

Alpha-Linolenic and Linoleic Fatty Acids

Subjects: **Nutrition & Dietetics**

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Good sources of the long-chain n-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) include cold-water fish and seafood; however, vegan diets (VGNs) do not include animal-origin foods.

n-3 fatty acid

n-6 fatty acid

alpha-linolenic acid

ALA

linoleic acid

LA

EPA

DHA

vegans

1. Introduction

The polyunsaturated n-6 and n-3 fatty acids are essential for a variety of functions in the body, including the synthesis of prostaglandins, leukotrienes, cellular membranes, phospholipids, retinal photoreceptors (vision), cerebral gray matter (brain tissue), testes, and sperm. Linoleic (18:2n-6; LA) and arachidonic acids (20:4n-6; AA) are classified as n-6 fatty acids, and α -linolenic (18:3n-3; ALA), eicosapentaenoic (20:5n-3; EPA) and docosahexaenoic acids (22:6n-3; DHA) are n-3 fatty acids ^[1]. Of these fatty acids, LA and ALA are considered essential and must be provided by the diet.

The Dietary Reference Intakes (DRIs) are “nutrient reference values” developed by the Institute of Medicine of The National Academies. They are intended to serve as a guide for good nutrition and provide the scientific basis for the development of food guidelines in both the United States and Canada, and these nutrient reference values are specified on the basis of age, gender and lifestage groups” ^[2]. The United States DRIs are used to make informed judgements during the dietary planning process. New research or discoveries of physiological factors, inborn errors of metabolism, health risks, characteristics of the nutrient sources, and nutrient bioavailability may require adjustments in DRI nutrient values for planning individual and group dietary intakes. The present 2003 version of the DRIs states that the nutrients of concern for vegetarians and vegans (VGNs) are vitamin B12, vitamin D, calcium, iron, zinc, and protein ^[3]. Essential fatty acids in the VGN and vegetarian diets are not presently a DRI concern.

When the DRI concludes that there is inadequate information to set either LA or ALA Estimated Average Requirements (EAR) or the Recommended Dietary Allowance (RDA) for healthy individuals, the Adequate Intake (AI) is used. The present essential fatty acid AI is based on “the highest median intake of LA and ALA in United States adults, where a deficiency is basically nonexistent in non-institutionalized populations” ^[4]. The present n-6 AI requirement range is 12–11 g/day for men and 17–14 g/day for adult women (non-pregnant/lactating), and the AI n-3 fatty acid recommendations are 1.1 g/day of ALA for women and 1.6 g/day for men ^[4]. However, it is unknown if

the ALs are beneficial or physiologically adequate because dose-response data studies are lacking, Essential fatty acid status is not usually clinically tested, and absence of deficiency symptoms is not necessarily evidence of adequacy.

The authors utilized the definition of 'vegan' as the following: a diet which is "devoid of all flesh foods. It excludes eggs and dairy products and may exclude honey" [5]. Frequently, the term 'strict vegetarian' or 'total vegetarian' is used instead of 'vegan' to describe their dietary pattern. Thus, the abbreviation 'VGN' is used in this manuscript as a description of the dietary pattern of total vegetarians/strict vegetarians and vegans.

People choose VGN or vegetarian diets for different reasons, which include but are not limited to health reasons, compassion toward animals, a desire to better protect the environment, to lower their risk of chronic diseases, or to therapeutically manage diseases; however, these diets require careful dietary planning. According to the Position Paper of the Academy of Nutrition and Dietetics regarding vegetarian diets, "Well designed vegetarian diets provide adequate nutrient intakes for all stages of the lifecycle and can also be useful in the management of some chronic diseases" [5].

Upon examination of the published articles that relate to 'vegetarian', the researcher's definitions for the terms 'vegan' and 'vegetarian' are inconsistent, and some researchers consider plant-based diets to be 'semi-vegetarian'. However, VGN diets are very different from omnivore diets and even diets that are considered to be 'vegetarian' (ex. 'lacto-ovo', 'pesco-vegetarian', 'plant-based vegetarian', 'pollo-vegetarian', or 'semi-vegetarian'). These 'vegetarian' diets may also include animal-origin foods such as eggs, dairy, fish, or chicken. Thus, dietary patterns and levels of biochemical indicators of essential fatty acid status are very different between VGN and omnivore diets or even other types of vegetarian diets. This narrative review focuses on apparently healthy VGNs and comparisons of VGNs and 'omnivore' or 'meat-eating' diets, rather than the comparisons of VGN to vegetarian diets or other terms that include the word 'vegetarian'.

Diet study results between VGNs and omnivores/meat-eaters are inconsistent. Additionally, interpretation or comparison is difficult when some of the information is not reported, or missing. For example, some studies report dietary total polyunsaturated fatty acids (PUFAs), total n-6, total n-3, or collected some, but not all lipid fractions [6] [7] [8] [9] [10] [11], which limits interpretation of essential fatty acid biological indicators as compared to dietary intakes.

Additional fatty acids of interest are EPA and DHA. They are not considered to be essential since they can be converted from ALA; however, they may be of concern for VGNs, since VGN diets are typically absent of EPA and DHA unless VGNs consume supplements containing EPA and DHA [9] [12] [13] [14] [15] [16].

2. Dietary Sources of the Essential Fatty Acids

The most plentiful dietary n-6 polyunsaturated fatty acid is LA. N-6 fatty acid food sources commonly consumed by VGNs include nuts, seeds, certain vegetables, and vegetable oils such as soybean oil, safflower oil, and corn oil. Therefore, any diet that is mostly plant-based leads to a high dietary intake of LA as well as fiber. Since there are

few plant sources high in ALA compared to LA, this may present an intake challenge for VGNs to meet the ALA DRI requirements.

The most abundant n-3 PUFA is ALA, which is found in plant-based oils and/or oil food sources like flaxseed (linseed), English walnut, hemp seed, and chia [17]. The major dietary plant-based sources of LA and ALA are shown in **Table 1**.

Table 1. Energy, protein, total lipid, 18:2 n-6, 18:3 n-3, carbohydrate, and fiber contents of oils and foods commonly consumed by vegans and vegetarians for the essential fatty acids.

Nutrient ¹		Energy	Protein	Total Lipid	18:2n-6	18:3n-3	CHO	Total Fiber
	Unit	Kcal	g	g	g	g	g	g
Oils								
Oil, Canola	100 g	884	0	100	18.64	9.137	0	0
Oil, Flaxseed/Linseed (Panos)	100 g	884	0.110	99.98	14.25	53.37	0	0
Oil, Soybean	100 g	763	0	100	50.42	6.789	0	0
Oil, Walnut	100 g	884	0	100	52.90	10.40	0	0
Oil, High Oleic Sunflower	100 g	884	0	100	3.61 *	0.192 **	0	0
Oil, High Oleic Safflower	100 g	884	0	100	12.72	0.096	0	0
Oil, Culinary Algae	100 g	800	0	93.33	n/a	n/a	0	0
Ovega-3 supplement ²	1 gel	n/a	0	n/a	n/a	0.5	0	0
Deva Vegan supplement ³	1 cap	5	0	0.5	n/a	0.2	0	0

Nutrient ¹		Energy	Protein	Total Lipid	18:2n-6	18:3n-3	CHO	Total Fiber
	Unit	Kcal	g	g	g	g	g	g
Nordic Naturals supplement ⁴	2 gels	10.0	0	1.00	n/a	0.715	0	0
Food Sources								
Almonds Raw	100 g	579	21.15	49.93	12.30	0.003	21.55	12.50
Amaranth	100 g	371	13.65	7.020	2.736	0.042	65.25	6.70
Avocados, Raw, California	100 g	167	1.960	15.41	1.674	0.111	8.640	6.80
Black Walnuts Dried	100 g	619	24.06	59.33	33.80	2.680	9.580	6.80
Brazil Nuts, Dried	100 g	659	14.32	67.10	23.859	0.018	11.74	7.50
Brown Rice Cooked	100 g	123	2.740	0.970	0.355	0.011	25.58	1.60
Bulgur Cooked	100 g	83	3.08	0.240	0.094	0.004	18.58	4.50
Cashews Raw	100 g	553	18.22	43.85	7.782	0.062	30.19	3.30
Chia Seeds Dried	100 g	486	16.54	30.74	5.840	17.80	42.12	34.4
English Walnuts Dried	100 g	654	15.23	65.21	38.09	9.08	13.71	6.70
Flaxseed Raw	100 g	534	18.29	42.16	5.903	22.81	28.88	27.3

Nutrient ¹	Energy		Protein	Total Lipid	18:2n-6	18:3n-3	CHO	Total Fiber
	Unit	Kcal	g	g	g	g	g	g
Hempseed Hulled	100 g	553	31.56	48.75	1.340	8.864	8.670	4.00
Millet Cooked	100 g	119	3.510	1.000	0.480	0.028	23.67	1.300
Oat Bran Cooked	100 g	40	3.210	0.860	0.324	0.015	11.44	2.60
Pistachio Raw	100 g	560	20.16	45.32	13.10	0.210	27.17	10.60
Poppy Seeds	100 g	525	17.99	41.56	28.30	0.273	28.13	19.50
1 Quinoa	100 g	368	14.12	6.070	2.977 [17]	0.260	64.16	7.00
2 Rye	100 g	338	10.34	1.630	0.659 [18] 3 [19] 4	0.108	75.86	15.1 [20]
Sesame Seeds dried	100 g	573	17.73	49.67	21.375	0.376	23.45	11.8
Soybeans Raw	100 g	446	36.49	19.94	9.925	1.330	30.16	9.30
Soybeans, Boiled	100 g	141	12.35	6.400	2.657	0.354	11.05	4.20
Sunflower Seeds	100 g	584	20.78	51.50	23.05 * [21]	0.06 **	20.00	8.60

Additionally, there are concerns and considerations such as nutrient bioavailability, physiological implications, and possible health risks of high LA and low ALA in the diet, as well as high LA in plasma, serum, erythrocytes, platelets, breastmilk and adipose tissue.

3. Nutrient Bioavailability

It is possible that high fiber diets interfere with fat absorption, including essential fatty acids. Since VGNs typically consume plant products, their diets are typically high in total fiber [\[6\]](#)[\[7\]](#)[\[8\]](#)[\[14\]](#)[\[21\]](#). Soluble fibers such as psyllium, gums and beta-glucan [\[17\]](#), bind fatty acids and prevents them from being absorbed and binds bile, which is necessary for micelle formation. Micelles are required for uptake of long-chain fatty acids into the enterocytes.

Insoluble fiber, such as wheat bran, fruit skins, and whole grains [17] increase transit time through the intestine and can also interfere with uptake of fats as well as nutrients in general, because both types of fiber are not digested or absorbed in the small intestine, and humans do not have enzymes to digest fiber. Presently, there are no studies on the effects of high soluble or insoluble fiber on fat digestion in VGNs.

4. Physiological Reasons for Special Consideration-Conversion of ALA to EPA and DHA

The essential PUFAs, LA and ALA, must be consumed from the diet, and since VGNs do not consume EPA and DHA from the diet, VGNs rely on endogenous synthesis to obtain long chain n-3 PUFAs. ALA is endogenously converted to EPA and DHA by the elongation and desaturation enzymes in the animal (or marine algae) and becomes incorporated into the animal's cells and/or stored in adipose tissue. Thus, almost all EPA and DHA dietary sources come from animals and VGNs are limited to algal supplements of EPA and DHA.

Most humans (except those with inborn errors of metabolism) can convert LA to AA and modestly convert ALA to EPA and/or DHA. The human conversion rate of ALA to EPA and DHA is about 5%–8% [22][23][24]. This low conversion rate suggests humans should consume dietary sources of EPA and DHA; however, evidence is not conclusive regarding the amount needed to maintain physiological function.

Both LA and ALA are metabolized by the same biochemical pathway, and excess consumption of LA or ALA results in competition between the elongation and desaturation enzymes for EPA and AA. Excess LA competitively interferes with the ability of ALA to utilize the elongation and desaturase enzymes, thereby suppressing the conversion of ALA to EPA and EPA to DHA [22][23][24][25][26][27] (Figure 1).

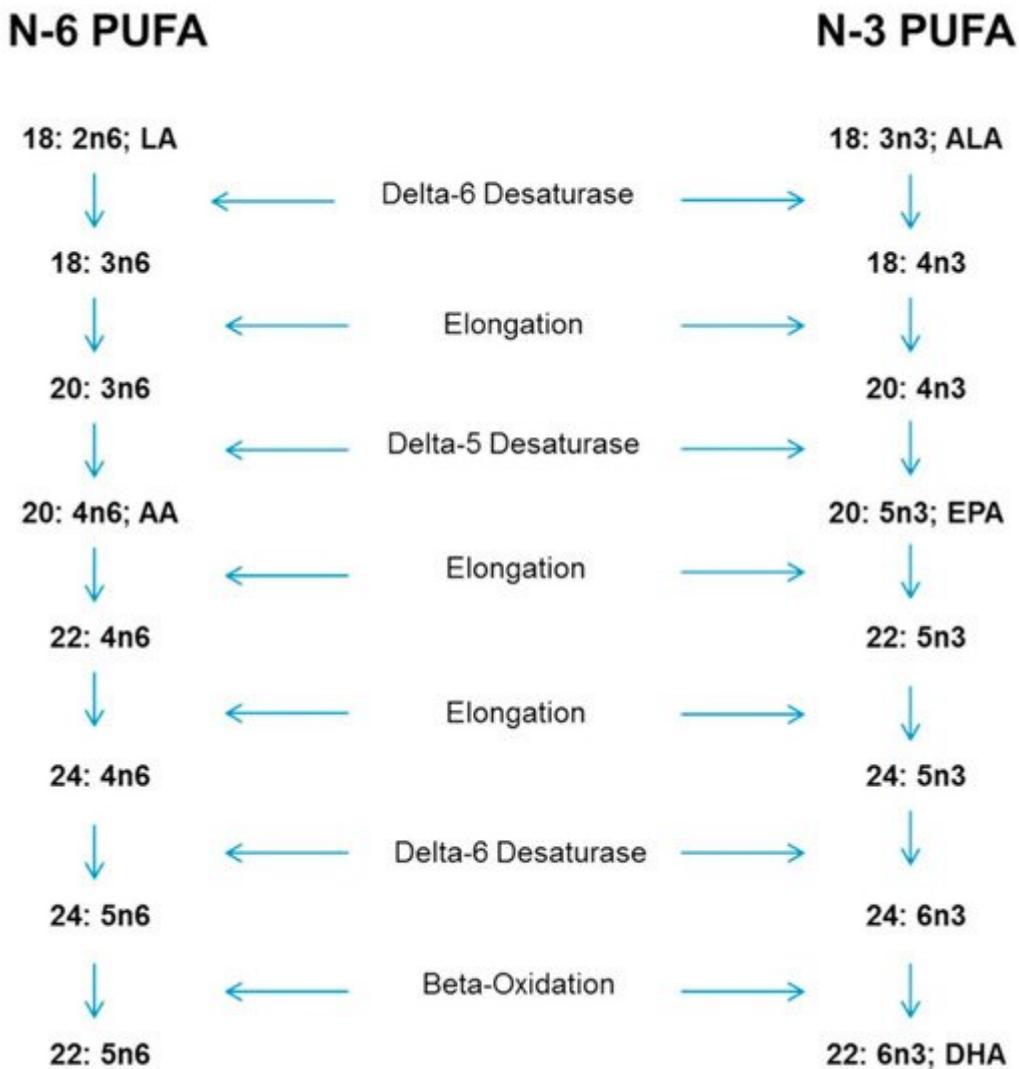


Figure 1. The elongation and desaturation of the essential fatty acids, linoleic acid (LA) and alpha-linolenic acid (ALA). AA: arachidonic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid; PUFA: polyunsaturated fatty acids. Permission by authors and Elsevier [28].

Adult and infant studies have demonstrated the conversion of ALA to EPA and DHA through desaturation and elongation, and LA desaturates and elongates to form AA. Through the process of elongation, desaturation and beta oxidation 22:5n-6 forms from AA, using the same enzyme system needed for conversion of EPA to DHA [19][20][21][22][23][24][25][26][27]. In supplemented omnivores and vegetarians, 9.4% of serum phospholipid DHA can be retro-converted to EPA [12].

It may be possible to observe alterations in the synthesis of EPA and DHA from ALA by following a VGN diet over the long-term, as it has been demonstrated that changes in dietary patterns may affect the synthesis of n-3 fatty acids. For example, there is an increased synthesis of DHA from ALA, especially if LA is decreased [29]; ALA is elongated and desaturated in a tissue-dependent manner [30]; and n-3 PUFAs may be depleted during overnutrition [31].

5. Recommended Intakes of n-3 and the n-6:n-3 Ratio

Expert opinions differ when it comes to n-3 and n-6:n-3 ratio recommendations (**Table 2**—most recent studies are listed first) and overall, the recommendations for dietary n-6:n-3 suggested by experts and researchers are lower than 10:1 and between the range of 2–4:1 [32][33][34][36].

Table 2. Recommendations by researchers and reviewers for adult vegans/total vegetarians (VGNs) (most recent studies first).

Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
						Combined
Agnoli et al., 2017 [36]	Females	Limit intake of sources of n-6 FA, & TFA. Limit consumption of processed, deep-fried foods, and alcohol.	-	Pregnant/breastfeeding or women with increased requirement for long chain n-3 fatty acids, should be advised to consume an algae-based supplement of known nutrient content.	Pregnant/breastfeeding or women with increased requirement for long chain n-3 fatty acids, should be advised to consume an algae-based supplement of known nutrient content.	-
	Combined- Males and Females	-	Improve n-3 nutritional status by regular consumption of good sources of alpha-linolenic acid.	-	-	-
Burdge et al., 2017 [37]	Females	-	-	-	Need more cognitive studies for children of	-

Recommendation:						
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
	Combined					
	vegetarian females due to low DHA levels.					
Pinto et al., 2017 [9]	Combined	-	Further research whether populations with low n-3 status are more at risk of having a pro-inflammatory profile.	-	-	-
Melina et al., 2016 [5]	Females	-	-	-	Low dose microalgae DHA supplements for pregnancy and lactation.	-
	Combined	High intakes of LA may suppress ALA conversion.	May be prudent to ensure higher intakes of ALA. N-3 needs of healthy individuals can be met with ALA alone;	Clinical relevance of reduced EPA and DHA status in VGNs are unknown. Low-dose micro-algae based DHA supplements are available for those with increased needs.	Clinical relevance of reduced EPA and DHA status in VGNs are unknown. Low-dose micro-algae based DHA supplements are available for those with increased needs.	A ratio of LA/ALA not exceeding 4:1 has been suggested for optimal conversion.

Recommendation:						
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
Combined						
			endogenous synthesis of EPA and DHA from ALA is sufficient.			
Harris, 2014 [38]	Combined	Consume more ALA and less LA to increase the Omega-3 Index.	Consume more ALA and less LA to increase the Omega-3 Index.	-	-	Omega-3 Index >8%.
Sarter et al., 2014 [16]	Combined	-	VGNs respond robustly to a relatively low dose of a vegetarian omega-3 supplement.	VGNs respond robustly to a relatively low dose of a vegetarian omega-3 supplement.	-	No direct evidence that omega-3 index confers additional health benefits over and above their already protective VGN diet.
Saunders et al., 2013 [15]	Combined	-	Double current AI of ALA if no direct sources of EPA and	-	-	-

Recommendation:						
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
Combined						
Craig, 2010; Review [39]	Combined	-	Regular consumption of plant foods naturally rich in n-3 fatty acid ALA, such as ground flaxseed,	-	Pregnant and lactating women may benefit from DHA-fortified foods and microalgal- derived DHA supplements.	-

Recommendation:						
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
	Combined					
	walnuts, soy products, and hemp seed beverages.					
Welch et al., 2010 [40]	Combined	-	Further research for conversion of ALA to long chain n-3 PUFAs for maintenance of adequate status in non-fish and fish-oil consumers is required.	-	-	-
Simopoulos, 2008 [41]	Combined	-	-	-	-	Ratio of 4:1 is associated with 70% decrease in total mortality in secondary prevention of cardiovascular disease.
Kornsteiner et al., 2008	Combined	-	Erythrocyte phospholipid	-	-	Ensure physical,

Recommendation:						
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	n-6:n-3 or Omega-3 Index
Combined						
		intake of LA to optimize FA status. The importance of long chain fatty acids in the diet needs further investigation.				
						[45][46]
					[45]	Gerster thy men
Davis et al., 2003 [34]	Combined	5.5–8% Kcals from n-6 FA. Reduce high n-6 oils in the diet, decrease processed foods. Primary fat should be MUFA.	<1.5–2% of calories should be obtained from n-3. Decrease trans fatty acids to increase conversion [21]bf ALA to EPA and DHA. Double intake of ALA; provide >1% of energy from n-3 or about 1.1 g/1000 calories.	Not essential, but it is important to ensure sufficient levels by relying on conversion from parent fatty acids. Two important steps to improve EPA status: 1) Maximize conversion of ALA to EPA and DHA and 2) Provide a direct source of EPA and DHA.	Not technically essential, but ensure sufficient levels by relying on conversion from parent fatty acids. Supplements of DHA should be 100–300 mg/day. DHA and ALA should also be adequate.	To achieve the 4:1 ratio, 15–2% of calories should be obtained from n-3 and 5.5–8% of calories from n-6 FA.
						40–54% DHA [46].

A dietary increase in flaxseed (linseed) oil increases plasma ALA and EPA and lowers the ratio of n-6:n-3 [40][47][48][49]. Li et al. showed dietary ALA from canola and linseed (flaxseed) oil increased the EPA tissue profile 2.5-fold in a high ALA diet compared with a 0.5-fold increase in a moderate ALA diet in male subjects 20 to 50 years old [50]. Indu found that a constant intake of 3.7 g/day of dietary ALA may have biological effects similar to those of 0.3 g/day of dietary long chain n-3 PUFAs from fish oil. Eleven grams of ALA from flaxseed produces 1 g of the long chain n-3 PUFAs, EPA and DHA, and results in a calculated ratio of 14.8 g LA: 3.7 g ALA equivalent to a 4:1 ratio [48]. Supplementation with high amounts of ALA (>5.3 g/day) increased EPA plasma fatty acid and platelet concentrations [49][51]. Bjerve et al. noted that the minimum requirement for ALA in immobile adults was equivalent to 0.2% of total energy intake when n-3 long chain fatty acids were 0.08% of energy [52].

Recommendation:						n-6:n-3 or Omega-3 Index
Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	
	Combined					
		Increased needs require 2.2 g/1000 calories. Aim for 2–4 g of ALA/day.				
Simopoulos, 2000 [35]	Combined	-	-	-	-	Ratio was 1:1 to 2:1 in ancient diets. Present ratio is 10 to 1:20 to 25 to 1- indicates a deficiency in Western Diets of n-3.
Fokkema et al., 2000 [33]	Combined	-	-	-	-	Found a 3:1 ratio increased EPA from 0.3 to about 1.0% in VGN plasma. A 3.7 g/day ALA diet for 4 weeks (ratio of 3.8:1) augmented ALA about 1% more. Total n- 3MI-

matched middle-aged vegans and omnivores. *Br. J. Nutr.* 2017, 117, 669–685.

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Author, Year	Males; Females	Recommendation:				n-6:n-3 or Omega-3 Index
		18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	
Combined						
Agren et al., 1995 [43]	Combined	Depressed levels of n-3 FA are depressed due to very low diet levels and high LA and oleic acid intake.	-	-	-	3 levels increased from 2.3 to 3.4% in plasma. DHA status was not increased.
Sanders et al., 1978 [44]	Females	-	More research is needed on low delta 4 desaturase in lactating women.	-	-	-
	Combined	-	Further research needed to establish whether	-	-	-

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2	Recommendation:						A
	Author, Year	Males; Females	18:2n-6 LA	18:3 n-3 ALA	20:5 n-3 EPA	22:6 n-3 DHA	
2	Combined						2
2	differences in the proportion of n-3 derivatives in tissues are of physiological importance.						2
2	ds is						2
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