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Industrial Crops and Rural Development

Proceedings of 2005 Annual Meeting of the Association for the Advancement of Industrial Crops:
International Conference on Industrial Crops and Rural Development
(17-21 September 2005, Murcia, Spain)

Editey by
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Publisher and design: Pardo comunicación, S.L.

Preprint: CompoRapid, S.L.

Print: Selegráfica, S.L.

I.S.B.N.: 84-689-3363-5
Legal Deposit: MU-1549-2005

ENRICHMENT OF ANIMAL PRODUCTS WITH OMEGA-3 FATTY ACIDS USING CHIA SEED-BASED INGREDIENTS

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Abstract

There is considerable evidence suggesting that regular consumption of omega-3 fatty acids prevents cardiovascular diseases, including atherosclerosis and thrombosis. Most studies, however, have been carried out with fish products. However, in many countries such as the U.S., annual per capita consumption of marine products is low. In addition, for many people, a strong limitation for the use of fish as a food is that fish has been recognized as a potent allergen, both in food and occupational allergies. An alternative is to enrich products of animal origin most consumed and the goal of this project was to obtain an alternative to fish products using chia seed-based feed ingredient. Methodology included dietary different levels of chia seed (whole and grown), and chia oil. The research and development showed the feasibility of enriching animal products like eggs, poultry meat, cow's milk and pork meat with omega-3 fatty acids, and suggested that none of the current levels of omega-3 fatty acids that can be produced by the incorporation of chia in animal diets can be reached using flax, fish oil or algae-based diets without strongly affecting animal performance and/or one or more of the intrinsic characteristics of the final product. In all cases, the limiting factor for utilization of high percentages of available omega-3 sources, with the exception of chia, is flavor, smell and/or atypical textures transmitted by these sources to the products. Also, in the case of flax, animal production would be negatively affected.

Keywords: Chia; Omega-3; Linolenic; Animal products; *Salvia hispanica*.

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1. INTRODUCTION

Coronary heart disease (CHD) is the leading cause of death in the western world. In recent years clinical and epidemiological studies have indicated that dietary omega-3 fatty acids may reduce the risk of coronary heart disease. Western diets, however, are typically low in omega-3 fatty acids and high in saturated and omega-6 fatty acids (Wright *et al.*, 1998).

Although omega-6 and omega-3 fatty acids have been known as necessary for normal growth and dermal function since 1930, omega-3 fatty acids have not received much attention until recently (Holman, 1998). Following the report of Bang *et al.* (1976) that indicated low mortality from CHD among Greenland Eskimos, which was attributed to antiatherosclerotic effects of a diet rich in fish oil, many studies have documented the effects of omega-3 fatty acids on biochemical and physiologic factors believed to influence the risk of CHD (Leaf and Kang, 1998).

There is considerable interest in providing natural sources of omega-3 fatty acids in human diets. Today, marine products are the main food source of omega-3 fatty acids; however availability, consumer preference, and other factors limit fish and marine product consumption (Marshall *et al.*, 1994). Many attempts have been made to produce foods high in omega-3 fatty acids by adding marine products without imparting an unpleasant "fishy flavor" to them, however this has met little success.

If food items such as eggs, milk, poultry, and pork with higher levels of omega-3 fatty acids were available, they could bring important health benefits to people of all social classes because of their wide consumption. Availability of such products would also help change the negative perception that consumers have about food products of animal origin that is attributed to the less than ideal fatty acid composition. This would also reverse the declining consumption of these products in recent years and increase grower returns. Thus, finding alternative sources of omega-3 fatty acids is of great importance in many ways.

1.1. Chia (*Salvia hispanica* L.)

Chia is an emerging oil seed crop, rich in omega-3 α-linolenic fatty acid (Ayerza, 1995), which has been used in human nutrition for more than 3000 years. It is the richest known botanical source of α-linolenic fatty acid (Ayerza and Coates, 2005).

In pre-Columbian times, chia was one of the basic foods of Central American civilizations, less important than corn and beans, but more important than amaranth. Tenochtitlan, the Capital of the Aztec Empire, received between 5,000 and15,000 tons of chia as an annual tribute from conquered nations (Codex Mendoza, 1542). Chia seed was not only a food, but also offered to the Aztec gods. Use of chia in pagan religious ceremonies was the reason why the Spanish conquistadors tried to eliminate it, and replace it by species brought from the old world (Sahagun, 1579).

The conquistadors were close to being successful in their crusade against New World cultures and traditions, not just with chia but with many other crops and customs. Corn and beans were an exception as they survived the conquistador's efforts and became two of the most important food crops. However because of its religious use, and probably because chia was unable to adapt to production under European climatic conditions, it had undergone a 500-year period of obscurity (Ayerza and Coates, 2005).

Chia survived and was maintained only in very small cultivated patches in scattered mountain areas of southern Mexico and Guatemala until a research and development program was initiated in 1991. A group of growers, commercial entities, as well as technical and scientific personnel from Argentina, Columbia, Bolivia, Peru, and the USA began collaborating through the Northwestern Argentina Regional Project (Ayerza and Coates, 1996). The idea behind the project was not only to provide growers with alternative crops, but also to improve human health by reintroducing chia to human diets as a source of omega-3 fatty acids, antioxidants and fiber.

Today, chia is commercially used as food in the U.S., Mexico, Central America, Chile, and Argentina. It is also used in commercial diets for laying hens, dogs, cats, horses, and pet birds in several countries in the European Union, USA, and Argentina.

1.2. Omega-3 fatty acids sources

There are four natural commercial sources of omega-3 fatty acids: fish oil/meal, flax seed, chia seed, and marine algae, of which flaxseed and fish oil/meal are the most widely known. However, these materials have a number of characteristics that limit their use as animal feed. These four raw materials are compared in Table 1.

Table 1. Main characteristics of four sources of omega-3 fatty acids.

Omega-3 source	Fish oil [1*]	Algae [2**]	Flaxseed [3]	Chia [4]
Origin	animal	vegetal	vegetal	vegetal
History as human food	No	No	No	Yes
Primarily used to manufacture	Feed	Feed	Industrial	Food
Omega-3 fatty acid (FA)	EPA & DHA	DHA	α-linolenic	α-linolenic
Total omega-3 fatty acids FA (%)	30	37	58	64
Total saturated FA (%)	27	50	7	9
Cholesterol	Yes	No	No	No
Anti-nutritional/toxic factors	Yes	No	Yes	No
Fat stability	very low	very low	low	high
Natural antioxidant	No	very low	very low	high
Antioxidant needs	Yes	Yes	Yes	No
Off-flavor (fishy flavor)	Yes	Yes	Yes	No
Handling & storage	difficult	difficult	difficult	easy

[1] *USDA, 1999;*

[2] *Abril et al., 2000;*

[3] *Sultana (1996);*

[4] *Coates and Ayerza, 1998;*

[*] *Menhaden oil;*

[**] *DHA Gold™ (Schizochytrium sp.)*

World fish stocks are in decline because of over fishing and pollution of waterways. Today, high concentrations of toxic substances present in marine fish is a cause of concern. A recent study monitored organic pollutants (PCB, DDT, oxychlordane, and others) in the blood of women from six circumpolar countries (Greenland, Canada, Iceland, Norway, Sweden, and Russia). Organic pollutants were highest among Inuit (Eskimo) populations, and this is logical since marine products are their main source of food. The blood concentration of PCBs in Greenlandic women was 3.7 times the level considered safe for women of reproductive age according to Canadian guidelines. As the Greenland Inuits traditionally consume fish and other sea products such as seal and small whales, these are considered the source of the PCBs (Hansen, 2000; Helm *et al.*, 2001). These findings agree with a study conducted in Sweden that found populations consuming large amounts of fish (including salmon and herring) accumulated significantly higher levels of dioxin in their body compared with non-fish consumers (Svensson *et al.*, 1991).

Because flax seed and oil are readily available and are inexpensive, many attempts have been made to use them as omega-3 fatty acid sources in animal production, but without much success. Numerous scientific publications have shown the negative effects that the anti-nutritional factors of flax have on the development of layers, broilers, pigs, laboratory animals, etc. (Kung and Kummerow, 1950; Homer and Schaible, 1980; Bell, 1989; Batterham *et al.*, 1991; Lee *et al.*, 1991; Ajuyah *et al.*, 1993; Bell and Keith, 1993; Bhatty,1993; Bond *et al.*, 1997; Prasad, 1997; Novak and Scheideler, 1998; Toug *et al.*, 1999; Treviño *et al.*, 2000). In order to use flax in animal diets, the seeds have to be detoxified. The most efficient processes require solvents, and even then the seeds cannot be completely detoxified (Madhusudhan *et al.*, 1986; Mazza and Oomah, 1995).

Chia lacks toxic substances and anti-nutrients, and has a balanced nutrient composition (Weber *et al.*, 1991). Trials have shown the feasibility of using chia seeds and oil as a feed for hens, broilers, cows, and laboratory animals without adversely affect body or liver weight. This makes the potential for using chia as a feed or food enormous (Ayerza and Coates, 1999, 2000, 2001, 2002a, 2002b; Neely, 1999).

2. FOOD SOURCES

2.1. Eggs

A number of trials have shown the advantages of using chia as a source of omega-3 fatty acid to enrich eggs. Table 2 presents a comparison when using chia, flax, and fish oil to enrich laying hen diets. An additional advantage is that eggs produced by hens fed chia have not shown differences in taste preferences or off-flavors compared with eggs from non-chia diets (Ayerza and Coates, 1999, 2001, 2002a).

Available information suggests that none of the current levels of omega-3 fatty acid incorporation produced by feeding chia could be reached using flax, fish oil, or algae-based diets without negatively affecting hen performance and/or one or more of the intrinsic characteristics of eggs. In all cases, the limiting factor for utilization of high amounts of available omega-3 sources, with the exception of chia, is flavor, smell and/or atypical textures transmitted from these feeds into the eggs. Also in the case of flax, poultry production has been negatively affected (Kung and Kummerow, 1950; Homer and Schaible, 1980; Bhatty, 1993; Bond *et al.*, 1997).

Table 2. Omega-3 fatty acids enriched eggs: advantage of chia over other raw materials (Ayerza and Coates, 2005).

Diet	Hen line	% of total fatty acids				
		Palmitic	Saturated	α-Linolenic	DHA	Σ omega-3
Commercial 1	Brown	22.4	31.1	0.9	1.7	2.8
	White	24.3	33.8	0.9	1.5	2.6
14% Flax	Brown	21.5	30.2	4.9	2.5	7.8
	White	22.7	31.1	5.8	2.1	8.1
Fish meal	Brown	23.9	32.6	1.8	3.5	5.6
	White	24.5	33.6	1.9	3.4	5.7
14% Chia	Brown	20.8	29.7	7.8	2.5	10.6
	White	21.7	30.4	11.2	2.1	13.5
Commercial 2	Brown	23.1	32.1	1.6	1.2	3.0
	White	24.6	33.0	1.0	1.0	2.1

2.2. Broilers

The feasibility to produce chicken meat enriched with omega-3 fatty acids based on diets supplemented with chia was also demonstrated (Ayerza *et al.*, 2001). Tables 3 and 4 show the results when broilers diets were enriched with 10 and 20% whole chia seeds.

Neither the acceptance nor flavor of either meat type (dark or white) was significantly different ($P<0.05$) when they were compared with meat from broilers fed the control diet (Ayerza *et al.*, 2002). Chicken meat holds a significant advantage over omega-3 eggs as a source of these fatty acids because the omega-3 contained in eggs (600 mg/100 g of egg) would be difficult to obtain. Additionally, eating these eggs means one would also consume 400 mg of cholesterol, compared with only 53.6 mg in the chia enriched chicken meat including the skin. Because the American Heart Association (1990) recommends consuming less than 300 mg of cholesterol daily, this brings into question whether eggs can ever be an unlimited source of omega-3 fatty acids.

The omega-3 fatty acid content of a 100 g serving of skinless leg from a broiler that had been fed a diet containing 10% of chia, provides 11.4% (126 mg) of the daily needs of this essential fatty acid. This compares with a serving (100 g) of canned commercial tuna which supplies 71% (177 mg) of the daily needs of this essential fatty acid, or the average of canned tuna from Australia, Malaysia, or Thailand that supplies 50% (256 mg) of the daily needs of this essential fatty acid (Sinclair *et al.*, 1998).

A serving (100 g) of thigh meat with skin from a broiler fed a diet of 10% chia provides 63% (573 mg) of the daily recommended omega-3 fatty acid intake. This is significantly greater than a serving of Thai tuna that possesses the highest commercially available omega-3 content for canned fish, as it contains only 370 mg. Another problem is that a serving of the Thai tuna contains 56.4 mg of cholesterol (United States Department of Agriculture, 1999), compared with 53.6 mg for the broiler meat.

Table 3. Fatty acid composition, fat content, and cholesterol content of white and black broiler meat – comparison of meat types (From Ayerza *et al.*, 2002).

Diet[1]	Cholesterol mg/100g	Lipids %	% of total fatty acids							
			Myristic	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	α-linolenic	Arachidonic
T_{o-d}	55.30[a]	19.03[a]	0.68[a]	30.50[a]	8.92[a]	5.68[a]	34.42[b]	1044[a]	0.58[a]	0.10[a]
T_{o-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	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[b]	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 lacking a common superscript differ significantly ($P<0.05$) according to Duncan's Multiple Range Test.*
[1] *T_{o-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_{o-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.*
CR = Critical range for mean separation.

Table 4. Total saturated (SFA), monounsaturated (MUFA, polyunsaturated (PUFA), omega-6 and omega-3 fatty acids and their ratios in white and dark broiler meat - comparison among treatments (From Ayerza *et al.*, 2002).

Diet[1]	% of total fatty acids						
	SFA	MUFA	PUFA	omega-6	omega-3	SFA-PUFA	omega-6: omega-3
T_{o-10}	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_{d-o}	38.86[a]	43.34[a]	11.22[b]	10.64[b]	0.58[b]	3.36[a]	18.84[a]
T_{d-1}	32.44[b]	41.05[a]	19.49[a]	14.88[a]	4.61[a]	1.74[b]	3.36[b]
T_{d-2}	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 lacking a common superscript differ significantly ($P<0.05$) according to Duncan's Multiple Range Test.*
[1] *T_{o-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_{o-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.*
CR = Critical range for mean separation.

Another important advantage of chia enriched omega-3 broiler meat over "common" broiler meat is the significant reduction in the saturated fatty acid content. Additionally, it has a lower omega-6:omega-3 ratio compared with common broiler meat. Clearly, there are huge advantages in the market place for meat coming from broilers fed chia. Thus, "omega-3" enriched broiler meat from chickens fed chia could replace fish from a health standpoint, especially for those countries with no access to fish, dislike to eat fish, or are allergic to fish.

2.3. Milk

Milk enriched with higher levels of omega-3 fatty acid is a product because of its wide consumption also could bring important health benefits to people of all social classes. Changing milk composition by changing a lactating cows' diet would seem to be a logical process, following the example of omega-3 enriched eggs and broiler meat.

The U.S. dairy industry, as is the case in other western countries, has been affected by the declining per capita consumption of milk and milk products in recent years. In the U.S., per capita consumption of fluid milk and cream has dropped from 110 kg in 1985, to 102 kg pounds in 1996 (USDA, 1996, 1998). Enriched milk, with higher levels of omega-3 fatty acids would help change the negative perception about milk that is attributed to its less than ideal fatty acid composition.

A 30-day feeding trial was conducted with multifarious lactating Holstein cows to determine the effect that feeding chia would have on milk. Results showed that milk production was not significantly different ($P<0.05$) between cows fed 1 kg of whole chia seeds per day, and the cows fed 1 kg of corn per day. This finding indicates that chia was not an inappropriate feed for lactating cows (Ayerza and Coates, 2002b).

Cholesterol and total fat contents were numerically lower in the milk obtained from the cows fed chia; however, no significant differences ($P<0.05$) were detected (Table 5). Oleic, linoleic (omega-6), and alpha-linolenic (omega-3) fatty acids (Table 5) were significantly higher with the chia diet than with the control diet, or total polyunsaturated fatty acid content. No significant differences in saturated fatty acids were detected between treatments. Significantly ($P<0.05$) lower SFA:PUFA and SFA:omega-3 ratios in the milk were found as compared with those of the control diet (Table 6).

Table 5. Influence of dietary chia on total fat content, cholesterol content, and fatty acid composition of milk (Adapted from Ayerza and Coates, 2002b).

		% of total fatty acids							Cholesterol	Total Fat
Day	Treatment	Myristic	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Linolenic	mg/ 100 ml	g/ 100 ml
30	Control	12.85[a]	29.98[a]	2.28[a]	12.55[a]	28.08[b]	3.10[b]	1.10[b]	27.75[a]	3.12[a]
30	Chia	11.27[a]	25.13[a]	2.47[a]	13.90[a]	32.47[a]	3.96[a]	1.32[a]	24.33[a]	2.92[a]
	CR	2.42	5.99	0.83	2.41	4.31	0.74	0.19	6.65	0.91

[a,b] Means within a column lacking a common subscript differ significantly ($P<0.05$) according to Duncan's multiple range test; CR = critical range for means separation

Table 6. Influence of dietary chia on saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated ratty acids (PUFA), and their ratios in milk (Adapted from Ayerza and Coates, 2002b).

		% of total fatty acids					
Day	Treatment	SFA	MUFA	PUFA	omega-6: omega-3	SFA:PUFA	SAT: omega-3
30	Control	55.38[a]	30.35[a]	4.20[b]	2.84[a]	13.29[a]	51.04[a]
30	Chia	50.30[a]	34.93[a]	5.28[a]	3.00[a]	9.61[b]	38.09[b]
	CR	6.26	4.63	0.77	0.73	3.24	1271

[a] *Means within a column lacking a common subscript differ significantly (P<0.05) according to Duncan's multiple range test;*
CR = critical range for means separation

These improvements would make milk more acceptable to health conscious consumers, and could reverse the declining per capita consumption of milk that has occurred in recent years.

3. CONCLUSIONS

Chia is a promising alternative for use as a substitute or to compliment other sources of omega-3 fatty acids such as flaxseed and fish meal/oil. Modern science explains why ancient mesoamerican civilizations considered chia a basic component of their diet. After 500 years of being forced into obscurity, the *Hidden Crop of the Aztecs* offers the world an opportunity to return to our origins and improve our nutrition by providing a natural source of omega-3 fatty acids for animals and humans.

REFERENCES

Abril J.R., Barclay W.R., Abril P.G., 2000. Safe use of microalgae (DHA GOLD) in laying hen feed for the production of DHA enriched eggs. In: Sim, J.S., Nakai, S., Guenter, W. (Eds.), Egg Nutrition and Technology. CAB International 2000, Wallingford, Oxon, U.K., pp. 197-202.

Ajuyah A.O., Hardin R.T., 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. Poultry Sci. 72, 125-136.

American Heart Association, 1990. The cholesterol facts. American Heart Association, and The National Heart, Lung, and Blood Institute, Special Report, Circulation, 81(5),1721-1733.

Ayerza R., 1995. Oil Content and Fatty Acid Composition of Chia (*Salvia hispanica L.*) from Five Northwestern Locations in Argentina. J. Am. Oil. Chem. Soc. 72, 1079-1081.

Ayerza R., Coates W., 1996. New industrial crops: Northwestern Argentina Regional Project: In: Janick, J.J. (Ed.) Progress in New Crops. ASHS Press, Alexandria, Virginia, pp. 46-51.

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

Ayerza R., 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., Coates W., 2002a. Dietary levels of chia: influence on hen weight, egg production, and egg sensory quality. Brit. Poultry Sci. 43(2), 283-290.

Ayerza R., Coates W., 2002b. Influence of chia on total fat, cholesterol, and fatty acid profile of Holstein cow_s milk. Annual Meeting of The Association for the Advancement of Industrial Crops, Saskatoon, Saskatchewan, Canada, Abst. p. 8.

Ayerza R., Coates W., Lauria M., 2002. Chia as an omega-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. Poultry Sci. 81, 826-837.

Ayerza R., Coates W., 2005. Chia: rediscovering a forgotten crop of the Aztecs. The University of Arizona Press, Tucson, Arizona, USA.

Bang H.O., Dyerberg J., Horne N., 1976. The composition of food consumed by Greenland Eskimos. Acta Med. Scand. 200, 69-73.

Batterham E.S., Andersen L.M., Baigent D.R., Green A.G., 1991. Evaluation of meals from linola low-linolenic acid linseed and conventional linseed as protein sources for growing pigs. Anim. Feed Sci. Tech. 35(3-4), 181-190.

Bell J.M., 1989. Nutritional characteristics and protein uses of oilseed meals. In: Robbelen, G., Downey, R.K., Ashri, A. (Eds.). Oil Crops of the World. McGraw-Hill Publishing Co., New York, NY, pp. 192-207.

Bell J.M., Keith M.O., 1993. Nutritional evaluation of linseed meals from flax with yellow or brown hulls, using mice and pigs. Anim. Feed Sci. Tech. 43(1-2), 1-18.

Bhatty R.S., 1993. Further compositional analyses of flax: mucilage, trypsin inhibitors and hydrocyanic acid. J. Am. Oil. Chem. Soc. 70(9), 899-904.

Bond J.M., Julian R.J., Squires E.J., 1997. Effect of dietary flaxseed on broiler growth, erythrocyite deformability and fatty acid composition of erythrocyte membranes. Can. J. Anim. Sci. 77, 279-286.

Coates W., Ayerza R., 1998. Commercial production of chia in Northwestern Argentina. J. Am. Oil. Chem. Soc. 75(10), 1417-1420.

Codex Mendoza, 1542. Editon of Francisco del Paso y Troncoso (1925). Museo Nacional de Arqueología, Historia y Etnografía, Mexico D.F., Mexico.

Hansen J.C., 2000. Environmental contaminants and human health in the Arctic. Toxicol. Lett. 112/113, 119-125.

Helm P.A., Bidleman T.F., Stern G.A., Koczanski K., 2002. Plychlorinated naphthalenes and coplanar polychrorinated biphenyls in beluga whale (Delphinapterus leucas) and ringed seal (Phoca hispida) from the eastern Canadian Arctic. Environ. Pollut. 119, 60-78.

Holman R.T., 1998. The slow discovery of the importance of omega-3 essential fatty acids in human health. J. Nutr. 128(2), 427s-433s.

Homer P., Schaible P.J., 1980. Poultry: Feeds and Nutrition. AVI Publishing, Westport, CT.

Kung T.K., Kummerow F.A., 1950. The deposition of linolenic acid in chickens fed linseed oil. Poultry Sci. 29, 846-851.

Leaf A., Kang J.K., 1998. Omega-3 fatty acids and cardiovascular disease. The return of omega-3 fatty acids into the food supply. In: Simopoulos, A.P. (Ed.), I- Land-based Animal Food Products and Their Health Effects. S. Karger AG, Basel, Switzerland, pp. 24-37.

Lee K.H., Olomu J.M., Sim J.S., 1991. Live perfomance, carcass yield, protein, and energy retention of broiler chickens fed canola and flax full-fat seeds and the restored mixtures of meal and oil. Can. J. Anim. Sci. 71, 897-903.

Madhusudhan K.T., Ramesh H.P., Ogawa T., Sasaoka K., Singh N., 1986. Detoxification of commercial linseed meal for use in broiler rations. Poultry Sci. 65, 164:171.

Marshall A.C., Kubena K.S., Hinton K.R., Hargis P.S., Van Elswyk M.E., 1994. N-3 fatty acid enriched table eggs: a survey of consumer acceptability. Poultry Sci. 73, 1324-1340.

Mazza G., Oomah B.D., 1995. Flaxseed, dietary fiber, and cyanogens. In: Cunnane, S.C., Thompson, L.U. (Eds.), Flaxseed in Human Nutrition. American Oil Chemists' Society Press, Champaign, IL., pp. 56-81.

Neely E., 1999. Dietary Modification of Egg Yolk Lipids. Thesis. School of Agriculture and Food Science, The Queen's University of Belfast, Northern Ireland, U.K.

Novak C., Scheideler S., 1998. The Effect of Calcium and/or Vitamin D, Supplementation of Flax Based Diets on Production Parameters and Egg Composition. University of Nebraska Cooperative Extension MP 70, Lincoln, NE.

Prasad K., 1997. Dietary flax seed in prevention of hypocholeterolemic atherosclerosis. Atherosclerosis 132, 69-76.

Sahagun B., 1579. Historia general de la cosas de Nueva España. Edition of A.M. Garibay (1989), Editorial Porrua, Mexico D.F., Mexico. General History of the Things of New Spain. Edition and Translation of Anderson, J.O., Dibble, C.E. (1963), The School of American Research, The University of Utah, Santa Fe, NM.

Sinclair A.J., Oon K.S., Lim L., Li D., Mann N.J., 1998. The omega-3 fatty acid content of canned, smoked and fresh fish in Australia. Australian J. Nutrition. Diet 55(3), 116-120.

Sultana C., 1996. Oleaginous flax. In: Karleskind, A., Wolff, J.P. (Eds.), Oils and Fats Manual. Lavoisier Publishing, Paris, France, volume 1, pp. 157-160.

Svensson B.G., Nilsson A., Hansson M., Rappe C., Akesson B., Skerfving S., 1991. Exposure to dioxins and dibenzofurans through the consumption of fish. N. Engl. J. Med. 32(1), 8-12.

Toug J.C., Chen J., Thompson L.U., 1999. Dose, timing, and duration of flaxseed exposure affect reproductive indices and sex hormone levels in rats. J. Toxicol. Env. Heal. A 56(8), 555-570.

Treviño J., Rodríguez M.L., Ortiz L.T., Rebole A., Alzueta C., 2000. Protein quality of linseed for growing broiler chicks. Anim. Feed Sci. Tech. 84, 155-166.

USDA-United States Department of Agriculture, 1999. USDA Nutrient database for standard Reference, Release 13. Agricultural Research Service, Nutrient Data Laboratory Home Page. Download March 26, 2001, from the World Wide Web, "http://www.nal.usda.gov/fnic/foodcomp".

USDA-United States Department of Agriculture, 1998. Agricultural Statistics 1998. United States Government Printing Office, Washington D.C., USA.

USDA-United States Department of Agriculture, 1996. Agricultural Statistics 1995-96. United States Government Printing Office, Washington D.C., USA.

Weber C.W., Gentry H.S., Kohlhepp E.A., McCrohan P.R., 1991. The nutritional and chemical evaluation of chia seeds. Ecol. Food Nutr. 26, 119-125.

Wright T.C., McBride B., Holub B., 1998. Docosahexaenoic acid-enriched milk.in The return of omega-3 fatty acids into the food supply. In: Simopoulos, A.P. (Ed.), I- Land-based Animal Food Products and Their Health Effects, S. Karger AG, Basel, Switzerland, pp. 160-165.