationship of the palmitic and stearic contents. The decrease in total SFA content was due primarily to the decrease in palmitic fatty acid. Because stearic acid is considered much less hypercholesterolemic, or not hypercholeterolemic compared to palmitic fatty acid (Bonanome and Grundy, 1988; Nelson, 1992; Katan et al., 1995; Grundy, 1997), addition of chia to the diet was clearly beneficial.

Dietary SFA are an independent risk factor associated with CHD; their negative effects on low-density lipoprotein cholesterol are stronger than the effects of dietary cholesterol (America Heart Association, 1988; Hornstra et al., 1998). The reduction in palmitic acid (up to 20.6% and 12.8% for white and dark meats, respectively) and in SFA (up to 17.5% and 12% for white and dark meats, respectively) in the chia trial could indicate a strong health advantage for these meats. Even with the magnitude of these changes; however, the reductions are probably not significant in practical terms for marketing because the Food and Drug Administration in the United States (1997) has stated that for a product to legally claim less or reduced amounts of a nutrient, it has to have 25% less than the normal amount. However, given that a 20.6% reduction in palmitic content was found in the white meat with the 20% chia diet, additional tests should be conducted to determine if chia diets could be formulated to further reduce the palmitic and total SFA contents and reach the 25% threshold.

MUFA

The decrease in white meat MUFA content found as ω-3 PUFA increased was similar to the change found in egg yolks from two lines of H&N laying hens fed 7, 14, 21, and 28% chia diets (Ayerza and Coates, 2000) and in the egg yolks of ISA Brown laying hens fed a 30% chia diet (Ayerza and Coates, 1999). As suggested in these papers, the decrease in oleic and palmitoleic acids could be related to the inhibition effect of PUFA against Δ9-desaturase activity, preventing the formation of MUFA from their precursors. Δ-9 Desaturase is the key enzyme needed to convert palmitic to palmitoleic acid and stearic to oleic acid (Brenner, 1989). This interaction between MUFA and PUFA has been reported in other animals as well (Brenner, 1974; Garg et al., 1988).

The results of the chia trial are in agreement with those reported when broilers were fed flaxseed (Sheehy et al., 1993) or menhaden-and-herring-oil-enriched diets (Miller and Robisch, 1969) but are opposite to those found when broilers were fed redfish meal (Hulan et al., 1989; Ratanayake et al., 1989) or redfish oil (Hulan et al., 1988). Differences among the trials could be due to the composition of the dietary fatty acid source. Poultry meat MUFA content has been shown to be much more dependent on MUFA content of the diet than on de novo formation in the body (Ratanayake et al., 1989).

The effect of chia on the oleic and palmitoleic contents of each type of meat was different and could be related to the influence of dietary antioxidants on the enzyme responsible for Δ9 desaturation. Such an effect has been reported for poultry white meat lipids but not for dark meat lipids (Asghar et al., 1990; Ajuyah et al., 1993). In the chia trial, both MUFA significantly ($P < 0.05$) decreased in the white meat, but not in the dark meat, with the magnitude of the change being greater for the palmitoleic than for the oleic acid. The same trend between meat types and unsaturated fatty acids was found when other ω-3 sources were included in the diet (Miller and Robisch, 1969).

PUFA

Linoleic content of the white meat was not significantly affected by the chia; however, a significant effect was detected with the dark meat. The 10% chia diet produced a significantly ($P < 0.05$) higher linoleic content in the dark meat than did the control diet. It should be noted that although significant differences were not detected with the white meat, the trend was similar to the dark meat; that is, the 10% chia diet yielded the highest linoleic content.

Adding chia to the broiler diet yielded a significantly ($P < 0.05$) higher linoleic content in the white meat compared to the dark. The lack of a significant difference between chia diets for the white meat suggests that a limit exists, beyond which increasing chia in the diet will not increase deposition in the white tissues. Variation between fatty acid deposition in tissue types resulting from antioxidants has been reported for linoleic acid and its metabolites (Asghar et al., 1990; Ajuyah et al., 1993; Sheehy et al., 1993; Surai and Sparks, 2000). Hence, an antioxidant × tissue interaction may be the source of the variation in linoleic acid deposition found in the chia trials.

Chia dramatically increased the ω-3 α-linolenic acid content of both the dark and white meat. Deposition in the white meat was much greater than in the dark meat, reaching 8.85% and 5.72% respectively with the 20% chia diet. The absence of a significant difference ($P < 0.05$) between α-linolenic acid content for the two chia diets for both meat types suggests that the chia content of the 20% diet may be below that which can produce a significantly higher concentration of α-linolenic acid, as compared to the 10% diet.

The different α-linolenic acid deposition patterns observed for the two meat types agrees with the results of others who fed menhaden-oil-enriched diets (Cherian et al., 1996; Miller et al., 1969), redfish meal (Hulan et al., 1988, 1989; Ratanayake et al., 1989), redfish oil (Hulan et al., 1988), and an unknown fish oil (Lopez-Ferrer et al., 1999). The chia findings, however, were opposite to those observed when broilers were fed flaxseed-oil-enriched diets, with or without antioxidants (Cherian et al., 1996;

Lopez-Ferrer et al., 1999; Crespo and Esteve-Garcia, 2001). These two sets of observations clearly show opposite deposition patterns between broilers fed fish products and those fed flaxseed and suggests that ω-3 fatty acid tissue deposition is source-dependent. Fish products are a source of eicosapentaenoic acid (EPA) and docosahexanoic acid (DHA), whereas crops such as flaxseed provide α-linolenic acid. Although chia is also a source of α-linolenic acid, the findings in this study are different than those of Cherian et al. (1996), Lopez-Ferrer et al. (1999) and Crespo and Esteve-Garcia (2001) and agree with those previously reported (Ayerza and Coates, 2001b). There are clearly differences in deposition patterns between flaxseed and chia.

Long-chain ω-6 and ω-3 fatty acids were either not detected or were detected in very low concentrations in both meat types. These findings are in agreement with those presented by others when poultry were fed soybean oil, rapeseed oil, flaxseed, palm oil, and sunflower oil but not when fed menhaden oil, bulk fish oil, and algae (Ajuyah et al., 1993; Cherian et al., 1995, 1996; Hrdinka et al., 1996; Lopez-Ferrer et al., 1999). These results indicate a limited capacity of broilers to desaturate and elongate linoleic and α-linolenic fatty acids from plant sources into their long-chain metabolites but less of a problem with marine sources. Differences in laying hens abilities to desaturate and elongate linoleic and α-linolenic fatty acids were detected in an earlier trial. Hens that were fed chia-enriched diets were able to elongate and desaturate the α-linolenic acid in the chia and incorporate it as a DHA metabolite in egg yolks, but those fed flax were not able to convert the α-linolenic acid (Ayerza and Coates, 2000, 2001b).

Fatty Acid Ratios

General recommendations for reducing the risk of CHD are an ω-6:ω-3 ratio of 5:1 to 4:1 in the diet (Canada Health and Welfare, 1990; Food and Agricultural Organization, 1994; Okuyama et al., 1997; British Nutrition Foundation, 1999). Currently, Western diets do not meet these recommendations, mainly due the high ω-6 fatty acid content of present diets (British Nutrition Foundation, 1992). Feeding chia to broilers significantly reduced the ω-6:ω-3 ratio of the meat produced compared with that of the broilers fed the control diet, which brought the meat ω-6:ω-3 ratio more in line with nutritional recommendations.

Inclusion of chia in the diet resulted in a lower SFA:PUFA ratio for both types of meat as compared with the control. Several nutritional studies strongly support a relationship between SFA and the risk of CHD, and hence there is a need to reduce consumption of SFA and increase consumption of PUFA. Chia improved the SFA:PUFA ratio in both meat types and brought it more in line with the 1:1 ratio that has been recommended (Canada Health and Welfare, 1990; American Heart Association, 1991).

Poultry Meat Vs. Other ω-3 Sources

A chia-enriched diet could make poultry meat an attractive alternative for those consumers not willing to include fish products in their daily diets. Poultry meat could provide between 2.7 and 3.5 times the amount of ω-3 PUFA per edible portion of white and dark meats, respectively, compared to an equal sized portion of canned tuna fish. A serving of 100 g of white meat from a broiler fed the 10% chia diet would provide approximately 703 mg of ω-3 PUFA. This amount compares to an average of 256 mg provided by an equivalent serving of commercial canned tuna fish obtained from supermarkets in Australia, Malaysia, and Thailand (Sinclair et al., 1998). Even when consumed with the skin on, ω-3-enriched white meat from poultry fed chia had a cholesterol content that was not much different than that of canned tuna fish (42 mg/100 g), and was lower than that of several other types of fish such as canned European anchovy, canned pink salmon, and fresh trout (mixed species) which have 85, 55, and 58 mg of cholesterol/100 g of an edible portion, respectively (USDA, 1999).

One edible portion of white meat from a broiler fed the 20% chia diet can meet 46.9% and 63.9% of the daily ω-3 fatty acids recommended, based on 2,700 and 2,000 calorie diets for men and women, respectively (Canada Health and Welfare, 1990). Thus, daily consumption of two 100-g portions of ω-3-enriched meat from broilers fed 20% chia, one serving of white and one dark, would match nutritional recommendations for both sexes and keep cholesterol intake at less than the 200 g per day recommended by the American Heart Association (1991). Hence a strong advantage exists for using poultry meat compared to ω-3-enriched eggs to provide ω-3 fatty acids in the diet. A 100-g portion of an ω-3-enriched egg will have, on average, 500 mg of cholesterol, based on a survey of ω-3 eggs sold in 20 supermarkets in Argentina, Belgium, Italy, Netherlands, Spain, UK, and US (Ayerza, 2000), whereas a common US egg contains 425 mg of cholesterol (USDA, 1999).

As a source of ω-3 fatty acids for humans, ω-3-enriched poultry meat has greater potential than fish products. Consider that the US per capita consumption of poultry increased 15% between 1987 and 1991 and between 1992 and 1997, whereas consumption of fish decreased 9%. Today, per capita consumption of poultry and fish is 80.1 and 14.5 pounds, respectively (Putnam and Allshouse, 2000).

Sensory Evaluation

Neither acceptance nor flavor of either meat type was significantly different ($P > 0.05$) between the 10% chia diet and the control. Other trials have shown increasing off-flavor with increasing percentages of fish products in broiler diets. Unacceptable off-flavors have been reported in poultry fed as little as 1.5, 1.8, and 2.5% fish oil (Hardin et al., 1964; Fry et al., 1965; Holdas and May, 1966; Miller and Robisch, 1969). Ratanayake et al. (1989) observed no

differences in broiler meat fed control, 4%, and 8% redfish meal diets but a lower preference with a 12% redfish meal (10.1% lipid content) diet. Fish meal tends to produce fewer off-flavors compared with fish oil; however, it has been suggested that the resulting flavor characteristics may still not be readily accepted by consumers (Hargis and Van Elswyk, 1993). Lopez-Ferrer et al. (1999) reported that panelists scored meat from broilers fed 8% fish oil as unacceptable. Replacement of fish oil with 8% flaxseed oil improved the sensory quality of meat, but some fish-like flavor remained.

Fatty acid oxidation increases as saturation decreases. The difference in sensory results found between birds fed flaxseed and birds fed fish products could be due to the greater instability of DHA and EPA compared to α-linolenic acid, combined with the presence of antioxidants capable of lessening this degenerative process (Shukla and Perkins, 1998). Even though α-linolenic acid is more stable than long-chain PUFA, EPA and DHA, it still is susceptible to oxidation compared with SFA and MUFA (Baudet et al., 1984; White, 1992). Hence, the different organoleptic characteristics of broiler meat that were reported among experiments that used fish products, flaxseed, and chia could arise because of antioxidants in the chia (Shukla et al., 1996; Taga et al., 1984), which are absent from fish and flax. Another source of the difference could be the interaction between other components of flax and bird physiology, as suggested by Marshall et al. (1994b).

Because consumers generally are reluctant to eat poultry products smelling or tasting like fish (Marshall et al., 1994a; Scheideler et al., 1997), the absence of these atypical organoleptic characteristics in the white and dark meats produced by broilers fed chia could represent a significant commercial advantage for this grain compared to flaxseed, when marine products and by-products are used as poultry feed.

In conclusion, the most significant findings in this trial were the effects that chia had on palmitic SFA, ω-3 PUFA, and the ω-6:ω-3 fatty acid ratio of broiler white and dark meats. Enriched ω-3 PUFA poultry meat brought about by feeding chia could be an alternative to fish to help consumers meet health recommendations, without having to change dietary habits. However, more research is needed to determine the physiological mechanism by which chia affects broiler growth and to identify the optimum method to include chia in broiler diets so as to improve bird development.

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