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Omega-6 (n-6) and omega-3 (n-3) fatty acids in tilapia and human health: a review

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Omega-6 (n-6) and omega-3 (n-3) fatty acids in tilapia and human health: a review

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Abstract
A recent publication questions the nutritional value of tilapia in the human diet following the movement to eat fish for their omega fatty acid (FA) content. It suggests that tilapia have an elevated amount of omega-6 FAs (n-6) and a deficient amount of omega-3 FAs (n-3), a possibly unhealthy proportion for humans. A high n-6:n-3 ratio is problematic because too much arachidonic acid, an n-6 FA, promotes inflammation, which aggravates heart disease and other illnesses. This paper analyzes the numbers from different tilapia composition studies in an effort to understand the range of n-6 and n-3 totals and ratios present in both farmed and wild tilapia. Generally, wild tilapia have more n-3 FAs than farmed tilapia, but diet adjustments can alter the body composition of the domesticated variety. Consumers should consider fish as part of a balanced diet and evaluate their FA needs on an individual basis.

Keywords: *Human health, omega-3 polyunsaturated fatty acids, tilapia*

Introduction

With increased incidence of cardiovascular disease, the fatty acid (FA) content and composition of fish, particularly the omega FAs, have become important nutritional elements in relation to human heath. However, scientific findings have moved beyond statements that all fish will provide us with omega FAs (specifically omega-6 and omega-3). The research has turned to *which* fish provide us with the correct amount of *which* type of omega FAs. With the recent questions lingering about the health benefits of tilapia, the answers can be found in reviewing the results of several studies. The purpose of this paper is to compile the findings of various tilapia studies for comparison of the omega-6 (n-6) and omega-3 (n-3) FA composition of tilapia.

A brief review of FAs is helpful. FAs are long, straight-chain carboxylic acids found in fats and oils (McMurry 2004). FAs are characterized as saturated (no double bonds), monounsaturated (one double bond), or polyunsaturated (more than one double bond). The omega FA families of concern here (n-6 and n-3) are polyunsaturated fatty acids (PUFAs) but are derived from two different C18 (18-carbon chain) FAs. 'The n-6 series are derived from linoleic acid (LA), and the n-3 series are derived from α-linolenic acid (ALA)' (Steffens 1997, page 97), the structures of which are shown in Figure 1. Arachidonic acid (AA) is an n-6 FA. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) seem to be the n-3

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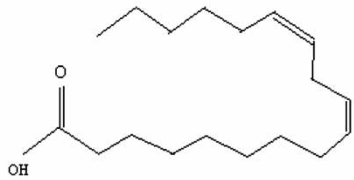
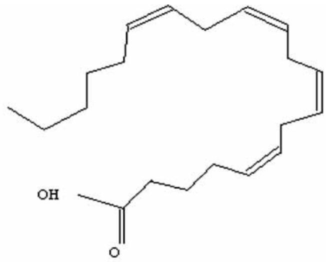


Linoleic acid (LA)
Adapted from Brooks (n.d.).



Arachidonic acid (AA)
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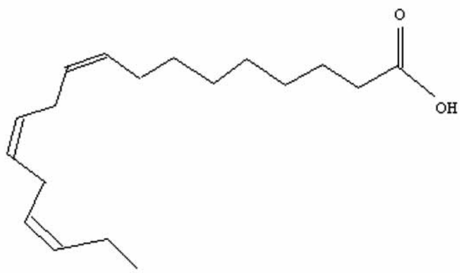
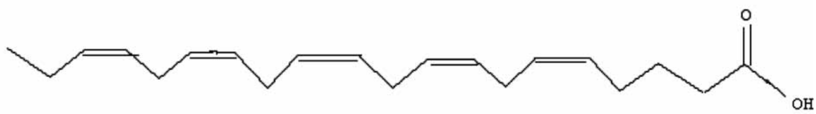
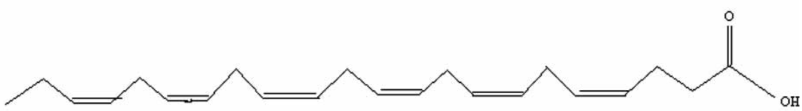


Alpha-linolenic acid (ALA)
Adapted from Dickinson College (n.d.).



Eicosapentaenoic acid (EPA) (20:5 n-3)
Adapted from Lansbury Research Site, Harvard University (n.d.).



Docosahexaenoic acid (DHA) (22:6 n-3)
Adapted from Lansbury Research Site, Harvard University (n.d.).

Figure 1. Chemical structures of linoleic acid (LA), α-linolenic acid (ALA), arachidonic acid (AA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Often the FAs are referred to by number combinations, such as 18:2, instead of by their name. The first number indicates the number of carbons in the chain and the second number indicates the number of double bonds. LA has 18 carbon atoms and 2 double bonds; thus 18:2. The '-6' and '-3' designation indicates at which carbon-to-carbon bond from the methyl (CH_3) end the first double bond occurs.

FAs most relevant to this argument. These structures can also be found in Figure 1. Figure 2 breaks down the C18 PUFAs and the metabolic derivatives important to this discussion.

Essential fatty acids (EFAs) are those that organisms must obtain from their diet because they cannot synthesize them in the body. Both n-6 and n-3 FAs are EFAs for humans, but there are several foods other than fish that provide us with n-6, such as

18:2*n-6* linoleic acid (LA) → 20:4*n-6* arachidonic acid (AA)

18:3*n-3* α- linolenic acid (ALA) → 20:5*n-3* eicosapentaenoic acid (EPA) → 22:6*n*-3 docosahexaenoic acid (DHA)

Figure 2. PUFA categorization. There are several different n-6 and n-3 PUFAs. However, this figure only shows the categorization and the metabolic derivatives of the FAs relevant to this discussion.

grains, poultry, and eggs. AA is found exclusively in animal products and is important in tissue composition (Whelan 1996). n-3 FAs are primarily found in cold water fish.

The controversy revolves around the n-6:n-3 ratio. It is thought that there is competition between these two PUFA families that slows the formation of eicosanoids (Lands 1986) (Figure 3), including prostaglandins, thromboxanes, and leucotrienes, which are all thought to be responsible for several negative physiological effects (McMurry 2004). Prostaglandins are biosynthesized in nature from the C20 AA and 'can lower blood pressure, affect blood-platelet aggregation during clotting, lower gastric secretions, control inflammation, affect kidney function, affect reproductive systems, and stimulate uterine contractions during childbirth ... [and] the release of thromboxanes and leukotrienes triggers asthmatic response' (McMurry 2004, page 1034). Ingesting a larger proportion of n-6 than n-3 FAs disrupts this beneficial competition, increasing the risk of harmful effects. It is thought that increasing the amount of dietary EPA and DHA inhibits the production of these antagonistic eicosanoids, establishing equilibrium.

The typical American diet in particular consists of high amounts of AA and 14–25 times more n-6 than n-3 FAs (University of Maryland Medical Center n.d.). Because of this, there is concern that tilapia is less beneficial than other food fish because it contains higher amounts of n-6 FAs than n-3. However, there are certain factors that affect the FA composition of tilapia.

Diet is the main factor affecting the n-6 and n-3 FA content in tilapia, but location, species, and environmental conditions may also play a role. Whether the diet is natural (i.e. wild tilapia) or compounded (i.e. farmed tilapia), '[t]he fatty acid (FA) composition of fish muscle is clearly influenced by their diet' (Justi et al. 2003, page 489). Fish muscle composition directly reflects their food source; their flesh will not have any nutritional value to humans beyond what their diet can offer. Freshwater

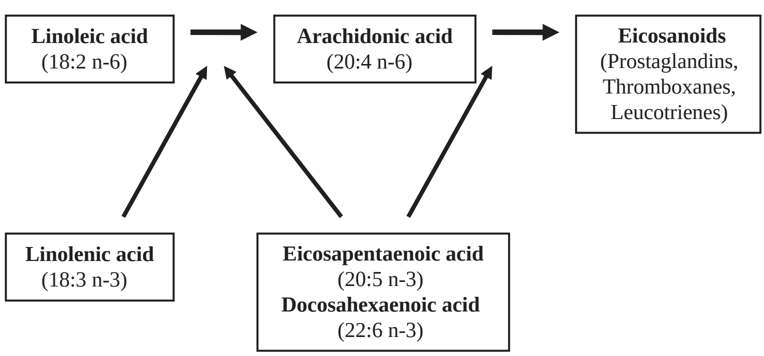


Figure 3. Interference between n-6 and n-3 fatty acids in the formation of eicosanoids. (Modified from Steffens 1997.) It is thought that n-3 FAs impede the formation of harmful eicosanoids and that a high dietary intake of n-6 FAs overrides this beneficial interference.

Table I. n-6 and n-3 totals in percentage total fatty acids from various tilapia studies.

Citation	Total n-6	Total n-3	Citation	Total n-6	Total n-3
Corporate data, internal documents, 2009			USDA (n.d.)	12.33	11.288
Sample 1	11.1	4	Hearn et al. (1987)	13.1	20.7
Sample 2	10.1	5.7	Suloma et al. (2008)	17.69	27.07
Sample 3	10.5	8	Zenebe et al. (1998)		
Sample 4	8.4	7.6	Lake 1—Ziway	13.975	22.050
Justi et al. (2003)			Lake 2a—Langeno1	12.271	30.198
0 days	38.7	3.64	Lake 2b—Langeno2	11.443	31.841
10 days	37.81	4.74	Lake 3—Chamo	15.184	24.068
20 days	35.3	6.15	Lake 4—Awassa	12.009	18.587
30 days	33.4	7.77	Lake 5—Haiq	4.385	27.181
Weaver et al. (2008)	22	8			

algae, the natural diet for freshwater fish like tilapia, generally contain 18:3(n-3). 'The lipids of freshwater feeds [compounded diets for farmed fish] are [generally] characterized by linoleic (C18:2n6), α-linolenic (C18:3n3), and EPA' (Henderson and Tocher 1987; Justi et al. 2003, page 489).

The data being compared in the present paper come from published studies, four commercial analyses, and US Department of Agriculture (USDA) data. The raw data for the graphs (n-6 and n-3 totals and the ratios of the two parameters) are presented in Table I and II. It is recognized that region, diet, sampling methods, and sample testing may differ between studies and may account for deviations. Justi et al. (2003) analyzed the FA composition of farmed tilapia while feeding them a diet supplemented with flaxseed oil (to make it n-3 rich). This diet was fed for 20 days. It is clear from both data plots that the supplemental diet made the FA composition and ratio more favorable (smaller n-6:n-3). Weaver et al. (2008) used an unrepresentative, non-random sample of tilapia to determine that the ratio of n-6 to n-3 is ' >2.5'. The absolute numbers used in the plots were estimated from the study's charts because no raw data were included. This same paper includes a plot of the amount of n-3 FAs in several types of fish, where tilapia is two-thirds up the list—by no means the 'worst' fish to consume. Two-thirds of the 30 fish sampled have fewer milligrams of n-3 FAs/100 g fish. Although the type of

Table II. Ratios of n-6 and n-3 in tilapia.

Citation	n-6:n-3	n-3:n-6	Citation	n-6:n-3	n-3:n-6
Corporate data, internal documents, 2009			USDA (n.d.)	1.092	0.916
Sample 1	2.780	0.360	Hearn et al. (1987)	0.625	1.6
Sample 2	1.766	0.566	Suloma et al. (2008)	0.654	1.53
Sample 3	1.307	0.765	Zenebe et al. (1998)		
Sample 4	1.319	0.758	Lake 1—Ziway	0.625	1.6
Justi et al. (2003)			Lake 2a—Langeno1	0.380	2.633
0 days	10.9	0.092	Lake 2b—Langeno2	0.333	3
10 days	8.26	0.121	Lake 3—Chamo	0.612	1.633
20 days	5.81	0.172	Lake 4—Awassa	0.612	1.633
30 days	4.34	0.230	Lake 5—Haiq	0.155	6.467
Weaver et al. (2008)	2.5	0.4			

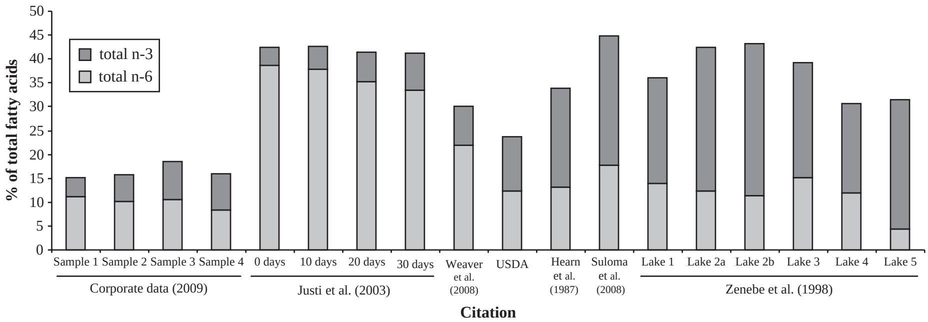


Figure 4. Comparison of total n-6 and n-3 fatty acids in tilapia. Raw data presented in Table I.

preparation is unclear, according to the USDA data the amount of n-3 increases in cooked tilapia (USDA n.d.). Hearn et al. (1987) analyzed the body composition of tilapia from an Atlanta fish market. It is not clear whether the fish were farmed or wild. Suloma et al. (2008) compared the lipid content of wild tilapia. The location also affects the n-6 and n-3 FA content of wild tilapia because diet changes with location. The natural diet varies by region, even by areas in close proximity to one another. Zenebe et al. (1998) compares the regional variation of FA and lipid content of tilapia in five different lakes in Ethiopia. The food source in these lakes, the phytoplankton, has a profound effect on the tilapia body composition in terms of FAs.

Figure 4 compares the omega FA totals from these studies. It is evident that wild tilapia have a greater amount of n-3 than n-6 FAs. Farmed tilapia have much less n-3, but the amount of n-6 is comparable with that in wild tilapia. Even in the Justi et al. (2003, page 492) study, n-6 decreases and n-3 increases over a 1-month period of feeding an omega-3-rich diet. The results would show stronger differences after several months.

As consumers, we take wild fish as they come, but the body composition of farmed fish can be altered. Fish feed can be supplemented with protein and lipids to make the body composition more favorable for humans and to promote maximum growth. Justi et al. (2003, page 492) report that the *Oreochromis niloticus*, which 'received, during 30 days [the longest exposure], a diet with the addition of flaxseed oil [high in n-3 fatty acid] presented the highest index for n3 PUFA and the best n6/n3 ratio'. This trend can be seen in Figure 4 and 5. It is logical to expect that, over time, the n-3 FA content would increase, and therefore the n-6:n-3 ratio would improve. This shows that it is

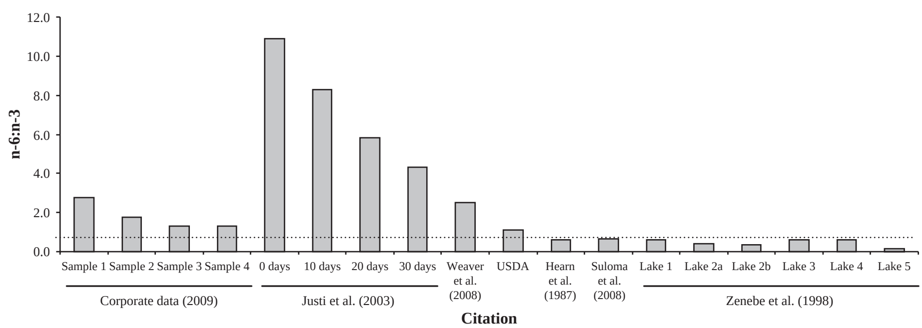


Figure 5. Comparison of n-6:n-3 in tilapia. Raw data presented in Table II.

possible to favorably change the body composition of tilapia through changes in diet (Steffens 1997). Sargent et al. (1989, page 182) agree: 'It is technically possible to produce a fish with a ratio of n-3/n-6 polyunsaturated FAs that is optimal for human nutrition'.

It is important, however, not to neglect the health of fish as dietary changes are made. Just as humans consider EFAs, fish farmers consider the EFAs of tilapia. They want fish to provide the nutrition humans need and also be healthy. Teshima et al. (1982) report the highest weight gain in *Tilapia nilotica* with diets of 1% 18:2n6 (LA) or 20:4n6 (AA), indicating that '*T. nilotica* requires n6 fatty acids such as 18:2n6 and 20:4n6 rather than n3-fatty acids in contrast to other fishes'. A similar study performed by the same authors (Teshima et al. 1980) found that *Tilapia zillii* requires 18:2n-6 and 20:4n-6 as EFA also. Sargent et al. (1995) also concedes that 18:2*n-6* is an EFA for both species. This could explain why there is more n-6 than n-3 in the farmed tilapia. However there are studies that show the opposite—that better growth occurs with feeds supplemented with n-3 FAs (Yone 1978). The challenge is finding a balance between the nutritional needs of the fish and the alterations that can be made for optimal human nutrition.

Figure 5 shows the ratios of n-6 to n-3 FA totals from the compared studies, even though the ratio is an ambiguous and unreliable number. The majority of these studies show small n-6:n-3 ratios close to 1. A ratio of 2.5 is too large to be healthy according to Weaver et al. As shown in Figure 4, there is a positive effect of feeding tilapia the diet supplemented with n-3 FAs, where a finishing diet would drive the ratio even lower. This figure shows that the natural diet provides n-6:n-3 ratios <1.

Weaver et al. (2008) also report an AA:EPA ratio of 11:1. This number is misleading and proves the effect that number manipulation has on the public. Whelan (2009) shows that DHA, not EPA, has proven effects to lower the risk of cardiovascular disease. The amount of DHA in tilapia in these studies is consistently higher than EPA. A ratio of AA:DHA would be much lower and more accurate and more relevant to human health.

In order to evaluate the FA composition findings of these studies, several conversions were performed to arrive at numbers that could be compared at face value. Table III presents the data in its original reported form. It is no wonder the ratio is used; it is the easiest way to compare results between studies. However, in terms of human health, the ratio is a misleading way to report data. With a ratio, it is impossible to know whether the actual amounts are large or small. The magnitude of these numbers is important because the human body deals with absolute amounts. We can appreciate the confusion that the public must feel when the data are not reported in a consistent manner and, therefore, are difficult to compare.

To avoid the negative perception and the confusion that this controversy has caused, it would help to know the amount of n-6 and n-3 (and specific FAs) humans require. The experts cannot agree. In a 2007 food labeling proposal by the Food and Drug Administration, it is suggested that a 'good source' of n-3 FAs should have between 130 and 160 mg of ALA per reference amount customarily consumed (Food and Drug Administration 2007). Steffens (1997, page 111) states that '[o]ptimum requirements are assumed to be 0.3-0.4g/day of long-chain n-3 polyunsaturated fatty acids (Singer, 1989, 1994). Under deficiency conditions, the demand may even be considerably higher. In a balanced diet the n-3/n-6 polyunsaturated fatty acid ratio should be approximately 1:10.' The University of Maryland Medical Center (n.d.)

Table III. Raw data from various tilapia FA composition studies.

Citation	Total PUFA	Total n-6	Total n-3	n-3:n-6	n-6:n-3
Corporate data, internal documents, (2009)					
Sample 1	15.2% in fat	258 mg/100 g	92.8 mg/100 g	0.360	2.780
Sample 2	15.7% in fat	226 mg/100 g	128 mg/100 g	0.566	1.766
Sample 3	18.6% in fat	132 mg/100 g	101 mg/100 g	0.765	1.307
Sample 4	17.5% in fat	215 mg/100 g	163 mg/100 g	0.758	1.319
Justi et al. (2003)[a]					
0 days	44.7 ± 1.45	38.7 ± 1.40	3.64 ± 0.30	0.0917	10.9 ± 0.97
10 days	44.9 ± 2.88	37.81 ± 2.77	4.74 ± 0.78	0.121	8.26 ± 1.49
20 days	43.7 ± 2.09	35.3 ± 1.98	6.15 ± 0.64	0.172	5.81 ± 0.69
30 days	43.2 ± 2.24	33.4 ± 1.85	7.77 ± 1.25	0.23	4.34 ± 0.74
Weaver et al. (2008)				~0.4	~2.5
USDA (n.d.)	0.387 g/100 g	0.178 g/100 g	0.163 g/100 g	0.916	1.092
Hearn et al. (1987)		13.1%[b]	20.7%[b]	1.6	0.625
Suloma et al. (2008)[a]	44.76 ± 0.40	17.69 ± 0.26	27.07 ± 0.15	1.53 ± 0.02	0.654
Zenebe et al. (1998)					
Lake 1—Ziway	11.57 mg/g DW[c]	4.5 mg/g DW	7.1 mg/g DW	1.6	0.625
Lake 2a—Langeno1	6.83 mg/g DW	2.167 mg/g DW	5.333 mg/g DW	2.633	0.380
Lake 2b—Langeno2	8.666 mg/g DW	2.3 mg/g DW	6.4 mg/g DW	3	0.333
Lake 3—Chamo	8.1 mg/g DW	3.133 mg/g DW	4.97 mg/g DW	1.633	0.612
Lake 4—Awassa	16.9 mg/g DW	6.633 mg/g DW	10.27 mg/g DW	1.633	0.612
Lake 5—Haiq	24.266 mg/g DW	3.366 mg/g DW	20.87 mg/g DW	6.467	0.155

[a]Percentage of total FAs. [b]Weight percentage of total FA methyl esters. [c]DW = dry weight. Light shading indicates numbers calculated from the studies' raw data. Dark shading indicates numbers estimated from charts.

recommends that a healthy diet consist of a 4:1 ratio of n-6 to n-3 FAs, while still others state that a 5:1 ratio is reasonable (Sargent 1997).

It is also helpful to understand the limitations of reporting results as ratios. The n-6:n-3 ratios reported, such as 10:1 (Steffens 1997) for example, do not mean that we eat 10 units of n-6 for every 1 unit of n-3. It is entirely possible to consume 1 unit of n-6 and 0.1 unit of n-3 and maintain that ratio. Our bodies function in total amounts, however, not ratios. Like any other food, the nutritional value of tilapia must be considered along with the other foods in the human diet. Articles like Weaver et al. (2008) suggest that the amount of n-6 FAs from a serving of tilapia is unhealthful, when the total daily intake from all the foods eaten should be considered. The resulting perception that tilapia is 'bad' is not truthful because the numbers used to support this view are valid only if tilapia makes up the entire diet.

Conclusions

The high incidence of cardiovascular disease has triggered research into the health benefits of eating fish for their omega FA content. This paper explores the range of ratios between n-3 and n-6 FAs in tilapia. Contrary to the conclusions of recent controversial research, the studies referenced in this paper show a small range of n-6 to n-3 ratios. The cases where the ratio was high show that the body composition of tilapia can be altered by changing the diet. In the face of all the scientific research about FA composition, perception can change the meaning of the scientific data, especially when the issue relates to human health. It is a disservice to the public when the published results misrepresent the actual relationships. It is clear from the resulting confusion that more research is needed to clarify how the composition of the fish is translated into human nutrition. With further research into the functions of specific FAs and how the human body uses them, along with public awareness, the role of fish, especially tilapia, as a healthy part of the human diet can be better understood.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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