

Omega-3 enriched broiler meat: The influence of dietary α -linolenic- ω -3 fatty acid sources on growth, performance and meat fatty acid composition

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Azcona, J. O., Schang, M. J., Garcia, P. T., Gallinger, C., Ayerza, R. Jr. and Coates, W. 2008. **Omega-3 enriched broiler meat: The influence of dietary α -linolenic- ω -3 fatty acid sources on growth, performance and meat fatty acid composition.** *Can. J. Anim. Sci.* **88**: 257–269. Western diets are typically low in ω -3 fatty acids, and high in saturated and ω -6 fatty acids. There is a need to increase dietary ω -3 fatty acid content. Chia (*Salvia hispanica* L.) has the highest botanical source of alpha-linolenic acid (ALA) known, and recently has been receiving more attention because of this. Feeding ALA to animals has been shown to increase the ω -3 fatty acid content of the foods they produce, and hence offers consumers an easy way to increase their intake of ω -3 fatty acids without altering their diet. Broilers were fed rapeseed, flaxseed, chia seed and chia meal to assess the ability of these feed ingredients to increase the ω -3 fatty acid content of the meat, and also to determine whether any negative effects on bird production would arise. Flaxseed produced significantly ($P < 0.05$) lower body weights, weight gains and poorer feed conversion ratios than did the other feeds. Except in the case of the chia meal with the dark meat, the chia seed significantly ($P < 0.05$) reduced the saturated fatty acid (SFA) content of the white and dark meats compared with the control diet. Adding ALA increased the ALA, LC ω -3 fatty acid and total polyunsaturated fatty acid (PUFA) ω -3 fatty acid content of both meat types, except in the case of the white meat of the birds fed rapeseed. Chia seed gave the highest total PUFA ω -3 increase, yielding 157 and 200% increases for the dark and white meat, respectively, compared with the control. The ω -6: ω -3 and SFA: ω -3 ratios dramatically improved in both types of meat when chia seed, chia meal or flaxseed was added to the diet. The study also showed that not all ALA-rich seeds are biologically equivalent sources in terms of producing ω -3 enriched broiler meat. Chia proved to be superior to the other sources examined in this trial.

Key words: Chia seed, flaxseed, rapeseed, omega-3, alpha-linolenic, broiler meat, fatty acid

Azcona, J. O., Schang, M. J., Garcia, P. T., Gallinger, C., Ayerza, R. Jr. et Coates, W. 2008. **La chair de poulet enrichie d'oméga-3 : incidence des sources alimentaires d'acide α -linoléique- ω -3 sur la croissance des volatiles, leur rendement et la composition d'acides gras dans la viande.** *Can. J. Anim. Sci.* **88**: 257–269. L'alimentation des Occidentaux est typiquement pauvre en acides gras ω -3 mais renferme beaucoup d'acides gras ω -6. Il faudrait donc accroître la concentration d'acides gras ω -3 dans la nourriture. De toutes les plantes connues, le chia (*Salvia hispanica* L.) est celle qui contient le plus d'acide alpha-linoléique (ALA), ce qui explique pourquoi on s'y intéresse davantage depuis peu. Les animaux nourris d'ALA donnent des produits plus riches en acides gras ω -3, ce qui permet facilement aux gens d'accroître leur consommation d'acides gras ω -3 sans modifier leurs habitudes alimentaires. Les auteurs ont nourri des poulets de chair avec du colza, du lin, des graines de chia et de la farine de chia en vue de déterminer dans quelle mesure ces ingrédients augmentent la teneur en acides gras ω -3 de la viande et de vérifier si une telle alimentation a des effets négatifs éventuels sur l'élevage. Le lin réduit sensiblement plus ($P < 0,05$) le poids corporel, le gain de poids et augmente l'indice de consommation que les autres aliments. Comparativement à la ration témoin, le chia diminue ($P < 0,05$) sensiblement la concentration d'acides gras saturés (AGS) dans la viande blanche et brune, sauf pour la farine de chia et la viande brune. L'addition d'ALA augmente la concentration d'ALA, d'acides gras ω -3 à longue chaîne et d'acides gras ω -3 polyinsaturés totaux (AGPT) dans les deux types de viande, sauf la viande blanche des sujets recevant du colza. Comparativement à la ration témoin, les graines de chia entraînent la plus forte hausse d'AGPT ω -3, soit une augmentation de 157 % et 200 %, respectivement, pour la viande brune et la viande blanche. L'addition de graines de chia, de farine de chia ou de lin à la ration entraîne une amélioration radicale des ratios AGS ω -6: ω -3 et AGS: ω -3 dans les deux types de viande. L'étude révèle que les graines riches en ALA ne

Abbreviations: ALA, alpha-linolenic acid; CHD, coronary heart disease; LC ω -3, long-chain ω -3 fatty acid; LC ω -6, long-chain ω -6 fatty acid; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid; T₁, control diet; T₂, 15% flaxseed diet; T₃, 15% rapeseed diet; T₄, 15% chia seed diet; T₅, 15% chia meal diet

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s'équivalent pas toutes biologiquement pour ce qui est de donner de la viande de poulet enrichie d'acides gras ω -3. Le chia s'est avéré supérieur aux autres sources d'ALA examinées dans le cadre de l'expérience.

Mots clés: Graines de chia, lin, colza, oméga-3, alpha-linolénique, poulet, acide gras

Coronary heart disease (CHD) is the single largest cause of death in the United States, and is a contributing factor in one in five deaths. In 2006 the estimated direct and indirect cost of CHD was \$142.5 billion (American Heart Association 2006a).

Unhealthy diets contribute to atherosclerosis, the primary cause of heart attacks and stroke. It is estimated that up to 30% of CHD deaths are due to unhealthy diets (American Heart Association 2006a). Diets high in total fat, saturated fatty acids, trans fatty acids, and having high ω -6: ω -3 fatty acid ratios have been directly related to increased CHD risk (American Heart Association 2006a, b; British Nutrition Foundation 1999). The opposite effect has been found with ω -3 fatty acid-enriched diets (Lorgeril et al. 1994, 1996; Okuyama 2001; Grundy 2003).

Western diets are typically low in ω -3 fatty acids, and high in saturated and ω -6 fatty acids (Simopoulos 2004). This imbalance developed during the 20th century with the introduction of processed foods, grain fattened livestock, and hydrogenated vegetable fats, all of which dramatically reduced ω -3 fatty acid intake. This situation worsened with increased intake of ω -6 fatty acids and saturated fats brought about by increased intake of soybeans and the emergence of the fast food industry (Simopoulos 1998). The consequence is that dietary intake of ω -3 fatty acids must be increased.

In an effort to help balance dietary fatty acid intake, a number of studies have been undertaken in which domestic animals were fed ω -3 enriched diets (Ayerza and Coates 2005). The reason being that if food products such as eggs, milk, beef, poultry, and pork had higher ω -3 fatty acid levels, they could provide health benefits to all social classes because of their generally wide consumption. None of these studies, however, have compared diets enriched with flaxseed and chia seed, the two botanical sources containing the highest ALA content known (54 and 64%, respectively) (Firestone 1999; Ayerza and Coates 2004). The objective of the present study was to determine the effect different dietary ω -3 fatty acid sources, including flax and chia, would have on broiler performance, abdominal fat deposition and composition, and on the fatty acid composition of the white and dark meat.

MATERIALS AND METHODS

Animals, Housing, Diets and Sampling

Three hundred 1-d-old Cobb-500 broiler chicks, half male and half female, were distributed randomly among 20 pens (each 1 × 1.5 m), 10 for males and 10 for females, in the INTA (National Institute of Agricultural Technology) facility located in Pergamino, Province of

Buenos Aires, Argentina. Wood shavings were used as litter. Handling followed the principles established for the care of animals used in experiments defined by the Argentine Government's National Institute of Agricultural Technology.

Five diets, containing either corn-soybean (control diet), flaxseed, rapeseed, chia seed or chia meal (labeled as T₁, T₂, T₃, T₄, and T₅, respectively), were fed. The flaxseed, rapeseed and chia seed were ground to 0.8 mm or smaller using a hammer mill. The oil from the chia seed used to make the meal had previously been extracted using a cold press. Feed for all treatments was prepared on the same date using a small hand-fed mixer, which was thoroughly cleaned out between batches to prevent cross contamination. The mixtures were then stored under ambient conditions until fed.

Birds from each treatment were fed three diets during the experimental period. The first diet, fed from day 0 to day 21, was identical for all treatments, and was a typical starter diet. This was done to reduce project costs, and because earlier work by the authors had shown that increasing the length of the feeding period did not significantly alter the lipid relationship of the meat.

The second and third diets were consumed from day 22 to day 35, and from day 36 to day 46, respectively. These were the test diets, with the change between diets made so as to meet the changing physiological requirements of the birds during the growth period (Table 1). Feed and water were provided ad libitum. During the first 48 h of the trial, lighting was provided 24 h a day; after that only natural lighting was used, and this lasted approximately 14 h a day.

Bird weight and feed consumption for each pen were recorded on days 21, 28, 36, 42, and 46. Weekly feed consumption was not recorded prior to day 21 as this was not thought necessary because the birds were to be weighed on that day and then evenly divided by weight into groups for the test period. It should be noted that the feeding period was somewhat longer than is normally used in North America, but was chosen because the Argentine market generally requires birds weighing at least 2 kg. Over the course of the trial, mortality rate was 2.5% on average, with feed conversion ratio adjusted by changing the number of birds used in a calculation, accordingly.

On day 46, eight birds (four males and four females) from each treatment were randomly selected, weighed, killed, processed, and eviscerated. After evisceration, carcass weights were obtained, then the birds were apportioned by hand into commercial cuts. Abdominal fat (from the proventriculus surrounding the gizzard) as

Table 1. Nutritional composition of the broiler diets

Ingredient	Starter	T ₁	T ₂	T ₃	T ₄	T ₅	T ₁	T ₂	T ₃	T ₄	T ₅
	(0–21 d)	(22–35 d)					(36–46 d)				
Ingredient											
Corn (%)	48.4	51.1	45.9	45.2	43.7	40.1	59.1	52.5	49.4	50.7	50.5
Soybean meal (%)	27.925	21.7	28.9	31.4	25.1	14.3	16.5	23.6	22.9	20	8.86
Soybean (%)	15	18.6	1.57		7.78	22.4	15.7			5.79	17
Meat meal ^z (%)	5.321	4.58	4.58	4.43	4.43	4.46	5.09	5.08	4.86	4.93	5.01
Wheat bran (%)									4.3		
Soybean oil (%)	1.56										
High oleic sunflower oil (%)		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Limestone (%)	0.44	0.66	0.6	0.6	0.51	0.46	0.43	0.37	0.39	0.27	0.24
Salt (%)	0.32	0.32	0.33	0.33	0.33	0.33	0.31	0.37	0.32	0.32	0.32
Vitamin-mineral premix ^y (%)	0.2	0.25	0.25	0.25	0.25	0.25	0.2	0.2	0.2	0.2	0.2
Lysine (%)	0.016		0.12		0.1	0		0.1		0.1	0.1
Methionine (%)	0.06	0.21	0.24	0.18	0.21	0.19	0.23	0.24	0.2	0.22	0.22
Choline (%)	0.05	0.1	0.1	0.1	0.1	0.1	0	0	0	0	0
Cocciostat (%)	0.05	0.1	0.1	0.1	0.1	0.1					
Flaxseed-34% oil- (%)			15					15			
Rapeseed-34% oil- (%)				15					15		
Chia seed-28% oil- (%)					15					15	
Chia meal-18% oil- (%)						15					15
Analyzed nutrient content											
Moisture (%)		10.2	9.7	10	9	9	10.5	10.2	9.75	9.47	9.44
Protein (%)	23	19.8	20.4	19.5	19.4	19.4	17.5	18.1	18.1	18	17.5
Peroxide Index (meq/g)		5.7	5.9	6.8	1	2.9					
TME ^x (kcal kg ⁻¹)	3350	3443	3411	3406	3492	3469	3696	3472	3479	3651	3643
Gross energy (kcal kg ⁻¹)		4303	4458	4427	4472	4508	4278	4395	4404	4492	4469
TME/gross energy		80	76.5	76.9	78.1	77	86.4	79	79.2	81.3	81.5
Calculated nutrient content											
Lipids (%)	7.6	8.8	11	10.6	10.9	11.5	8.6	11	10.8	10.8	11
Methionine + cystine (%)	0.937	0.81	0.81	0.81	0.81	0.81	0.77	0.77	0.77	0.77	0.77
Lysine D (%)	1.168	1.07	1.07	1.08	1.07	1.07	0.91	0.91	0.91	0.91	0.91
Threonine D (%)	0.773	0.72	0.68	0.75	0.68	0.7	0.63	0.6	0.65	0.6	0.59
Valine D (%)	0.998	0.93	0.91	0.99	0.9	0.9	0.83	0.82	0.88	0.81	0.77
Isoleucine D (%)	0.896	0.83	0.79	0.87	0.79	0.79	0.73	0.7	0.74	0.69	0.65
Arginine D (%)	1.519	1.4	1.37	1.43	1.39	1.44	1.21	1.2	1.3	1.22	1.2
Tryptophan (%)	0.243	0.23	0.22	0.23	0.22	0.23					
Fatty acids:											
14:0 (%)		0	0	0	0	0	0	0	0	0	0
16:0 (%)		0.93	1	0.89	1.07	1.17	0.94	1.03	0.93	1.09	1.15
16:1 (%)		0	0	0	0	0	0	0	0	0	0
18:0 (%)		0.41	0.6	0.41	0.46	0.48	0.42	0.61	0.42	0.47	0.47
18:1 (%)		4.19	4.42	6.41	3.88	4.36	4.18	4.46	6.47	3.9	4.28
18:2 (%)		3.27	2.48	2.73	3.01	3.89	3.2	2.49	2.88	2.99	3.67
18:3 (%)		0.34	3.01	0.67	2.98	2.2	0.3	2.99	0.67	2.95	2.14
18:2/18:3 ratio		9.7	0.8	4.1	1	1.8	10.6	0.8	4.3	1	1.7
SFA (%)		1.4	1.6	1.3	1.6	1.7	1.4	1.7	1.4	1.6	1.7
MUFA (%)		4.2	4.5	6.5	3.9	4.4	4.2	4.5	6.5	3.9	4.3
PUFA (%)		3.6	5.5	3.4	6	6.1	3.5	5.5	3.6	5.9	5.8

^z42% protein.

^yVitamin-mineral premix provided (per kg of diet) = vitamin A, 5 300 000 IU; vitamin D₃, 1 560 000 IU; vitamin E, 15 000 IU; vitamin B₁ (thiamin), 1000 mg; vitamin B₂ (riboflavin), 4000 mg; Vitamin B₃ (Niacin), 26 000 mg; vitamin B₄ (Pyridoxin), 2000 mg; vitamin B₅ (Pantothenic), 6500 mg; vitamin B₈ (Biotin), 50 mg; vitamin B₉ (folic acid), 600 mg; vitamin B₁₂ (cyanocobalamin), 10 mg; vitamin K₃ (menadione), 1700 mg; choline, 60 000 mg; selenium, 140 mg; iodine, 400 mg; copper, 4000 mg; zinc, 40 000 mg; manganese, 50 000 mg; iron, 30 000 mg; excipient csp, 1000 g.

^xTrue metabolizable energy.

well as breast (white meat) and leg (dark meat), both without skin, were weighed and placed separately into plastic bags and refrigerated at (4–6°C) during transport to the laboratory. In the laboratory, the samples were frozen at –18°C until they were analyzed. Yield (carcass yield) was determined using live- and carcass

weights, and white meat (breast) yield was determined using carcass and breast weights.

Laboratory Analyses

Fatty acid composition was determined using aliquot samples of abdominal fat, breasts and entire legs. One

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aliquot sample of 10 g from the breast and leg tissues was dried and extracted in a Tekator apparatus using boiling hexane as the extraction solvent to obtain intramuscular fat percent. This procedure followed those of the Association of Official Analytical Chemists (1992).

A second aliquot sample of 5 g was extracted according to Folch et al. (1957) and used for fatty acid determination. The methyl esters from the fatty acids were prepared according to the method of Pariza et al. (2001) and measured using a Chrompack CP 900S fitted with a flame ionization detector (Chrompack International, Middelburg, the Netherlands) equipped with a 50-mm capillary column (Model CP-SIL 88 50-m \times 0.25-mm i.d. coating, Chrompack International, Middelburg, the Netherlands). The temperature was programmed at 70°C for 4 min, increased from 70 to 170°C at a rate of 13°C min⁻¹, then increased from 170 to 200°C at 1°C min⁻¹. Individual fatty acids were identified by comparing relative retention times with individual fatty acid standards (PUFA-2 Animal Source, Supelco, Bellafonte, PA). Results were expressed as percentages of total fatty acids.

TME values of the diets were determined following the method described by Sibbald (1976), with peroxide indices determined according American Association of Cereal Chemists (1995) Method 58-16.

Statistical Analysis

The feeding trial was set up as a randomized block design, with four replications of 15 birds each (two replication of each sex) for each treatment. Each variable was compared by analysis of variance, when the *F*-value was significant ($P < 0.05$), means were separated using Duncan's multiple-range test (Cohort Stat. 2006).

RESULTS

Production Performance

Body weight, weight gain, feed consumption, and feed conversion ratio (feed consumption/body weight) values are presented in Table 2. On day 46, both broiler weight and weight gain were significantly ($P < 0.05$) less for the flax diet, compared with the other diets. No significant ($P < 0.05$) differences were detected between the other diets throughout the trial.

Table 2. Effect of diet on broiler performance

Diet	Day				
	21	28	36	42	46
Body weight (g)					
T ₁	783a	1337a	1991a	2518a	2745a
T ₂	801a	1249b	1693b	2117b	2327b
T ₃	801a	1342a	2012a	2528a	2734a
T ₄	789a	1305a	1940a	2458a	2660a
T ₅	807a	1350a	2005a	2496a	2722a
LSD	82.818	42.558	71.288	173.142	158.013
Weight gain (g)					
T ₁	–	554a	1208a	1735a	1962a
T ₂	–	448b	892b	1316b	1526b
T ₃	–	541a	1211a	1727a	1933a
T ₄	–	516a	1151a	1669a	1871a
T ₅	–	542a	1197a	1689a	1915a
LSD	–	40.722	63.652	167.458	150.029
Feed consumed (g)					
T ₁	–	1911bc	3165bc	4470bc	4980c
T ₂	–	2011a	3362a	4858a	5501a
T ₃	–	1955ab	3254b	4623b	5163b
T ₄	–	1873c	3073c	4397c	4917c
T ₅	–	1925bc	3168bc	4478bc	5006bc
LSD	–	61.875	96.565	149.383	169.655
Feed conversion (feed consume/body weight)					
T ₁	–	1.43b	1.59b	1.78b	1.82b
T ₂	–	1.61a	1.99a	2.29a	2.36a
T ₃	–	1.46b	1.62b	1.83b	1.89b
T ₄	–	1.44b	1.59b	1.79b	1.85b
T ₅	–	1.43b	1.58b	1.79b	1.84b
LSD	–	0.053	0.068	0.141	0.131

a–c Values in a column with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test. LSD, least significant difference for $P < 0.05$.

Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

Feed consumption was highest for the flax diet, with the difference being significant from day 28 on. With the exception of day 46, when the broilers fed rapeseed showed significantly ($P < 0.05$) higher feed consumption than the control diet, no significant ($P < 0.05$) differences between the other diets and the control diet were found. Throughout, consumption of the broilers fed chia seed was significantly ($P < 0.05$) less than that of the broilers fed rapeseed.

Feed conversion was significantly ($P < 0.05$) poorer for the flaxseed diet compared with the other diets. No significant ($P < 0.05$) difference among the T₃, T₄, and T₅ diets was detected.

Body Composition

White meat, abdominal fat, and yield as percentage of live weight are shown in Table 3. White meat and yield percentages were not significantly ($P < 0.05$) different among treatments. Abdominal fat percentage was significantly ($P < 0.05$) lower in broilers fed flax and chia seed, compared with the control diet. Abdominal fat was significantly ($P < 0.05$) lower for the broilers fed flaxseed compared with those fed either form of chia.

Fatty Acid Composition

Abdominal Fat

Fatty acid composition of the abdominal fat is shown in Table 4. Palmitic fatty acid was significantly ($P < 0.05$) higher for the broilers fed the control diet. However, total saturated fatty acid (SFA) content, calculated as the sum of myristic, palmitic, and stearic, was not significantly ($P < 0.05$) different among treatments.

Monounsaturated fatty acids (MUFA) comprised the greatest percentage of fatty acids in the abdominal fat, with oleic fatty acid being predominant. Abdominal fat of the broilers fed rapeseed had a significantly ($P < 0.05$) higher MUFA content. The chia diets gave a significantly ($P < 0.05$) lower MUFA content than the other diets, with the control and flaxseed diets showing no significant ($P < 0.05$) difference in MUFA content.

Table 3. Comparison of broiler body composition among treatments

Diet	White meat	Abdominal fat	Yield
	% of liveweight		
T ₁	25.27a	1.87a	71.44a
T ₂	24.91a	0.89c	71.13a
T ₃	25.40a	1.57ab	72.33a
T ₄	25.30a	1.48b	72.36a
T ₅	25.12a	1.65ab	71.95a
LSD	1.100	0.356	1.873

Means in a column with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test.

LSD, least significant difference for $P < 0.05$.

Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

Table 4. Comparison of fatty acid composition of abdominal broiler fat among treatments

Diet	% of total fatty acids											SFA	MUFA	PUFA	SFA:PUFA	ω 6: ω -3	SFA: ω -3
	14:0	15:0	16:0	16:1	18:0	18:1	18:2	18:3	18:3	SFA	MUFA						
T ₁	0.58b	0.23c	19.15a	3.43a	5.87ab	44.03b	24.28ab	2.15c	25.83a	47.45b	26.42c	1.02ab	11.51a	13.07a			
T ₂	0.64ab	0.78ab	15.98b	2.76bc	6.27ab	44.42b	19.74cd	9.19ab	23.67a	47.18b	28.93bc	0.84bc	2.16d	2.65b			
T ₃	0.75a	0.52bc	17.18b	3.07ab	5.63b	52.87a	17.30d	2.43c	24.08a	55.94a	19.73d	1.27a	7.28b	10.70a			
T ₄	0.63ab	0.49bc	17.07b	2.51bc	6.42a	40.76c	21.91bc	10.10a	24.62a	43.27c	32.01ab	0.79bc	2.29d	2.70b			
T ₅	0.68ab	1.04a	16.55b	2.35c	5.99b	39.85c	25.70a	8.42b	23.86a	42.20c	34.13a	0.71c	3.09c	2.92b			
LSD	0.146	0.431	1.841	0.580	0.683	1.387	2.638	1.448	2.385	1.613	3.687	0.259	0.767	3.307			

a-d Means in a column with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test.

LSD, least significant difference for $P < 0.05$.

Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

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Linoleic fatty acid, an ω-6 PUFA, was lowest in the abdominal fat of broilers fed rapeseed; however, it was only significantly ($P<0.05$) less than in the control and chia diets. The linoleic content of the broilers fed flaxseed showed no significant ($P<0.05$) difference compared with that of broilers fed chia seed, but was significantly ($P<0.05$) less than those fed chia meal.

Alpha-linolenic fatty acid, an ω-3 PUFA, was significantly ($P<0.05$) higher in the abdominal fat of broilers fed flaxseed, chia seed, and chia meal, compared with the control diet. Abdominal fat from chia seed diet showed the highest ALA content; however, the difference was significant ($P<0.05$) only when compared with the rapeseed diet.

Total PUFA content in the abdominal fat was significantly ($P<0.05$) higher for both chia diets than for the control and rapeseed diets. Total PUFA content was significantly ($P<0.05$) lower with the rapeseed diet compared with all other diets.

The ω-6:ω-3 and SFA:ω-3 ratios were significantly ($P<0.05$) lower for the abdominal fat of the broilers fed all test diets compared with the control. One exception was the T₃ diet for the SFA:ω-3 ratio.

Intramuscular Fat

Results Within Meat Types. Total fat percentage and fatty acid composition for the dark and white meats are shown in Table 5 and 6. Total fat content of the white meat was not significantly ($P<0.05$) different among treatments (Table 5). Total fat content of the dark meat was not significantly ($P<0.05$) different for the chia meal diet compared with the control diet; however, the other three treatments, T₂, T₃, and T₄, had a significantly ($P<0.05$) lower total fat content compared with the control diet.

Myristic fatty acid content was not significantly ($P<0.05$) different for either type of meat compared with the control (Table 5). For the white meat, the flaxseed and chia diets had a significantly ($P<0.05$) lower content compared with the rapeseed diet. Palmitic fatty acid, which comprised the greatest percentage of SFA for both meat types, was lower in all test diets compared with the control diet for the white meat. With the dark meat, only the flax seed and chia seed diets showed a significantly ($P<0.05$) lower content than the control, but these values were not less than those of the rapeseed and chia meal diets. Stearic fatty acid, the second largest percentage of SFA, was not significantly ($P<0.05$) different for either meat type, for any of the treatments, compared with the control.

All of the test diets yielded both white and dark meat having a lower total SFA content compared with the control (Table 6). For the dark meat, the difference was significant ($P<0.05$) only for the chia seed diet. For the white meat, all but the flaxseed diet showed a significant ($P<0.05$) difference.

Table 5. Intramuscular lipid content, fatty acid composition in white and dark broiler meats among treatments

Diet	% of total fatty acids														
	Lipids	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:2	20:3	20:4	20:5	22:4	22:5	22:6
T ₁ -d	4.02a	0.45a	15.48a	2.82a	7.12ab	35.69b	26.37a	3.19d	0.28a	0.40ab	3.30a	0.11c	0.76a	0.57b	0.47c
T ₂ -d	2.34b	0.45a	13.77b	2.23b	7.76a	34.23bc	21.24b	10.03b	0.21b	0.38ab	2.43bc	0.55b	0.40c	1.19a	0.85ab
T ₃ -d	2.60b	0.45a	14.68ab	2.77a	6.69b	40.94a	20.84b	3.69d	0.26ab	0.42a	2.96ab	0.16c	0.66ab	0.70b	0.60bc
T ₄ -d	2.51b	0.39a	13.88b	2.20b	6.69b	32.17cd	24.76a	11.73a	0.26ab	0.34b	2.06c	0.92a	0.36c	1.23a	0.72abc
T ₅ -d	3.04ab	0.45a	14.53ab	2.11b	7.22ab	30.90d	25.91a	8.82c	0.26ab	0.35ab	2.14c	0.32bc	0.55b	1.16a	0.89a
LSD	1.217	0.056	0.905	0.368	0.776	2.381	1.588	1.108	0.054	0.068	0.654	0.314	0.139	0.218	0.250
T ₁ -w	0.99a	0.47ab	18.18a	2.31a	7.28ab	34.26b	21.60b	2.03c	0.39ab	0.44ab	3.93a	0.13d	1.11a	0.82c	0.79b
T ₂ -w	1.94a	0.42b	16.34bc	1.86c	7.60a	32.92b	18.28c	7.91b	0.30b	0.51a	2.67bc	0.79a	0.56c	1.93a	1.46a
T ₃ -w	1.03a	0.51a	16.62b	2.12ab	6.80ab	41.98a	17.58c	2.79c	0.39ab	0.48ab	3.07b	0.16d	0.87b	0.92c	0.86b
T ₄ -w	1.24a	0.43b	15.42c	1.6c	6.76ab	32.16b	21.40b	10.82a	0.34ab	0.38b	1.99c	0.60b	0.44c	1.51ab	1.02b
T ₅ -w	1.46a	0.45ab	16.08bc	1.83bc	6.53b	32.12b	23.70a	8.73b	0.42a	0.43ab	2.12c	0.42c	0.44c	1.19bc	0.95b
LSD	0.532	0.061	1.114	0.391	0.903	2.451	2.043	1.283	0.104	0.113	0.800	1.165	0.204	0.424	0.398

a-d Means in a column with the same letter are not statistically different ($P<0.05$) according to Duncan's multiple range test. LSD, least significant difference for $P<0.05$. N/A, not available. d, dark meat; w, white meat. Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

Table 6. Total saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), ω -6, ω -3, and long chain (LC) ω -6 and ω -3 fatty acids and their ratios in intramuscular fat of white and dark broiler meats -comparison among treatments

Diet	SFA	MUFA	ω -3	ω -6	PUFA	LC ω -6	LC ω -3	SFA:PUFA	ω -6: ω -3	SFA: ω -3
	% of total fatty acids									
T _{1-d}	23.05a	38.50b	4.35d	30.83a	35.18b	4.74a	1.15b	0.66b	7.22a	5.39a
T _{2-d}	21.98ab	36.46bc	12.62b	24.46c	37.08b	3.43b	2.59a	0.60bc	1.95d	1.76cd
T _{3-d}	21.82ab	43.71a	5.15d	24.87c	30.03c	4.29a	1.46b	0.73a	4.87b	4.28b
T _{4-d}	20.96b	34.37cd	14.60a	27.50b	42.10a	3.01b	2.87a	0.49d	1.89d	1.45d
T _{5-d}	22.20ab	33.01d	11.19c	28.95b	40.14a	3.30b	2.37a	0.56cd	2.60c	2.02c
LSD	1.44	2.519	1.051	1.582	2.036	0.747	0.576	0.065	0.589	0.496
T _{1-w}	25.92a	36.58b	3.77d	26.49a	30.26c	5.87a	1.74c	0.86a	7.20a	7.04a
T _{2-w}	24.37ab	34.72b	12.08b	21.71c	33.80b	4.04bc	4.17a	0.73b	1.81cd	2.04c
T _{3-w}	23.93b	44.09a	4.74c	21.56c	26.30d	4.82ab	1.95c	0.92a	4.62b	5.15b
T _{4-w}	22.60b	33.78b	13.95a	24.21b	38.16a	3.15c	3.13b	0.59c	1.74d	1.63c
T _{5-w}	23.06b	33.95b	11.30b	26.48a	37.78a	3.41c	2.57bc	0.62c	2.35c	2.06c
LSD	1.829	2.663	0.835	1.809	2.191	1.086	0.792	0.095	0.550	0.619

a-d Means in a column with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test.

LSD, least significant difference for $P < 0.05$; d, dark meat; w, white meat.

Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

Monounsaturated fatty acids comprised the greatest percentage of fatty acids in both meat types, with oleic fatty acid being the largest constituent. Monounsaturated fatty acids content (Table 6) was less in both meat types when flaxseed, chia seed, and chia meal were fed, compared with the control diet. The difference was significant ($P < 0.05$) only for the dark meat with both chia treatments. The MUFA content was significantly ($P < 0.05$) higher with the rapeseed diet for both meat types, than for all of the other diets.

Among treatments, for both types of meat, linoleic fatty acid was significantly ($P < 0.05$) lower for T₂ and T₃ compared with the other diets (Table 5). For the white meat, linoleic fatty acid was significantly ($P < 0.05$) higher with the chia meal diet than for the other diets.

ALA content was significantly ($P < 0.05$) higher in the white and dark meats of the broilers fed chia seed, flaxseed, and chia meal, compared with the control (Table 5). For both meat types, the chia seed diet gave a significantly ($P < 0.05$) higher ALA content than did the flaxseed or the chia meal. For the dark meat, the flaxseed diet gave a significantly ($P < 0.05$) higher ALA content than did the chia meal diet. The rapeseed diet did not produce any significant ($P < 0.05$) difference in ALA content compared with the control diet.

Long-chain ω -3 fatty acid (LC ω -3) (Table 6), calculated as the sum of eicosapentaenoic (EPA), docosapentaenoic (DPA), and docosahexaenoic (DHA) fatty acids, was significantly ($P < 0.05$) lower in the control and rapeseed diets for the dark meat. In the white meat, the difference was not significant ($P < 0.05$) between the control, rapeseed and chia meal diets. No significant ($P < 0.05$) differences between the flaxseed and two chia treatments were found for the dark meat; however, the white meat from the broilers fed flaxseed had a

significantly ($P < 0.05$) higher LC ω -3 content than that from broilers fed either chia diet.

Addition of flaxseed, chia seed and chia meal to the diet significantly ($P < 0.05$) lowered the SFA:PUFA, SFA: ω -3, and ω -6: ω -3 ratios (Table 6), with the exception of the SFA:PUFA ratio of the dark meat for the flaxseed diet, compared with the control. Chia seed gave the largest decrease in the ratios in all cases; however, the difference was not always significant ($P < 0.05$).

Results Between Meat Types. Comparison of total fat content and fatty acid composition between white and dark meats is presented in Table 7 and 8. Significantly ($P < 0.05$) less fat was found in the white meat than in the dark meat for all diets. SFA, and its major component, palmitic fatty acid, were significantly ($P < 0.05$) lower in the dark meat than in the white meat for all diets except in the case of the chia meal diet, where there was no difference in SFA content (Table 8). Linoleic fatty acid content and total ω -6 fatty acids were significantly ($P < 0.05$) lower in the white meat than in the dark meat for all treatments, except for the chia seed–linoleic fatty acid combination (Table 7).

ALA content was significantly ($P < 0.05$) lower in the white meat than in the dark meat for the control, flaxseed, and rapeseed diets (Table 7). ALA was not significantly ($P < 0.05$) different between meats for either chia treatment. Total LC ω -3 fatty acid content followed the same pattern (Table 8).

SFA:PUFA and SFA: ω -3 ratios were significantly ($P < 0.05$) higher in the white meat than the dark meat, except for the chia meal diet (Table 8). With the chia meal diet a significantly ($P < 0.05$) higher ω -6: ω -3 ratio was found in the dark meat compared with the white meat. All other treatments gave no significant ($P < 0.05$) differences between meat types within treatments.

Table 7. Intramuscular lipid content and its fatty acid composition of white and dark broiler meats -comparison of meat types

Diet	% of total fatty acids													
	14:0	16:0	16:1	18:0	18:1	18:2	18:3	20:2	20:3	20:4	20:5	22:4	22:5	22:6
T _{1-d}	4.02a	15.48b	2.82a	7.12a	35.69a	26.37a	3.19a	0.28b	0.40a	3.30a	0.11a	0.76b	0.57b	0.47b
T _{1-w}	0.99b	18.18a	2.31b	7.28a	34.26a	21.60b	2.03b	0.39a	0.44a	3.93a	0.13a	1.11a	0.82a	0.79a
LSD	1.396	0.879	0.396	0.739	2.091	1.537	0.514	0.092	0.114	0.899	0.042	0.275	0.179	0.209
T _{2-d}	2.34a	13.77b	2.23a	7.76a	34.23a	21.24a	10.03a	0.21b	0.38b	2.43a	0.55b	0.40a	1.19b	0.85b
T _{2-w}	0.94b	16.34a	1.80b	7.60a	32.92a	18.28b	7.91b	0.30a	0.51a	2.67a	0.79a	0.56a	1.93a	1.46a
LSD	0.836	0.809	0.319	0.818	1.989	1.752	1.463	0.01	0.073	0.691	0.219	0.169	0.574	0.549
T _{3-d}	2.60a	14.67b	2.77a	6.69a	40.94a	20.84a	3.69a	0.26b	0.42a	2.96a	0.16a	0.66a	0.70b	0.60b
T _{3-w}	1.03b	16.62a	2.12b	6.80a	41.98a	17.58b	2.79b	0.40a	0.48a	3.07a	0.16a	0.87a	0.92a	0.86a
LSD	0.877	0.094	0.077	0.821	2.950	0.642	0.719	0.071	0.103	0.669	0.120	0.215	0.219	0.181
T _{4-d}	2.51a	13.88b	2.20a	6.70a	32.17a	24.75a	11.73a	0.26b	0.34a	2.06a	0.92a	0.36a	1.23a	0.72b
T _{4-w}	1.24b	15.42a	1.62b	6.76a	32.16a	21.40a	10.82a	0.34a	0.39a	1.99a	0.6a	0.44a	1.51a	1.02a
LSD	0.747	0.029	0.238	0.924	1.55	2.279	1.748	0.077	0.105	0.734	0.624	0.156	0.455	0.299
T _{5-d}	3.04a	14.53b	2.11a	7.22a	30.90a	25.91a	8.82a	0.26b	0.35a	2.14a	0.32a	0.55a	1.16a	0.89a
T _{5-w}	1.46b	16.08a	1.83b	6.53a	32.11a	23.70b	8.73a	0.42a	0.43a	2.12a	0.42a	0.44a	1.19a	0.95a
LSD	1.197	0.082	0.224	1.169	1.313	1.922	1.498	0.149	0.112	0.776	0.133	0.114	0.169	0.118

a, b Means in a column, within a treatment, with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test. LSD, least significant difference for $P < 0.05$; d: dark meat; w: white meat. Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

DISCUSSION

Production Performance

This study showed a significantly ($P < 0.05$) lower final body weight, less weight gain, along with higher feed consumption and poorer feed conversion ratio for broilers fed flaxseed compared with the other diets. This finding agrees with numerous other published reports that have shown the negative effect flaxseed has on broiler and layer performance (Kung and Kummerow 1950; Bell 1989; Bhatti 1993; Caston et al. 1994; Scheideler and Froning 1996; Treviño et al. 2000). Several studies have suggested that this arises because of antinutritional cyanogenic glucosides and vitamin B₆ antagonist compounds present in flaxseed (Oomah et al. 1992; Chadha et al. 1995; Bond et al. 1997; Vetter 2000).

Significant ($P < 0.05$) differences in growth between the broilers fed flaxseed and those fed chia seed, the two the highest known plant sources of ALA, support earlier work by Ayerza and Coates (2001), in which body weight and body weight gain were negatively affected when chia was replaced with flaxseed in laying hen rations. Comparing the two ALA ω -3 fatty acid sources shows that the chia seed produced broilers having up to 23% more weight gain. In another study, Ayerza et al. (2002) showed small but significant ($P < 0.05$) weight reductions of 5 and 6.2% with 10 and 20% chia diets, respectively, when fed to broilers. The differing results between the two studies could be related to the fact that some of the chia seed fed in the current trial was ground, but it was not in the earlier trial. Additionally, different strains of broilers were used, and the length of the feeding period was different. Hence, interaction of the feed with one or more of the other variables could be responsible for the different findings between experiments.

Body Composition

Abdominal Fat

The significantly ($P < 0.05$) lower abdominal fat deposition occurring in broilers fed flaxseed and chia seed, compared with those fed the control diet, agrees with other research findings. The decrease might be explained by an increased rate of β -oxidation of unsaturated dietary fats through an enhanced expression of acyl-oxidase enzyme and subsequent reduced endogenous fatty acid synthesis, as has been proposed (Rise and Galli 1999; Rosebrough et al. 1999; Sanz et al. 2000; Crespo and Esteve-Garcia 2001; Christaki et al. 2006).

The abdominal fatty acid profile, in essence, reflected the dietary fatty acid profiles. In general, MUFA was the predominant fatty acid in abdominal fat. The significantly ($P < 0.05$) lower MUFA content found with the chia diets, compared with control diet, agrees with an earlier report in which diets containing 10 and 20% chia were fed to broilers (Ayerza et al. 2002). Similar findings when feeding omega-3 to poultry and

Table 8. Total saturated (SFA), monounsaturated (MUFA), polyunsaturated (PUFA), ω -6, ω -3, and long chain (LC) ω -6 and ω -3 fatty acids and their ratios in intramuscular fat of white and dark broiler meats -comparison of meat types

Diet	SFA	MUFA	ω -3	ω -6	PUFA	LC ω -6	LC ω -3	SFA:PUFA	ω -6: ω -3	SFA: ω -3
	% of total fatty acids									
T _{1-d}	23.05 ^b	38.50 ^a	4.35 ^a	30.83 ^a	35.18 ^a	4.74 ^a	1.15 ^b	0.66 ^b	7.22 ^a	5.39 ^b
T _{1-w}	25.92 ^a	36.58 ^a	3.77 ^a	26.49 ^b	30.26 ^b	5.87 ^a	1.74 ^a	0.86 ^a	7.19 ^a	7.04 ^a
LSD	1.447	2.371	0.729	1.656	1.940	1.187	0.419	0.069	1.159	0.798
T _{2-d}	21.98 ^b	36.46 ^a	12.62 ^a	24.46 ^a	37.07 ^a	3.43 ^a	2.59 ^b	0.60 ^b	1.95 ^a	1.76 ^b
T _{2-w}	24.37 ^a	34.72 ^a	12.08 ^a	21.71 ^b	33.80 ^b	4.04 ^a	4.17 ^a	0.73 ^a	1.81 ^a	2.04 ^a
LSD	1.296	2.272	1.290	1.451	1.576	0.813	1.290	0.064	0.292	0.258
T _{3-d}	21.82 ^b	43.71 ^a	5.15 ^a	24.87 ^a	30.03 ^a	4.29 ^a	1.46 ^b	0.73 ^b	4.87 ^a	4.28 ^b
T _{3-w}	23.93 ^a	44.09 ^a	4.74 ^a	21.56 ^b	26.30 ^b	4.82 ^a	1.95 ^a	0.92 ^a	4.62 ^a	5.15 ^a
LSD	1.386	3.175	0.921	0.817	1.618	0.938	0.386	0.066	0.649	0.850
T _{4-d}	20.96 ^b	34.37 ^a	14.60 ^a	27.50 ^a	42.10 ^a	3.01 ^a	2.87 ^a	0.50 ^b	1.90 ^a	1.45 ^b
T _{4-w}	22.60 ^a	33.78 ^a	13.95 ^a	24.21 ^b	38.16 ^b	3.15 ^a	3.13 ^a	0.59 ^a	1.74 ^a	1.63 ^a
LSD	1.551	1.703	0.974	1.771	2.239	0.952	1.263	0.062	0.156	0.183
T _{5-d}	22.20 ^a	33.01 ^a	11.19 ^a	28.95 ^a	40.14 ^a	3.30 ^a	2.37 ^a	0.56 ^a	2.60 ^a	2.02 ^a
T _{5-w}	23.06 ^a	33.95 ^a	11.30 ^a	26.48 ^b	37.79 ^a	3.41 ^a	2.57 ^a	0.61 ^a	2.35 ^b	2.06 ^a
LSD	2.222	1.434	1.365	1.362	2.437	0.893	0.299	0.101	0.250	0.461

a, b Means in a column, within a treatment, with the same letter are not statistically different ($P < 0.05$) according to Duncan's multiple range test. LSD, least significant difference for $P < 0.05$; d, dark meat; w, white meat. Diets: T₁, control; T₂, flaxseed; T₃, rapeseed; T₄, chia seed; T₅, chia meal.

other animals have also been reported (Garg et al. 1988; Caston and Leeson 1990; Ayerza and Coates 2000). The decline in MUFA content could be related to the inhibition effect of PUFA against Δ^9 -desaturase activity, an enzyme involved in the formation of oleic fatty acid (Brenner 1974), which is its main constituent.

The ALA content increased dramatically, 370, 327, and 292% with chia seed, flaxseed, and chia meal, respectively, compared with the control diet. On the other hand, LC ω -6 and LC ω -3 fatty acids were not detected in the abdominal fat. This could indicate a limited capacity of the broilers to metabolize linoleic and ALA fatty acids in abdominal fatty tissue compared with the white and dark meat. Another explanation might be the low concentration of phospholipids in the abdominal fat. Because long-chain PUFAs are mainly concentrated in the phospholipids, and phospholipids have the lowest concentration in adipose fat compared with dark meat, white meat and liver tissues, the absence of LC PUFA could be the result, as has been proposed by Marion et al. (1965), Miller et al. (1967), and Crespo and Este-Garcia (2001).

Intramuscular Fat

Total Fat. The white meat of all ALA diets did not have a significantly ($P < 0.05$) higher fat content than that of the control diet. With the exception of T₅, total fat content of the dark meat was significantly ($P < 0.05$) lower than that of the control. These findings agree with Ayerza et al. (2002) when broilers were fed chia enriched diets. Similarly, Cherian et al. (1995) found a fat reduction in dark meat, and none or only minor changes in white meat, with some strains of hens fed high ALA diets.

Although the dark meat had significantly ($P < 0.05$) higher total fat content than the white meat, both amounts were dramatically lower than those of broilers fed 10 and 20% chia enriched diets, as reported by Ayerza et al. (2002). The difference most likely came about because the samples used herein were skinless, unlike those used by Ayerza et al. (2002). Another factor could be bird strain. Cherian et al. (1995) reported significant ($P < 0.05$) differences in total fat deposition among bird strains for both meat types, and suggested that a genetic effect existed. This could also be a factor, and help to explain the difference between the chia seed treatments of the two trials, because different strains of broilers were used.

Fatty Acid Composition. The effect of dietary fats on the fatty acid profile of broiler meat has been demonstrated by a number of authors, with the magnitude of change varying with fat source (Yau et al. 1991; Zollitsch et al. 1997; Crespo and Esteve-Garcia 2001).

Saturated Fatty Acid. A significant finding of the current trial was the effect that chia seed had on total SFA content of both meat types. Chia seed was the only treatment that resulted in significantly ($P < 0.05$) less total SFA for both meat types, compared with the control (Table 6). Flaxseed, did not produce significantly ($P < 0.05$) different results compared with chia seed or the control for either meat type. It was, however, less effective in terms of decreasing the SFA content. The reduction brought about by the chia seed was 9 and 13% for the dark and white meats, respectively. This supports the earlier work of Ayerza et al. (2002) in which SFA reductions of 8.6 and 17.5% for dark and

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white meat, respectively, were found when broilers were fed a 20% chia diet.

The concentration of SFA in bird tissues is related to its content in the ration, its oxidation rate, and its synthesis in the liver (Nir et al. 1988). Inhibition of fatty acid synthesis in the liver is greater during the digestion of unsaturated fats than of saturated fats (Sim and Qi 1995). Thus, the greater reduction in SFA found with the chia seed diets compared with flaxseed could partially be attributed to different degrees of lipogenesis reduction brought about by lower PUFA absorption from flaxseed compared with chia seed. Others have demonstrated that broiler utilization of flaxseed nutrients is poor, and this has been attributed to the presence of antinutrients in flaxseed (Treviño et al. 2000). Hence, differences in SFA reduction for the white and dark meats appears to be feed dependent. Since dietary SFA is an independent risk factor associated with CHD (American Heart Association 1988), the greater reduction in SFA found with the broilers fed chia seed could indicate a health advantage for consumers eating these meats.

Significantly ($P < 0.05$) higher palmitic and SFA contents found in the white meat (Tables 7 and 8) compared with the dark meat (with the exception of SFA for the chia meal treatment) is opposite to that reported by Ayerza et al. (2002) when diets containing 10 and 20% chia seed were fed to broilers. The reason for the difference between the two experiments is not evident based upon available data, but it might be that in one trial the skin was left on and in the other it was removed. The results, however, are in agreement with a trial in which six different strains of laying hens were fed diets either high or low in ω -3 PUFAs. In this case a higher SFA content was found in the white rather than the dark meat (Cherian et al. 1995).

The reduction in SFA content was greatest with the chia seed diet. Compared with the control diet the reduction was 11% on average, and 9.1 and 12.8% for the dark and white meats, respectively. The greater decrease in SFA for the white meat indicates a decreased conversion efficiency for the dark meat, compared with the white. As was suggested by Ayerza et al. (2002), the difference 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).

Monounsaturated Fatty Acids. A concomitant decrease in total MUFA, as ω -3 PUFA increased, has been reported in egg yolks from hens fed 7, 14, 21, and 28% chia seed (Ayerza and Coates 1999), and in both white and dark meat of broilers fed 10 and 20% chia seed (Ayerza et al. 2002). In the current study, the decrease in MUFA was significant ($P < 0.05$) only for dark meat for both chia treatments compared with the control. The same trend in terms of decreased MUFA content

between meat types and unsaturated fatty acids was found when other ω -3 sources were used to enrich diets (Miller and Robisch 1969). As suggested by Ayerza and Coates (1999, 2000), the decrease in MUFA content in poultry could be related to the inhibition effect of PUFA against Δ ₉-desaturase activity, the key enzyme used to desaturate and elongate palmitic to palmitoleic and stearic to oleic fatty acid (Brenner 1989). Thus the opposite effect produced by the rapeseed-enriched diet on MUFA content found herein could be related to the higher content of dietary fat and MUFA of this diet, compared with the control diet. Broiler meat MUFA content has been reported as being much more dependent on dietary MUFA content than on endogenous fatty acid synthesis in the body (Ratanayake et al. 1993).

Polyunsaturated Fatty Acid ω -6. Differences in PUFA ω -6 and its major constituent, linoleic fatty acid, between treatments, could be due to different dietary contents among treatments and/or to a different rate of absorption between sources.

The significant ($P < 0.05$) reduction in total LC ω -6 content found in the dark and white meats of all treatments compared with the control diet has been reported when feeding other ω -3 enriched diets (Ajuyah et al. 1993). The decrease has been suggested to result from the inhibition of the linoleic fatty acid metabolism process brought about by the competition with linolenic fatty acid for Δ ₅ and Δ ₆ enzymes involved in desaturation and elongation. This has been reported not only in poultry, but in other animals as well (Craig-Schmidt et al. 1987; Hayek and Reinhart 1998).

The lack of significant ($P < 0.05$) differences in LC ω -6 fatty acid content between broilers fed the control and rapeseed diets, and broilers fed the T₂, T₄, and T₅ diets for both meat types could be due to the high ω -6: ω -3 ratio of these two diets, compared with the other three diets. A low ω -6: ω -3 fatty acid ratio in the diet has been found in other animals to be more important in terms of inhibiting linoleic elongation and desaturation processes, than the absolute amount of dietary ω -3 fatty acid in the diet (Boudreau et al. 1991).

Polyunsaturated Fatty Acid ω -3. Except for the white meat of birds fed the rapeseed diet, adding ALA sources to the diet increased ALA, LC- ω -3, and total PUFA- ω -3 contents of both meats. Chia seed gave the highest total PUFA- ω -3 increase, yielding 157 and 200% increases for dark and white meat, respectively. In addition, the chia seed diet dramatically increased the ALA and total PUFA- ω -3 content compared with the T₂, T₃, and T₅ diets. Chia seed gave 16.9 and 37% increases in ALA content for the dark and white meat, respectively, compared with flaxseed, which yielded the second largest ALA and total PUFA- ω -3 increases. The chia seed provided significantly ($P < 0.05$) higher ω -3 fatty acid deposition compared with the flaxseed, with this

possibly being related to the difference in antioxidant contents of the two sources of ALA. Variation in fatty acid incorporation resulting from the presence of antioxidants has been reported. Ajuyah et al. (1993) showed higher deposition of ω -3 fatty acid in broilers fed a flaxseed plus antioxidant enriched diets than broilers fed flaxseed. Adding antioxidants to a flaxseed diet fed to broiler chicks also showed increased oxidative stability of white and dark meat compared with a diet without antioxidants (Nam et al. 1997).

Stability analysis of the diet fed during the first part of the trial (Table 1) showed an advantage with the chia seed and chia meals, compared with the other diets. The greater stability of these ω -3 fatty acid diets, compared with the flaxseed diet could be due to the presence of antioxidants lessening the degenerative process. Chia seed contains chlorogenic acid, caffeic acid, myricetin, quercetin and kaempferol flavonols. These compounds, absent in flaxseed, are both primary and synergistic antioxidants, and contribute in a major way to the strong antioxidant activity of chia (Taga et al. 1984; Castro-Martinez et al. 1986).

The lack of a significant ($P < 0.05$) difference in LC ω -3 content between meat types that was found for the chia diets, but which existed with the flaxseed diet, has been demonstrated by others when comparing ω -3 fatty acid deposition patterns among ω -3 sources (Miller et al. 1969; Hulan et al. 1988; Cherian et al. 1996; Lopez-Ferrer et al. 1999, Ayerza et al. 2002). The results herein support the finding that deposition is source-dependent, as there were differences in deposition patterns between flaxseed and chia seeds.

A serving of dark meat (100 g) obtained from a broiler fed flaxseed, chia meal or chia seed provides 295, 340, and 367 mg of ω -3 fatty acids, respectively. This represents a 1.7, 2, and 2.1-fold increase compared with a standard diet. These values compare favorably to a 100-g portion of tuna canned in water, which provides 281 mg of total ω -3 fatty acids (United States Department of Agriculture 2006). Consumption of two servings of skinned dark meat from a broiler fed a 15% chia seed diet can provide 58% of the daily ω -3 fatty acid recommended for a 2700 calorie diet (Canada Health and Welfare 1990). Hence, meat derived from broilers fed vegetable ALA-rich sources show great potential as a sustainable source of ω -3 food for humans.

Fatty Acid Ratios. The ω -6: ω -3 and SFA: ω -3 ratios were dramatically improved in both types of meat by inclusion of chia seed, flaxseed and chia meal in the broiler diets. These ratios are considered important predictors of CHD, and a balanced relationship between fatty acids is needed to provide good cardiovascular health in humans. Nutritional recommendations suggest a dietary ω -6: ω -3 fatty acid ratio be no greater than 5:1 (Food and Agricultural Organization 1994; British Nutrition Foundation 1999), with the ideal ratio being 1:1 (Simopoulos

2004). Since SFA is hypercholesterolemic, but PUFA is hypocholesterolemic, having foods with low SFA:PUFA, ω -6: ω -3, and SFA: ω -3 ratios is important in terms of lowering the risk of suffering CHD.

In conclusion, adding vegetable ALA-rich sources to broiler diets is an alternative to using sea sources to produce ω -3-enriched products. It must be noted, however, that not all ALA-rich seeds are biologically equivalent sources in terms of producing ω -3-enriched broiler meat. This paper supports other research, which suggests that the composition of the dietary ALA source affects fatty acid absorption and utilization, and that there are different interactions between type of fatty acid and type of poultry tissue. Furthermore this paper supports other findings that show the negative effects that flaxseed has on poultry production, which chia seed does not. Based on these findings, chia holds a significant advantage over flaxseed in terms of its ability to produce products with a high ω -3 fatty acid content.

Ajuyah, A., Hardin, R. T. and Sim, J. S. 1993. Effect of dietary full fat flax seed and without antioxidant on the fatty acid composition of major lipid classes of chicken meats. *Poult. Sci.* **72**: 25–136.

American Association of Cereal Chemists. 1995. Approved methods of the AACC. Method 58-16. American Association of Cereal Chemists, St. Paul, MN.

American Heart Association. 2006a. Heart disease and stroke statistics: 2006 update. *Circulation*, **113**: 85–151.

American Heart Association. 2006b. Know the facts, get the stats 2006. American Heart Association and American and Stroke Association. [Online] Available: <http://circ.ahajournals.org> [2006 Jun. 19].

American Heart Association. 1988. Dietary guidelines for healthy American Adults: A statement for physicians and health professionals. *Arteriosclerosis* **8**: 221A.

Association of Official Analytical Chemists. 1992. Official methods of analysis. 15th ed. 3er supplement. AOAC International, Gaithersburg, MD. pp. 139–140.

Ayerza, R., and Coates, W. 1999. An omega-3 fatty acid enriched chia diet: its influence on egg fatty acid composition, cholesterol and oil content. *Can. J. Anim. Sci.* **79**: 53–58.

Ayerza, R. and Coates, W. 2000. Dietary levels of chia: influence on yolk cholesterol, lipid content and fatty acid composition, for two strains of hens. *Poult. Sci.* **78**: 724–739.

Ayerza, R. and Coates, W. 2001. The omega-3 enriched eggs: the influence of dietary linolenic fatty acid source combination on egg production and composition. *Can. J. Anim. Sci.* **81**: 355–362.

Ayerza, R. and Coates, W. 2004. Protein and oil content, peroxide index and fatty acid composition of chia (*Salvia hispanica* L.) grown in six tropical and subtropical ecosystems of South America. *Trop. Sc.* **44**: 131–135.

Ayerza, R. and Coates, W. 2005. Enrichment of animal products with omega-3 fatty acids using chia seed-based ingredients. Pages 797–807 in M. J. Pascual-Villalobos, F. S. Nakayama, C. A. Bailey, E. Correal, and W. W. Schloman, Jr., eds. Industrial crops and rural development. The Association for the Advancement of Industrial Crops, and Instituto Murciano de Investigacion y Desarrollo Agrario y Alimentario, Murcia, Spain.

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- Ayerza, R., Coates, W. and Lauria, M. 2002.** Chia as an ω -3 fatty acid source for broilers: influence on fatty acid composition, cholesterol and fat content of white and dark meat, on growth performance and on meat flavor. *Poult. Sci.* **81**: 826–837.
- Bell, J. M. 1989.** Nutritional characteristics and protein uses of oilseed meals. Pages 192–207 in G. Robbelen, R. K. Downey, and A. Ashri, eds. *Oil crops of the world*. McGraw-Hill Publishing Co., New York, NY.
- Bhatty, R. S. 1993.** Further compositional analyses of flax: mucilage, trypsin inhibitors and hydrocyanic acid. *J. Am. Oil Chem. Soc.* **70**: 899–904.
- Bond, J. M., Julian, R. J. and Squires, E. J. 1997.** Effect of dietary flaxseed on broiler growth, erythrocyte deformability and fatty acid composition of erythrocyte membranes. *Can. J. Anim. Sci.* **77**: 279–286.
- Boudreau, A. M. D., Chanmugam, P. S., Hart, S. B., Lee, S. H. and Hwang, D. H. 1991.** Lack of dose response by dietary n-3 fatty acids at a constant ratio of n-3 to n-6 fatty acids in suppressing eicosanoid biosynthesis from arachidonic acid. *Am. J. Clin. Nutr.* **54**: 111–117.
- Brenner, R. R. 1974.** The oxidative desaturation of unsaturated fatty acids in animals. *Mol. Cell. Biochem.* **3**: 41–52.
- Brenner, R. R. 1989.** Factors influencing fatty acid chain elongation and desaturation. Pages 45–79 in A. J. Ergoesen and M. Crawford, eds. *The role of fats in human nutrition*. Academic Press, New York, NY.
- British Nutrition Foundation. 1999.** N-3 fatty acids and Health. British Nutrition Foundation, London, UK.
- Canada Health and Welfare. 1990.** Nutrition recommendation. Canadian Government Publishing Center, Ottawa, ON.
- Caston, L. J. and Leeson, S. 1990.** Research note: Dietary flax and egg composition. *Poult. Sci.* **69**: 1617–1620.
- Caston, L. J., Squires, E. J. and Lesson, S. 1994.** Hen performance, egg quality and the sensory evaluation of eggs from SCWL hens fed dietary flax. *Can. J. Anim. Sci.* **74**: 347–353.
- Castro-Martinez, R., Pratt, D. E. and Miller, E. E. 1986.** Natural antioxidants of chia seeds. Pages 392–396 in *Proceedings of the World Conference on Emerging Technologies in the Fats and Oils Industry*. American Oil Chemists' Society ed. American Oil Chemists' Society Press, Champaign, IL.
- Cha, M. C. and Jones, P. J. H. 1996.** Tissue fatty acid deposition is influenced by an interaction of dietary oil source and energy intake level in rats. *J. Nutr. Biochem.* **7**: 650–658.
- Chadha, R. K., Lawrence, J. F. and Ratanayake, W. M. N. 1995.** Ion chromatographic determination of cyanide released from flaxseed under antihydrolysis conditions. *Food Addit. Contam.* **12**: 527–533.
- Cherian, G., Li, S. X. and Sim, J. S. 1995.** Dietary α -linolenic acid and lying hen strain: fatty acids of liver, adipose tissue, white meat, dark meat, and egg yolk. *J. Agric. Food Chem.* **43**: 2553–2559.
- Cherian, G., Wolfe, F. W. and Sim, J. S. 1995.** Dietary oils with added tocopherols: effects on egg or tissue tocopherols, fatty acids, and oxidative stability. *Poult. Sci.* **75**: 423–431.
- Christaki, E. V., Florou-Paneri, P. C., Fortomaris, P. D., Tserveni-Gousi, A. S. and Yannakopoulos, A. L. 2006.** Effects of dietary inclusion of natural zeolite and flaxseed on broiler chickens' body fat deposition in an extended fattening period. *Arch. Geflugelk.* **70**: 106–111.
- Cohort Stat. 2006.** Cohort Stat 6.311. Cohort Software Inc., Monterey, CA.
- Craig-Schmidt, M. C., Faircloth, S. A. and Weete, J. D. 1987.** Modulation of avian lung eicosanoids by dietary omega-3 fatty acids. *J. Nutr.* **117**: 1197–1206.
- Crespo, N. and Esteve-Garcia, E. 2001.** Dietary fatty acid profile modifies abdominal fat deposition in broiler chickens. *Poult. Sci.* **80**: 71–78.
- Firestone, D. 1999.** Physical and chemical characteristics of oils, fats, and waxes. AOCS Press, Urbana, IL.
- Folch, J., Lees, M. and Sloane-Stanley, G. H. A. 1957.** A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **226**: 497–507.
- Food and Agricultural Organization. 1994.** Fats and oils in human nutrition: Report of a joint expert consultation. Food and Nutrition Paper N:57. FAO, Rome, Italy.
- Garg, M. L., Sebkova, E., Wierzbicki, A., Thomson, A. and Clandini, M. T. 1988.** Different effects of dietary 18:2n-6 and 18:3n-3 acid on lipid metabolism in rat tissues. *Lipids* **23**: 847–851.
- Grundy, S. M. 2003.** N-3 fatty acids: priority for postmyocardial infarction clinical trials. *Circulation* **107**: 1834–1836.
- Hayek, M. G. and Reinhart, G. A. 1998.** Utilization of omega-3 fatty acids in companion animal nutrition. Pages 176–185 in A. P. Simopoulos, ed. *The return of omega-3 fatty acids into the food supply*. Karger AG, Basel, Switzerland.
- Hulan, H. W., Ackman, R. G., Ratanayake, W. M. N. and Proudfoot, F. G. 1988.** Omega-3 fatty acid levels and general performance of commercial broilers fed practical levels of redfish meal. *Poult. Sci.* **68**: 153–162.
- Kung, T. K. and Kummerow, F. A. 1950.** The deposition of linolenic acid in chickens fed linseed oil. *Poult. Sci.* **29**: 846–851.
- Lopez-Ferrer, S., Baucells, M. D., Barroeta, A. C. and Grashorn, M. A. 1999.** N-3 enrichment of chicken meat using fish oil: Alternative substitution with rapeseed and linseed oils. *Poult. Sci.* **78**: 356–365.
- Lorgeril, M. de, Renaud, S., Mamelie, N., Salen, P., Martin, J. L., Monjaud, I., Guidollet, J., Touboul, P. and Delaye, J. 1994.** Mediterranean alpha-linolenic acid-rich diet in secondary prevention of coronary heart disease. *Lancet* **343**: 1454–1459.
- Lorgeril, M. de, Salen, P., Martin, J. L., Mamelie, N., Monjaud, I., Toubouli, P. and Delaye, J. 1996.** Effect of a Mediterranean type of diet on the rate of cardiovascular complications in patients with coronary artery disease. *J. Am. Coll. Cardiol.* **5**: 103–105.
- Marion, J. E. and Woodroof, J. G. 1965.** Lipid fractions of chicken broiler tissues and their fatty fatty acid composition. *J. Food Sci.* **30**: 38–40.
- Miller, D. and Robisch, P. 1969.** Comparative effect of herring, menhaden, and safflower oils on broiler tissues fatty acid composition and flavor. *Poult. Sci.* **48**: 2146–2157.
- Miller, D., Gruger, E. H., Leong, K. C. and Knobi, G. M. 1967.** Dietary effect of menhaden oils ethyl esters on the fatty acid pattern of broiler muscle lipids. *Poult. Sci.* **46**: 438–441.
- Miller, D., Leong, K. C. and Smith, P., Jr. 1969.** Effect of feeding and withdrawal of menhaden oil. *J. Food. Sci.* **59**: 561–563.
- Nam, K. T., Lee, H. A., Min, B. S. and Kang, C. W. 1997.** Influence of dietary supplementation with linseed and vitamin E on fatty acids, α -tocopherol and lipid peroxidation in

- muscles of broiler chicks. *Anim. Feed Sci. Technol.* **66**: 149–158.
- Nir, I., Nitzan, Z. and Keren-Zvi, S. 1988.** Fat deposition in birds. Pages 141–174 in B. Leclercq and C. C. Whitehead, eds. *Leanness in domestic birds*. Butterworth, London, UK.
- Okuyama, H. 2001.** High n-6 to n-3 ratio of dietary fatty acids rather than serum cholesterol as a major risk factor for coronary heart disease. *Eur. J. Lipid Sci. Technol.* **103**: 418–422.
- Oomah, B. D., Mazza, G. and Kenaschuk, E. O. 1992.** Cyanogenic compounds in flaxseed. *J. Agric. Food Chem.* **40**: 1346–1348.
- Pariza, M. W., Park, Y. and Cook, M. E. 2001.** The biologically active isomers of conjugated linoleic acid. *Prog. Lipid Res.* **40**: 283–298.
- Ratanayaque, W. M. N., Ackman R. G. and Hulan, H. W. 1969.** Effect of redish meal enriched diets on the taste and n-3 PUA of 42-day-old broiler chickens. *J. Sci. Food Agric.* **49**: 59–74.
- Rise, P. and Galli, C. 1999.** Arachidonic and docosahexaenoic acid differential affect the expression of fatty acyl-CoA oxidase, protein kinase and lipid peroxidation in HepG2 cells. *Prostaglandins Leukot. Essent. Fatty Acids* **60**: 367–370.
- Rosebrough, R. W., McMurtry, J. P. and Vasilatos-Younken, R. 1999.** Dietary fat protein interactions in the broiler. *Poult. Sci.* **78**: 992–998.
- Sanz, M., Lopez-Bote, C. J., Menoyo, D. and Bautista, J. M. 2000.** Abdominal fat deposition and fatty acid synthesis are lower and β -oxidation is higher in broiler chickens fed diets containing unsaturated rather than saturated fat. *J. Nutr.* **130**: 3034–3037.
- Scheideler, S. E. and Froning, G. W. 1996.** The combined influence of dietary flaxseed variety, level, form, and storage conditions on egg production and composition among vitamin E-supplemented on hens. *J. Appl. Poult. Res.* **6**: 137–146.
- Sheehy, P. J. A., Morrissey, P. A. and Flynn, A. 1993.** Influence of heated vegetable oils and α -tocopherol acetate supplementation on α -tocopherol, fatty acids and lipid peroxidation in chicken muscle. *Br. Poult. Sci.* **34**: 367–381.
- Sibbald, I. R. 1976.** A bioassay for true metabolizable energy in feedingstuffs. *Poult. Sci.* **55**: 303–308.
- Sim, J. S. and Qi, G. H. 1995.** Designing poultry products using flaxseed. Pages 315–333 in S. C. Cunnane and L. U. Thompson, eds. *Flaxseed in human nutrition*. AOCS Press, Champaign, IL.
- Simopoulos, A. P. 1998.** Overview of evolutionary aspects of ω -3 fatty acids in the diet. Pages 1–11 in A. P. Simopoulos, ed. *The return of ω -3 fatty acids into the food supply*. S. Karger AG, Basel, Switzerland.
- Simopoulos, A. P. 2004.** Omega-6/omega-3 essential fatty acid ratio and chronic diseases. *Food Rev. Int.* **1**: 87–90.
- Surai, P. F. and Sparks, N. H. C. 2000.** Tissue-specific fatty acid and α -tocopherol profiles in male chickens depending on dietary tuna oil and vitamin E provision. *Poult. Sci.* **79**: 1132–1142.
- Taga, M. S., Miller, E. E. and Pratt, D. E. 1984.** Chia seeds as a source of natural lipid antioxidants. *J. Am. Oil Chem. Soc.* **61**: 928–931.
- Treviño, J., Rodriguez, M. L., Ortiz, L. T., Rebole, A. and Alzueta, C. 2000.** Protein quality of linseed for growing broiler chicks. *Anim. Feed Sci. Technol.* **84**: 155–166.
- United States Department of Agriculture. 1999.** USDA nutrient database for standard reference. Release 19. Agricultural Research Service, Nutrient Data Laboratory [Online] Available: <http://www.nal.usda.gov/fnic/foodcomp/Data/SR18/sr18.html> [2006 Nov. 12].
- Vetter, J. 2000.** Plant cyanogenetic glycosides. *Toxicon* **38**: 11–36.
- Yau, J. C., Denton, J. H., Bailey, C. A. and Sams, A. R. 1991.** Customizing the fatty acid content of broiler tissues. *Poult. Sci.* **70**: 167–172.
- Zollitsch, W., Knaus, W., Aichinger, F. and Lettner, F. 1997.** Effects of different dietary fat sources on performance and carcass characteristics of broilers. *Anim. Feed Sci. Technol.* **66**: 63–73.