14 Chia as a New Source of ω-3 Fatty Acids

Nutritional Comparison with Other Raw Materials and Its Advantages When Producing ω-3 Enriched Eggs

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Abstract

In pre-Columbian times chia was one of the basic foods of Central American civilizations, following corn and beans in terms of importance, but being more important than Amaranth. Tenochtitlan, the capital of the Aztec Empire, received between 5,000 and 15,000 tons of chia as an annual tribute from conquered nations. Chia seed was not used just as a food, but also offered to the Aztec gods. Today there are ω-3 enriched eggs on the market that are produced by adding flaxseed, chia seed, fish oil/meal or marine algae to the hen's diet. The purpose of this paper is to compare chia with these other raw materials. Available information suggests that the level of ω-3 found in chia eggs could not be reached using flax, fish oil or algae based diets without negatively affecting the hens and/or one or more of the intrinsic characteristics of eggs. In all cases a limiting factor when feeding high percentages of the other ω-3 sources is flavor, smell and/or atypical texture transmitted by these products to the eggs. In the case of flax production also decreases.

Key Words: Chia; ω-3; flax; fish; algae; eggs.

1. A LOST CROP OF THE AZTECS

In pre-Columbian times chia was one of the basic foods of Central America civilizations and followed corn and beans, but was more important than Amaranth. Tenochtitlan, the capital of the Aztec Empire, received between 5,000 and 15,000 tons of chia as an annual tribute from conquered nations *(1)*. Chia seed was not used just as a food, but was also offered to the Aztec gods *(2)*.

The use of chia in pagan religious ceremonies was one reason the Spanish conquistadors tried to eliminate it, and replace it by species brought from the old world *(2,3)*. The conquistadors were close to being successful in their crusade against such New World cultures, not just with chia but with many other crops and customs as well, as they almost disappeared. Corn and beans were an exception, they survived the conquistador's efforts and became two of the most important crops for humanity. Because of its religious use, and maybe because chia was unable to adapt to production under European climatic conditions, it was pushed into a 500 yr period of obscurity *(4)*.

From: *Wild-Type Food in Health Promotion and Disease Prevention*
Edited by: F. De Meester and R. R. Watson © Humana Press Inc., Totowa, NJ

Table 1
Oil Content and Fatty Acid Composition of Chia and Flaxseed

		*g/100 g**				
Seeds	*Oil %*	*18:3*	*18:2*	*18:1*	*18:0*	*16:0*
Chia	32.8	20.3	6.66	2.36	0.95	2.13
Flaxseed	43.3	25.4	6.32	7.32	1.3	2.25

*Per 100 g of seed.
Adapted from ref. *4*.

Chia survived only in very small cultivated patches in scattered mountain areas of southern Mexico and Central America until a research and development program was initiated in 1991. A group of growers and commercial entities, as well as technical and scientific personnel from Argentina, Columbia, Bolivia, Peru, and the United States began collaborating through the Northwestern Argentina Regional Project. 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 ω-3 fatty acids, antioxidants and fiber *(5)*.

2. ω-3 FATTY ACID SOURCES

At present there are ω-3 enriched eggs on the market obtained by adding flaxseed, chia seed, fish oil/meal, or marine algae to laying hen diets. The purpose of this chapter is to compare the performance of chia to the other raw materials.

Of these raw materials, only flax (*Linum usitatissimum L.*) and chia (*Salvia hispanica L.*) are agricultural crops. These are vegetal species having the highest concentration of ω-3 α-linolenic (ALA = 18:3) fatty acid known (Table 1)*(6–9)*.

The other two sources are of marine origin, that is algae and fish oil/meal. Both contain long chain ω-3 fatty acids, eicosahexaenoic (EPA = 20:5) acid and docosahexaenoic acid (DHA = 22:6). Comparing the four sources shows that the terrestrial ones to have a much higher ω-3 content than the marine sources (Table 2).

3. METABOLISM OF ω-3 FATTY ACIDS IN HUMANS AND POULTRY

The mechanism by which ω-3 fatty acid-rich diets reduce Coronary Heart Disease (CHD) mortality remains controversial. Recent literature discusses the role of different ω-3 fatty acids in human and animals and means of obtaining optimal levels for normal growth and development as well as for the prevention and treatment of CHD and other diseases. ALA cannot be synthesized *de novo*, that is why it is an "essential fatty acid." EPA and DHA can however be formed from ALA through the action of the desaturase and elongase enzymes.

Humans of all ages, including preterms and very likely fetuses, convert ALA to DHA *(10–12)*. This process has been reported for other species as well *(13,14)*. The efficiency of this conversion within species depends on age and diet, whereas between species it is a controversial issue *(15)*. Currently this topic is generating a lot of discussion regarding how to determine the most convenient way to provide ω-3 fatty acids to humans and animals. The main disagreement comes about because of the poor scientific knowledge that describes the biochemistry and physiologic functions of ω-3 fatty acids in general, and of ALA in particular.

Table 2
Fatty Acid Composition of Chia, Flax, Menhaden Fish, and Algae Oils

Fatty acids	*% of total fatty acids*																
oil	*14:0*	*16:0*	*16:1*[1]	*18:0*	*18:1*[2]	*18:2*[3]	*18:3*[4]	*20:3*[4]	*20:4*[4]	*20:5*[4]	*22:5*[4]	*22:6*[4]	*SFA*	*MUFA*	*PUFA*	*ω-6*	*ω-3*
Menhaden[1]	7.9	15	10.5	3.8	14.5	2.2	1.5	0.4	1.2	13.2	4.9	8.6	26.9	25	32	2.2	29.8
Algae[2,*]	17	32	7.8	1.1	4.8	–	–	–	–	0.7	8.4	27.6	50.3	12.6	36.7	–	36.7
Chía[3]	–	6.9	–	2.8	6.7	19	63.8	–	–	–	–	–	9.7	6.5	82.8	19	63.8
Flaxseed[4]	–	5.5	–	1.4	19.5	15	57.5	–	–	–	–	–	6.9	19.5	72.5	15	57.5

[1]ω-7; [2]ω-9; [3]ω-6; [4]ω-3.
*DHA Gold™ *(Schizochytrium sp.)*
Adapted from ref. *4*.

General acceptance has been that ALA fatty acids act as a precursor of the long-chain polyunsaturated fatty acids (PUFAs). This came about because the first epidemiological studies were conducted in populations with high fish intakes, and led to low estimates for ALA requirements *(16)*. Results from recent epidemiological and controlled studies regarding the role of ALA in humans and animal, are changing the way ω-3 sources are thought to work. Evidence is that vegetarians do not suffer from diets lacking DHA *(17,18)* and that ALA supplementation lowered the serum concentration of inflammatory markers in dyslipaedic subjects *(19)*. Additionally medical studies have shown that consumption of ALA is associated with a reduced risk of suffering CHD *(10,18,20–41)*.

The beneficial effects of fish oil have received much attention. However, EPA and DHA fatty acids are easily peroxidized to form hydroperoxides and their secondary degradation products which are thought to be deleterious to cells. There is strong evidence that lipid-derived aldehydes are really cytotoxic and the availability of a cellular GSH-depleting agent is critical for the detoxification of the aldehydes *(42)*. EPA and DHA are more readily oxidized and result in more toxic oxidation products than are linoleic, ALA, and arachidonic acids *(43)*. Scientific evidence shows that EPA and DHA are able to exert beneficial effects in terms of reducing the risk of suffering CHD, only if antioxidative protection against oxidative stress is sufficient to minimize the peroxidative damage of tissue lipids *(44)*.

Oxidation of food lipids is a major concern for both consumers and food manufacturers. If not controlled, oxidation can produce not only food off-flavors (typically known as fishy flavor), but also promote aging and the degenerative diseases associated with aging such as cancer, cardiovascular diseases, cataracts, immune system decline, and brain dysfunction *(45)*.

Chia as an ω-3 source does not require the use of artificial antioxidants such as vitamins. Antioxidant vitamins have been shown to nullify the protector effects of cardiovascular drugs. Research has found that a combination of antioxidant vitamins such as vitamin E, vitamin C, and β-carotene blunt the rise in high-density lipoprotein (HDL) cholesterol levels seen with the drug simvastatin *(46)*. Also, vitamin E has been demonstrated to promote oxidation processes when an upper level is exceeded. The problem is that the low and high limits are too close together, making it very difficult to obtain a correct amount for ingestion when ingredients are mixed for animal feed *(47)*. An advantage of ALA from a plant source over ω-3 fatty acids derived from fish/algae products is that insufficient antioxidant intake does not exist with higher intakes *(15,48)*.

Another concern with recommendations that have been made to increase the intake of EPA as a source of ω-3 fatty acid is the potential for adverse immunological effects resulting from excessive intakes. Moderate to high amounts of EPA, but not ALA, can decrease natural killer (NK) cell activity in healthy subjects *(49)*. NK cells play an important role in host defense against virus infections and in inmunosurveillance against tumor cells *(50)*.

High amounts of DHA can also inhibit the action of Δ_5 and Δ_6 enzymes working on the essential fatty acid, linoleic (ω-6) and ALA (ω-3). Although this action will not affect the total number of ω-3 long chain fatty acids it will cause an imbalance in the ω-6:ω-3 ratio which is considered vital for good function of the human body, including prevention of CHD *(51–55)*.

Table 3
Total ω- Fatty Acid Content and α-Linolenic:DHA Ratios in Eggs Produced by Hens Fed Two Levels of Chia

Fatty acid[1]	*mg/egg*			
diet	*18:3*	*22:6*	*ω-3*	*22:6 : 18:3*
Chia 7%	231	123	354	1:1.9
Chia 14%	438	138	576	1:3.2

[1]Eggs from H&N white hens at 27 weeks age.
Adapted from ref. *14*.

Egg yolks from hens fed chia-enriched diets show a significant increase not only in ALA, but in DHA as well. As in humans, poultry showed the capacity to produce DHA through the desaturation and elongation of ALA, as chia seed lacks DHA (Table 2).

Different organizations involved in human healthcare have made recommendations for the minimum consumption of ω-3 fatty acids which should take place, but these only include ALA the precursor of the other two *(55–59)*. A position paper which The European Society for Pediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) published in November 2005 gave recommendations for nutrition levels in infant formulae. ESPGHAN set minimum and maximum levels of ALA in infant formulae at 0.3 and 1.2 g/100 kcal, respectively. DHA is listed only as an optional addition, and should not exceed 0.05% of total fat (4.4–6.0 g/100 kcal) intake, arachidonic fatty acid should be at least equal to the concentration of DHA, and EPA should not exceed DHA content *(60)*.

Although there are variations between the recommendations made by nutritionists regarding the relationhip among different ω-3 acids in the diet, especially between DHA and ALA, nutritionists agree that the ALA content must be significantly higher than the DHA content because that is how these fatty acids are found in human milk. Breast milk has a DHA:ALA ratio of, 1:2.1; 1:2.2; 1:2.2; 1:3.3; 1:3.6; 1:3.6; 1:4;1:8; and 1:10.2 in women from Cuba, Germany, France, Nigeria, Argentina, Japan, China, and Nepal, respectively *(61–66)*. Breast milk of women eating a traditional fish-rich diet in East Africa (Tanzania) has a DHA:ALA ratio of 1:1.6 *(67)*. In the United States. DHA:ALA ratios in breast milk from women living in Maryland, Connecticut, and Oklahoma were found to be 1:4.4; 1:2.1 and 1:5, respectively *(68,69)*. Thus in human milk, fatty acid contents vary. In the case of DHA, the observed variations go from 0.04 to 0.25% of total fatty acids *(70)*, and the ALA level was always significantly higher than the DHA content.

Eggs from hens fed 7% chia diets have an ALA:DHA ratio similar to that found in milk of woman from countries where smaller ratios were recorded, that is Cuba, Germany, and France. The DHA:ALA ratios of the eggs (Tables 3 and 4) are almost equal to those (1:1.6) of women consuming a traditional fish-rich diet in East Africa. This ratio has been suggested as being close to that of early *homo sapiens* because of the similarity of their lifelong consumption of East-African fish-based foods *(67)*. The DHA:ALA ratios also are similar to those of eggs from hens raised under free range conditions and consuming green leafy vegetables, fresh and dried fruits, insects and occasional worms *(71)*.

Research has shown that eating regular eggs compared to ω-3 enriched eggs reduces the risk of CHD by lowering plasma triglyceride and cholesterol contents as

Table 4
Cholesterol, Total Fat, Total ω-3 Fatty Acid, α-Linolenic and DHA Content of Eggs Produced by HR White and HR Brown Hens Fed 5 Different Levels of Chia[1]

Chia	*Total fat*	*mg/100 g**			
%	*g/100 g**	*Cholesterol*	*ω-3*	*18:3*	*22:6*
0	9.25	412	95	32	62
7	8.98	318	606	376	231
14	8.62	384	983	812	171
21	9.44	368	1286	1111	175
28	9.29	355	1580	1454	127

[1]Average of eggs from H&N brown and H&N white hens at 27 weeks age.
*Per 100 g of egg, without shell.
Adapted from ref. *14*.

well as blood pressure. Regular eggs, on the other hand, increase these parameters and therefore increase the possibility of CHD *(72–75)*. ALA enriched eggs also significantly reduce platelet aggregation compared with DHA enriched eggs, hence an independent mechanism for dietary ALA-induced reduction of platelet aggregation has been suggested *(76)*.

Reductions in total saturated fatty acids in general, and in palmitic fatty acid (up to 30.6%) in particular, in eggs from hens fed chia-enriched diets compared with eggs from hens fed control diets were significant *(14,77)*. Chia also provided a greater reduction in palmitic fatty acid content than other ω-3 sources when added to the hen diet. Two comparative trials that fed hens ω-3 enriched diets showed eggs from hens fed chia were 16 and 18% lower in palmitic fatty acid than those from hens fed fish oil (Table 5 and 6). Because palmitic and stearic acids are more than 95% of the total saturated fatty acid content of hen eggs, and stearic fatty acid is considered much less hypercholesterolemic than palmitic or not hypercholesterolemic at all *(78–81)*, the reduction in palmitic fatty acid content is more important than a reduction in total saturated fatty acid content in terms of improving the nutritional quality of eggs. Chia has also reduced the palmitic fatty acid content in other animals as well *(13,82)*.

Two trials have shown no differences in palmitic (Table 6) or total saturated (Table 7) fatty acid content of eggs from hens fed either chia or flaxseed enriched diets. As recent research suggests that the reduction of palmitic fatty acid content in egg yolk is feed dependent *(14,83)*, then the lower palmitic content of eggs from hens fed chia and flaxseed enriched diets compared with eggs from hens fed fish oil could be related to the lower palmitic fatty acid content of chia and flaxseed compared with fish oil (Table 2). This beneficial effect gives terrestrial sources of ω-3 fatty acids a dramatic advantage compared with fish and algae products that are very high in palmitic fatty acid, and indicates an additional health advantage for these ω-3-enriched eggs.

4. ω-3 FATTY ACID LEVELS IN COMMERCIAL EGGS

Table 8 lists some of the ω-3 eggs that are available in selected countries of Africa, European Union, and the Americas. The Mega-3 egg, obtained by including 14% chia in the layer diet, contains one of the highest ω-3 contents (1120 mg/100g's of egg

Table 5
Fatty Acid Composition of Egg Yolk Lipids Produced Using Fish Oil (1.6%) and Chia Seed (14%) as Sources of ω-3 Fatty Acid

	Diets			
	Control	*Fish oil*	*Chia*	*Statistical*
Fatty acids	*% of total fatty acid*			*significance*
16:0	28.49[a,1]	28.88[a]	24.17[b]	***
SFA	41.27[a]	41.17[a]	37.01[b]	***
MUFA	32.74[a]	34.83[b]	28.56[c]	***
ω-3	5.05[a]	7.21[b]	16.16[c]	***
ω-6	18.88[a]	14.41[b]	16.32[c]	***
PUFA	23.93[a]	21.61[b]	32.48[c]	***

[1]Means within a row with no common superscript letter are significantly different ($p < 0.05$) according to the Least Significant Difference (LSD).
*** $p < 0.001$.
Adapted from ref. *84*.

Table 6
Cholesterol, Total Fat, Saturated Fatty Acid, and ω-3 Fatty Acid Content of Eggs Produced by Hens Fed 5 Different ω-3 Diets[1]

	Fat	*mg/100 g**							
Diet	*g/100 g**	*Cholesterol*	*16:0*	*SFA*	*ω-3*	*18:3*	*22:6*	*ω-6*	*ω-6:ω-3*
Commercial EB	7.84	368	1719	2500	206	80	122	1062	5.2:1
14% Flax	7.10	354	1580	2180	548	388	138	952	1.8:1
Fish meal	7.92	380	1924	2600	438	160	248	951	2.2:1
14% Chía	7.72	362	1567	2280	948	750	158	1202	1.3:1
Purina layena	8.18	412	1918	2640	204	114	82	1341	6.7:1

[1]Average of eggs from brown and white hens.
*Per 100 g of egg, without shell.
Adapted from ref. *116*.

without shell) of all commercially available eggs (Table 8). However the Mega-3 egg content is far below the potential shown by chia (Table 4), and which has taken place without causing problems in hen development, egg production, or in the flavor, smell, or texture of the eggs *(14,77,83,84)*.

A number of trials were conducted to compare chia and other sources of ω-3 fatty acids. In general they show the advantage of chia over other additives including fish oil and flax for the production of ω-3 eggs (Tables 5 and 6). One recently published research report *(83)* shows the negative effects flax has on egg production when added to a chia enriched diet. The advantage of chia over flaxseed was also shown with broilers as well. This experiment, which compared chia and flaxseed as ω-3 fatty acid sources for poultry meat production, showed significantly ($p < 0.01$) less weight gain in birds fed flaxseed, than in birds fed chia or the control diet *(85)*.

Table 7
Cholesterol, Total Fat, Saturated, ω-6, and ω-3 Fatty Acid Content From Shaver White Laying Hens Fed 4 Different Flax–Chia Diets

Chia	*Flax*	*Fat*	*mg/100 g**						
%	*%*	*g/100 g**	*Cholesterol*	*SFA*	*ω-3*	*18:3*	*22:6*	*ω-6*	*ω-6:ω-3*
0	0	$10.75^{a,b}$	405^{a}	$3630^{a,b}$	199^{c}	81^{c}	$118^{a,b}$	2200^{a}	$11.1{:}1^{a}$
9	5	9.25^{c}	351^{a}	3020^{c}	1009^{b}	846^{b}	164^{a}	2146^{a}	$2.1{:}1^{b}$
11.5	2.5	$9.75^{b,c}$	407^{a}	3080^{c}	1250^{a}	1143^{a}	107^{b}	2276^{a}	$1.8{:}1^{b}$
14	0	9.50^{c}	359^{a}	$3190^{b,c}$	1209^{a}	1112^{a}	97^{b}	2120^{a}	$1.7{:}1^{b}$

*Per 100 g of egg, without shell. Means within a grouping lacking a common subscript differ ($p < 0.05$) according Duncan's Multiple range Test.

Adapted from ref. *83*.

If one compares the ALA content of flax and chia (Table 1) with the amount of ω-3 fatty acid incorporation that takes place in eggs, it can be seen that chia converts much more efficiently, almost 230% that of flax (Table 7). Table 6 also supports this, because chia gave a higher conversion efficiency than flaxseed, producing 217% the deposition/unit of ALA added to the diet, compared with flax. In another trial 119% higher ω-3 fatty acid deposition was found in the meat from broilers fed chia, than in that from broilers fed flaxseed *(85)*. The differences in deposition could be related to the different antioxidants found in flax and chia, and their subsequent influence on fatty acid incorporation. This effect has been suggested by Azcona et al. *(85)*, and by Ayerza and Coates *(83)*. Ajuyah et al. *(86)* observed that addition of antioxidants to broiler diets caused a significant increase in ω-3 fatty acid incorporation into white meat. Interestingly they also observed that the antioxidants did not decrease the negative effects flax had on body growth.

Differences in fatty acid deposition efficiency could also be related to the digestion process of the lipids. Numerous factors are capable of causing variations in intestinal absorption and tissue deposition of fat and fatty acids in nonruminants. These dietary factors include: saturated:unsaturated fatty acid ratio *(87)*; monounsaturated fatty acid plus polyunsaturated: saturated fatty acid ratio *(88)*; and total ω-6:ω-3 fatty acid ratio *(89)*. Digestive utilization of fatty acids varies according to the FA position on the glycerol molecule, hence differences in the ALA positions of chia and flax could explain the higher ω-3 fatty acid incorporation of chia compared with flax *(87,90,91,92)*.

Tables 6 and 7 present incorporation rates of ω-3 fatty acids when whole chia and flaxseed were fed to hens. When ground chia and flaxseed were fed to broilers, ω-3 fatty acid deposition in the meat was only 119% higher per unit of ALA in the broilers fed chia, than that in the birds fed flax *(85)*. Interestingly when whole and ground flaxseed were fed to hens, significant differences in egg yolk flavor were still found *(93,94)*. Given the chia-flax deposition differences obtained between eggs (Tables 6 and 7) and broiler meat it would seem that grinding could reduce the deposition efficiency when used to produce eggs as well.

There was a decrease in deposition differences when flaxseed and chia seeds were ground and fed to poultry. However, given the oxidation and off-flavor problems affecting animal performance and final product quality with flax, combined with the problems of grinding, feeding whole seed is preferred. This gives chia a significant advantage over flax as source of ω-3 fatty acid.

Table 8

Cholesterol, Total Fat and ω-3 Fatty Acid Content of Egg Yolk of Commercially Produced ω-3 Enriched Eggs Obtained From Selected Countries of Africa, European Union, and The Americas

Brand	*Country*	*Cholesterol mg/100 g**	*Total fat g/100 g**	*mg/100 g**					*ω-3 source*
				ω-3	*18:3*	*22:6*	*20:5*	*22:6 + 20:5*	
Avine	Brazil	n/a	9	418	n/a	n/a	n/a	n/a	Flaxseed
Columbus	UK	n/a	10.5	1200	n/a	n/a	n/a	n/a	Flaxseed oil
Columbus	France	n/a	10	1500	n/a	n/a	n/a	n/a	Flaxseed oil
Egg plus	USA	430	9	400	200	200	0	n/a	Flaxseed + fish oil
Gold circle	USA	430	9	350	0.00	350	0.00	n/a	Algae
Golden Premium	USA	450	n/a	378	46	239	93	n/a	Fish oil
Eggland's Best	USA	380	8	100	n/a	n/a	n/a	n/a	Canola
Mega-3	Argentina	384	9.2	1120	964	156	0	n/a	Chía
La Piara	Argentina	384	8.9	500	n/a	n/a	n/a	n/a	Chia
Naturegg	Canada	370	9.8	760	n/a	n/a	n/a	n/a	Flaxseed
Maple	Canada	354	9.6	620	n/a	n/a	n/a	n/a	Flaxseed
Born 3	Canada	312	9.8	800	n/a	n/a	n/a	n/a	Flaxseed
Maritime Pride	Canada	354	9.3	620	n/a	n/a	n/a	n/a	n/a
Dietazul	Spain	328	9	266	0.00	n/a	n/a	266	Fish oil
Pitas Pitas	Spain	n/a	n/a	280	0	260	20	n/a	Fish oil
Newstart	South Africa	280	9.5	620	300	250	70	320	Fish oil
SuperEgg	Ireland	n/a	11	228	0	228	0	228	Fish oil
Ovito Piu	Italy	n/a	8.7	350	n/a	280	n/a	n/a	Algae

Notes: n/a: not available.

*per 100 g of egg, without shell.

Ayerza and Coates *(83)* reported that hens fed ALA enriched diets made from a chia-flaxseed mixture produced significantly ($p < 0.05$) different ω-6:ω-3 ratios compared with the control diet. A negative relationship between dietary ALA content and egg ω-6:ω-3 ratio was observed, with the source of ALA having an effect. The higher the chia content, the lower the ω-6:ω-3 ratio. The ratio tended to increase when chia was replaced with flaxseed, however the differences were not statistically significant ($p < 0.05$). This source effect is demonstrated in Table 6, and shows that hens fed chia enriched diets produced eggs having ω-6:ω-3 ratios which were 28 and 41% lower than those of hens fed flaxseed and fish oil, respectively. Neely *(84)* reported ω-6:ω-3 ratios of 3.7:1; 2:1 and 1:1 for egg yolks of hens fed control, fish oil and chia enriched diets, respectively.

Today there is an abundance of evidence supporting the fact that high ω-6:ω-3 ratios of dietary fatty acids, rather than serum cholesterol, are a major risk factor in terms of suffering CHD *(95)*. A reduction in dietary ω-6:ω-3 fatty acid ratios, bringing them closer to the nutritional needs as determined by our genome and (a ratio of 1:1), is considered very important for good health and normal development *(96,97)*.

5. ORGANOLEPTIC CHARACTERISTICS

Eggs produced by hens fed flaxseed have a characteristic (unpleasant) smell, similar to that of hens fed fish oil *(47,98–104)*. In the United States, a study of five cities showed that consumers generally were reluctant to consume eggs smelling/tasting of fish *(105)*. The absence of atypical organoleptic characteristics in eggs produced by hens fed chia represents a significant advantage for this grain, compared with flax and fish by-products *(77,83,106)*.

The difference in organoleptic characteristics of eggs produced using flax and chia could result from the powerful action of the antioxidants in chia which are absent in flax *(107–110)*, and/or to the interaction between other components in flax and bird physiology *(111)*. In the case of fish oil the smell results from the greater instability of DHA and EPA than ALA, combined with an absence of antioxidants capable of preventing degenerative processes *(112,113)*.

In the case of marine algae available literature reports no fish smell or taste in eggs produced using this product as a feed. However, no published scientific papers have been found which support this statement. An indirect reference about off-flavors in eggs produced by hens fed algae is contained in a nonscientific paper written by Abril et al. *(114)*. They mention that including up to 1% algae in laying hen diets did not significantly decrease overall egg acceptability in terms of aroma and/or flavor. Although no scientific information appears to be available to support or refute the presence of off-flavors, the high content and known instability of DHA would logically lead one to assume that algae would transmit undesirable organoleptic characteristics to eggs when large quantities are consumed by hens.

Not all, but some, marine algae have shown antioxidant activity related to total polyphenol content. It has been suggested that polyphenol could prevent oxidative damage to important biological membranes. However, commercially produced algae shows very low antioxidant capacity. The decrease could be related to drying (50°C for 48 h) of the algae during commercial production. Jimenez-Escrig et al. *(115)* reported that

processing (drying) and storing decreases the antioxidant content of fresh algae. Thus the difference in shelf life between chia and algae may be associated with the difference in the quantity and/or quality of natural antioxidants in each.

In summary, several studies provide solid evidence that including more than 5% flaxseed, 1.5% fish oil, or 1% algae in laying hen diets will result in a significant decrease of egg acceptability in terms of aroma and/or flavor. It is possible, however, to include up to 30% chia in the diet without encountering any negative consumer preferences. This means maximum ω-3 fatty acid enriching potentials (mg/egg) of: 175 for algae, 207 for fish oil, 214 for flaxseed, and 986 for chia seed without affecting egg organoleptic characteristics *(14,93,99,106,114)*.

6. CONCLUSION

Available information suggests that none of the levels of ω-3 enrichment that chia can produce could be reached using flaxseed, fish oil or algae based diets without strongly affecting hen performacnce and/or one or more of the intrinsic characteristics of eggs. The limiting factor for utilization of high percentages of available ω-3 sources, with the exception of chia, is change in the flavor, smell and/or texture transmitted by these products to the eggs. Also in the case of flaxseed, egg production would be negatively affected.

Chia, when used as feed for laying hens holds great potential. This is true not only in producing eggs having a high level of ω-3 fatty acids lacking off-flavors and without affecting production parameters, but also by producing eggs having lower saturated fatty acid contents and better ω-6:ω-3 ratios than those produced by hens fed other ω-3 fatty acid sources.

Modern science thus explains why chia was one of the four most important foods not only for the Aztec and Mayan civilizations, but for millions of other Mesoamerica's inhabitants as well. As a result, chia seed has become an alternative to flaxseed and marine sources for the production of more acceptable eggs for the health conscious consumer.

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