Flax Bio-village Concept

2

Mahabaleshwar V. Hegde, Anand Arvind Zanwar, and Prakash B. Ghorpade

Introduction

The Flax Bio-village Concept (FBC) was formulated with holistic approach, its primary objective being to attain omega-3 nutritional security, at the same time promote flaxseed (linseed) agriculture. FBC researches and develops methods, to add value to linseed, by resourcing omega-3 fatty acid from linseed and enriching commonly consumed food, including egg milk chicken, for public health.

Functional Foods and Public Health

The focus of public health has to be to improve health and quality of life through prevention and treatment of disease and other physical and mental health conditions. Food is one of the most important and modifiable lifestyle determinants of human health. Under-nutrition and over-nutrition are both crucial determinants of morbidity and mortality and therefore nutritional interventions are needed to reduce morbidity and mortality through dietary changes. There are two approaches for micronutrient intervention, direct supplementation, or fortification (functional foods). Supplementation involves supplying the essential micronutrient nutrients in capsule form and requires a commitment of the consumer to take them regularly and religiously. On the other hand, functional foods provide the essential micronutrients as natural ingredients of the food. The latter, functional food approach is particularly suitable for developing countries like India, wherein a sea of illiterate masses divided on caste, religion, and regional basis, no one would understand the language of reason. Better way to tackle the problem is to provide functional foods that simultaneously attain food security as well as nutritional security.

There is a distinction between nutritional problems of developing and developed countries. Developed countries may suffer from over-nutrition and developing countries mostly with under-nutrition. Today, industrialized societies are characterized by increase in energy intake and decrease in energy expenditure; excessive increase in saturated fat, omega-6 unsaturated fat, and trans fat, along with drastic decrease in omega-3 fat intake; a decrease in complex carbohydrate and fiber; an increase in cereal grains; and a decrease in fruits and vegetables. On the other hand, developing countries, while struggling to catch up with developed world, have not only got the health problems of industrialized world, associated with affluent lifestyle, but at the same time a large section of the society face the problems of under-nutrition, malnutrition, with associated health problems like low birthweight, premature birth, infant mortality, and other pregnancy complications. Humans evolved on a diet in which the ratio of omega-6 to omega-3 essential fatty acids (EFAs) was about 1, whereas it is now become 15:1 or more [1], because the modern human diet is precariously low in omega-3 and harmfully excessive in omega-6 fatty acid. The phenomenon of omega-3/omega-6 imbalance exists in almost all parts of the world, equally in both developed and developing countries. Omega-3 functional food intervention would benefit both developed and developing countries.

Therefore, "bring back omega-3 fatty acids into food" chain has been a global cry.

These functional foods are responsible for overall well being and also protects from several disorders such as cancer, cardiovascular, inflammation, diabetes and many other degenerative diseases. It is well established that there is strong correlation between active constituent in food and its efficacy in controlling the progression or prevention of disease [2]. For the maximum reach, it is desirable to

M.V. Hegde (✉) · A.A. Zanwar · P.B. Ghorpade
Center for Innovation in Nutrition Health Disease, Interactive Research School for Health Affairs, Medical College Campus, Bharati Vidyapeeth Deemed University, Dhankawadi, Pune 411043, India
e-mail: mahabaleshwarh@yahoo.com

A.A. Zanwar
e-mail: anandzanwar10@gmail.com

P.B. Ghorpade
e-mail: prakashghorpade55@gmail.com

M.V. Hegde et al. (eds.), *Omega-3 Fatty Acids*, DOI 10.1007/978-3-319-40458-5_2

incorporate the most crucial omega-3, functional components, in daily consumed foods, such as egg, milk, and chicken.

Crucial Role of Omega-3 Fatty Acids in Public Health Today

Our health is very largely governed by nutrition in food. Health of our people is closely linked to our economy and progress. Today, we are faced with a very peculiar situation of malnutrition, under-nutrition, and over-nutrition. It is becoming increasingly evident from recent research that our health problem primarily originates from the inadequate supply of essential nutrient to our body. We need over 40 essential nutrients—vitamins, essential amino acids, minerals, and omega fatty acids. Of these essential nutrients, deficiency of omega fatty acids in modern human diet is responsible in a very major way to our disease-prone health status today.

Why omega-3 is so important? Omega-3 is part of cell membrane. They are responsible for hormonal regulation that regulates blood clotting, contraction and relaxation of artery walls, and inflammation. Both omega-6 and omega-3 are essential. However, most of us get too much omega-6 and very little of omega-3 fatty acid. Here is a situation of over-nutrition of omega-6 and under-nutrition of omega-3 fatty acid. This imbalance is largely the root cause of the increase in severity and incidences of several diseases, including heart disease, diabetes, arthritis, cancer, mental disorders, pregnancy complications, infant mortality, and child health. Role of omega-3 in well known during pregnancy in particular for infant nerve and eye function. Therefore it is critical to provide adequate supply of omega-3-poly unsaturated fatty acid during last trimester. It is therefore important to ensure adequate and balanced supply of EFAs, particularly to the nations with emerging economies and this would be the most prudent public health strategy for improving the health of the populations [3].

The ratio of omega-6 to 3 2.3:1 is recommended so as to maximize ALA to DHA conversion. This is because both omega-3 and omega-6-fatty acid compete for the same desaturase and elongase. Higher than this ratio of omega-6 (Linoleic acid) in the diet can affect ALA to EPA, DHA conversion in vivo. Kinetic studies conducted in vivo [4] have shown that ≈15 % of dietary ALA is converted to the long-chain omega-3 fatty acids, of which eicosapentaenoic acid (EPA; 20:5) and docosahexaenoic acid (DHA; 22:6) predominate at typical intakes of both linoleic acid (LA; 18:2), 15 g/d (5 % of energy) and alpha-linolenic acid (ALA; 18:3) 2 g/d (0.6 % of energy). Quantitatively, this conversion results in ≈300 mg of n-3 long-chain fatty acids being derived via conversion from ALA. When dietary linoleic acid is increased to 30 g/d, conversion of ALA to the long-chain omega-3 fatty acids is reduced by ≈40 % [5]. Thus, the conditions that favor maximal conversion of ALA to EPA and DHA are critically dependent on the amount of linoleic acid in the diet [6].

Inuit metabolism study revealed fish derived omega-3-fatty acids are protective. It seemed that Inuit were protected from cardiovascular disease and low incidence was attributed to their fat rich in traditional marine mammal diet. This findings led to recommendation, resulting in millions of westerners consuming fish oil to prevent heart disease. The rarity of ischemic heart disease in Greenland Inuits, once known as Eskimos, may partly be explained by the antithrombotic effect of the long-chained diets rich in marine oils [7]. On their traditional diet, rich in fat from marine mammals, Inuit seemed to be quite healthy with a low incidence of cardiovascular disease, so fish oil must be protective. Those conclusions eventually led to the recommendation that Westerners eat more fish to help prevent heart disease and sent tens of millions scrambling for fish oil pills.

Recently, it has been shown that Greenland Inuits show genetic signatures of diet and climate adaptation [8]. The adverse health effects of a high-fat diet are counterbalanced by high omega-3 (EPA and DHA) diet. They have unique mutations, nearly in 100 % of the Inuit, which is only 2 % in Europeans and 15 % in Han Chinese. The strongest signal of signature of adaptation was found on chromosome 11 in the cluster of fatty acid desaturases. Two genes FADS1 and FADS2, coding for delta 5 and delta 6 desaturase (D5D, D6D), are rate limiting steps and have been selected for adaptation to Inuit diet. It seems obvious that this mutation is vital for their survival of Inuit on high-fat diet. It was also noted that the mutation was found to be strongly associated with height because growth is in part regulated by person's fatty acid profile, which also affect the regulation of growth hormones. So it seems that what is true for Inuit, high EPA, and DHA fish diet may not be straightaway true for everyone else. Difference in the type omega-3 intake of vegetarian and non-vegetarian is depicted in Fig. 2.1.

Fish oils provide a source of EPA and docosahexaenoic acid (DHA), two fatty acids now recognized to be important for human health [9]. The increasing demand for EPA and DHA containing fish oils is putting pressure on fish species and numbers [10]. Fisheries provide fish for human consumption and supplement production, at a maximal historical rate, suggesting mass-scale fishing is no longer sustainable. High rate of fishing is resulting in a substantial effect on fish levels with the possibility of extinction [11]. The world's fish stocks are fast declining and it has been estimated that 100 % of the world's fish taxa will have collapsed by 2048 [12]. The major sources of these omega-3 fatty acids are oily fish species including salmon, mackerel, and herring [13].

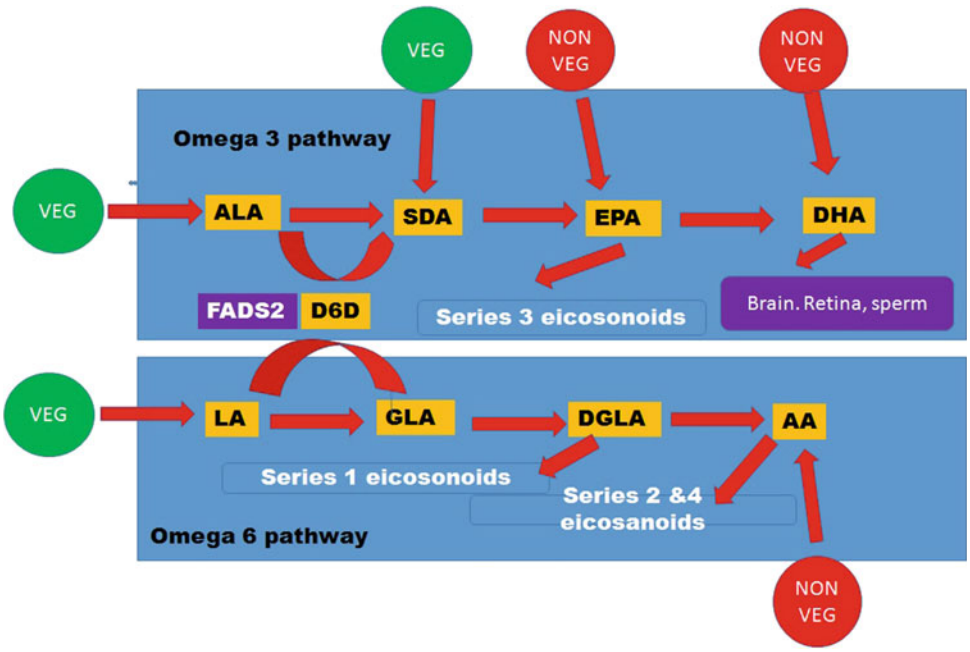

Fig. 2.1 Difference in the type of omega-3 and omega-6 fatty acids by vegetarian and non-vegetarians

The numerous health benefits provided by fish consumption may be compromised by the presence of toxic metals and metalloids such as lead, cadmium, arsenic, and mercury, which can have harmful effects on the human body if consumed in toxic quantities [14].

Health properties of omega-3 fatty acids have now been well established. High prevalence of degenerative disease, primarily attributed to the paucity of omega-3 fatty acid in human diet. In order to protect fish species and the ocean ecosystems, alternative sustainable sources of omega-3 fatty acids are need of the day.

Fish oil and algal DHA oil has problem of patient compliance in high dose therapy because of fishy taste and gastrointestinal complaints. The benefits and risks of algal, fish oil, plant, omega-3 fatty acid-enriched dairy products, animal-derived food, krill oil, and seal oil have been reviewed [3]. Algae are the primary producers of the ocean's ecosystem, providing the foundation of the oceanic food chain. Specifically, algae synthesize omega-3 fatty acids that are subsequently consumed by other marine life. Cost of extraction and purification methods are currently limiting the potential of using micro-algal oils on a large scale [15].

Admittedly, all omega-3 fatty acids are not equal (Fig. 2.2) ALA is available from plant sources and linseed is the richest vegetarian source of ALA. ALA cannot be synthesized in human body and therefore the essential omega-3 fatty acid. ALA is a precursor for EPA and DHA, which are physiologically more potent omega-3 fatty acids. Fish is a good direct source of EPA and DHA and hence regarded as more effective. There is a notion that ALA is not efficiently converted to EPA and DHA and therefore EPA and DHA are conditionally EFAs. ALA is the only form of omega-3 fatty acid available to vegetarians and hence there is a controversy as to whether ALA can really fulfill the omega-3 needs of vegetarians adequately. As fractional conversion of DHA from ingested ALA represents only the proportion of the dose that is found in the blood compartment, which is a very small portion of the DHA synthesized from ALA, these estimates are likely underestimates of actual DHA synthesis from ALA in humans [16]. When ALA is administered orally, it is absorbed into the lymphatic system and then deposited into systemic circulation. This is problematic for human tracer studies that administer ALA orally and measure appearance of labeled omega-PUFA products in the plasma, as a large portion of the trace will have taken up by tissues and adipose tissue and do not reach liver and then to plasma. In 2009, Barcelo-Coblijn and Murphy [17] have elegantly argued that dietary ALA is a significant contributor of tissue DHA. The pertinent issue raised is whether a terrestrial animal (humans) that is an omnivore truly requires dietary DHA of marine origin, in order to have optimal physiological performance, despite the true rarity of DHA in the world's terrestrial food web, where ALA exists in abundance? Dietary ALA is critical for maintaining tissue LC-PUFA levels. Absence of ALA results in omega-3 deficiency including that of DHA. There are three basic fates of ALA in human body: (A) ALA undergoes beta-oxidation and provides energy, (B) ALA gets converted to EPA and DHA in a tissue dependent manner, and (C) ALA is stored in adipose tissue and mobilized as and when required. Vegans and vegetarians have similar prevalence of neurological disease as compared with omnivores, suggesting that any

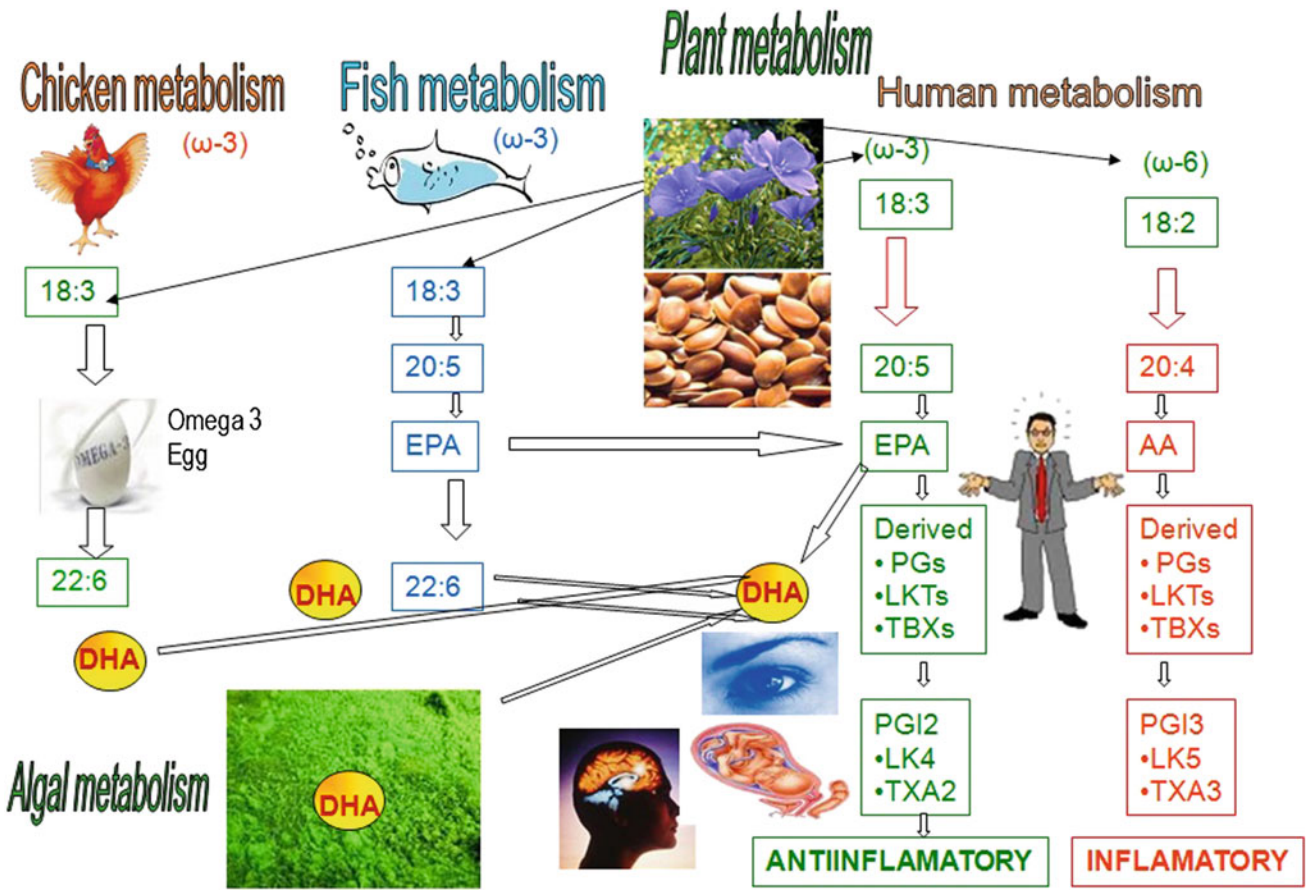

Fig. 2.2 Origin, supply, and utilization of omega-3 PUFAs

altered brain DHA metabolism in these individuals does not manifest neurologically [18]. The need-based regulation of conversion of ALA to LC-PUFA is also evident. Sex hormones may influence the enzymatic synthesis of LC-PUFA, which may lead to need-based sex-specific differences in LC-PUFA supply [19].

Both ALA and LA constitute the 18 carbon EFAs, precursors of physiologically potent 20 carbon eicosapentaenoic acid (EPA; 20:5) and arachidonic acid (AA; 20:4). The desaturation and elongation of both LA (18:2) and ALA (18:3) to their corresponding LC-PUFAs, arachidonic acid (AA; 20:4) from LA and EPA (20:5) and DHA (22:6) from ALA, are performed by the same sets of common desaturases and elongases. Fortunately, these enzymes have 10 times more affinity for ALA than for LA. Therefore, taking ALA instead of preformed EPA and DHA has additional benefit of reducing the conversion of LA to AA, which is responsible for the production of inflammatory eicosanoids. Further, a recent article provides evidences that ALA to DHA conversion is sufficient to maintain DHA levels in adult brain [20].

The epidemiologic evidence suggests comparable benefits of plant-based and marine-derived omega-3-PUFAs [21].

It is clear from the above account that the main three omega-3 fatty acids available from different sources have different effects on the omega-3 metabolism in humans (Fig. 2.2) Fish would provide EPA and DHA, non-vegetarian food like chicken would provide ALA, EPA, and DHA, and algae would provide DHA or EPA, whereas linseed, which is basic raw material being promoted through FBC, provides only ALA.

Although all omega-3 fatty acids are not equal, each one of them ALA, EPA, and DHA are all uniquely bioactive. DHA is considered most potent, main omega-3, fatty acid as it is concentrated in the brain, and constitutes 10–15 % of the brain fatty acids. Dietary DHA is known to downregulate enzymes involved in its own synthesis [22].

In view of the above considerations that promoting non-fish sources of omega-3, such as linseed, is particularly rewarding for vegetarians, we put forth "Flax Bio-village" Concept to resource omega-3 from linseed and enrich egg, milk, and chicken. We felt that although linseed is a source of ALA, a shorter chain omega-3-PUFA would be ideal as a sustainable, renewable, economical, and land source, and would substantially reduce the impact on fish levels.

ALA is the essential omega-3 fatty acid, as it cannot be synthesized in human body. Evidences of potential benefits of omega-3 for human health have largely come from the sea food omega-3 fatty acids, particularly EPA and DHA. However, fewer studies have evaluated the plant-derived omega-3 fatty acid ALA [23]. Because EPA and DHA are rapidly incorporated into plasma and membrane lipids, the efficacy of EPA and DHA is are higher than that of DHA. However, ALA being the primary essential omega-3 fatty acid, for the long-term beneficial effect, ALA may be more important in human nutrition [24]. ALA is beneficial as a nutraceutical/pharmaceutical candidate and is safe for use as food ingredient [25].

Data on beneficial effects of ALA in flax are not as mature as fish data. Nine major studies revealed inverse relation between ALA levels and cardiovascular disorders [26–34]. The results are persuasive as most of these studies are from large sample populations and/or over relatively long period [26–34]. Therefore, our initiative to implement "Flax Bio-village Concept" to promote linseed agriculture, resource omega-3 from linseed to enrich various food products, for omega-3 nutritional security, is justified.

Health benefits of plant-derived ALA have been recently been reviewed [35]. It has been reported that the rise in blood pressure during mental stress is ameliorated by flaxseed [36].

Flaxseed is the richest vegetarian source of omega-3 fatty acid (ALA). Omega-3 fatty acid being from plant source has wider acceptability to both vegetarians and non-vegetarians. If properly exploited flaxseed has the potential to meet the crucial need of omega-3 fatty acid nutritional security and good health for all. But there are many challenges that need technological solutions to exploit the full potential of flaxseed to achieve omega-3 nutritional security and good health for all.

However, flaxseed is not regarded readily edible because of cyanogenic glycosides and phytic acid, but processing of flaxseed for food stuff reduces its toxicity [37]. Flaxseed meal also contains 2.3–3.3 % phytic acid that can interfere with the bioavailability of micronutrients. Flaxseed meal also contains 10 mg/100 g linatin (gamma glutamyl-1-amino-D proline), which induces vitamin B_6 deficiency [38]. However, it has been observed that consumption of up to 50 g of flaxseed per day did not affect vitamin B_6 level. Flaxseed is also rich source of lignan which has antioxidant and weak estrogenic activity. Lignan (secoisolariciresinol diglucoside) content in flaxseed is 800 times more than other plant foods [39]. Secoisolariciresinol diglucoside is converted by bacteria in the gut to enterodiol and enterolactone which can provide health benefits due to their weak estrogenic and anti-estrogenic effects [40]. However, raw flaxseed can act as anti-nutrient, as it can interfere in postnatal development such as the estrous cycle [41]. In India, as the flaxseed is generally regarded as inedible, and the flaxseed oil has been mostly used in varnish and paints and there has not been much demand for flaxseed consequently, farmers do not get good price for their produce, and hence flaxseed has remained a neglected crop. The area under flaxseed has decreased from 20 lakh ha in 1980s to mere 2.9 lakh ha today [42].

Omega-3 fatty acids, being polyunsaturated fatty acid, are very unstable and they need to be stabilized to have better shelf life. Lastly in developing countries, like India, there has to be awareness about omega-3 fatty acids and their health benefits, the crucial need of these vital nutrients. It has also to be appreciated that in a sea of illiterate masses, divided on caste, religion, and regional basis, no one understands a language of reason, under the circumstances, to reach out to the masses faster, and it is better to provide omega-3 fatty acids through commonly eaten daily food such as egg milk and chicken.

Flax Bio-village Concept

Based on the above facts and recognizing that the incorporation of omega-3 fatty acid into our daily consumed food would be immensely rewarding for the health of our people, we decided that linseed, a naturally rich vegetarian source of omega-3 fatty acid, would be ideal to meet the challenge. However, this had several hurdles as mentioned above. We put forth a unique, innovative idea called it "Flax Bio-village Concept" [43]. We would like to briefly narrate the success story, wherein we have systematically tackled each one of the hurdles and have succeeded in developing a replicable model for resourcing omega-3 fatty acid from linseed and enrich egg, milk, and chicken meat besides other food products.

Omega-3 intake of mother is reflected in breast milk and omega-3 in breast milk is very low in populations living mainly on plant-based diet and high in fish-eating countries. The total n-3 fatty acid supply is below the recommended range in nine countries with the lowest GDP. The supply of n-3 fatty acid needs to be increased by using vegetable oils with higher ALA content [44]. Flax oil is richest in n-3 fatty acid. It is interesting that the conversion of ALA to EPA DHA is better in women than in men. Of course their need is higher. Generally, it can be stated that estrogen stimulates, whereas testosterone inhibits, the conversion of EFA to LC-PUFA [45].

Flaxseed (Linseed)

Flaxseed is one of the most important oilseed crops for industrial as well as food, feed fiber purposes [46]. Flaxseed, also called linseed, this is very traditional crop and because

of the presence of omega-3-fatty acid, fiber, phytoestrogen, protein, it has status of good nutritional functional food helpful in reducing cardiovascular diseases, decreases risk of cancer, anti-inflammatory activity, laxative effect, and alleviation of menopausal symptoms and osteoporosis [38].

Flaxseed is mainly cultivated in Canada followed by China, USA, India and Ethopia [47].

Based on the above facts and recognizing that the incorporation of omega-3 fatty acid into our daily consumed food would be immensely rewarding for the health of our people, we, at Bharati Vidyapeeth University, set out to take up this onerous task in right earnest. However, this had several challenges to be tackled. We put forth a unique, innovative idea called it "Flax Biovillage Concept" (FBC) [43]. We will briefly narrate the success story. We have systematically tackled the problems and have succeeded finding solutions and have developed a replicable model for resourcing omega-3 fatty acid from linseed and enrich egg, milk, and chicken meat besides other food products. FBC envisages backward linkages with linseed growing farmer and forward linkage with the consumer. From farm to fork at various stages of its implementation, FBC has tackled several hurdles which needed innovative solutions.

Linseed Is a Neglected Crop

Although linseed is an important high value oilseed crop, however, in India, it is a neglected crop. As the oil was mostly used in varnish and paints, linseed therefore did not fetch much value in the market and the crop has not been found to be lucrative to the farmer. The area under linseed and the production has been continuously decreasing in last three decades. The area under linseed cultivation was 19.51 lakh ha in 1980. Under All India Coordinated Research Project (AICRP) on Linseed, Indian Council of Agriculture has developed more than 58 varieties of linseed and has released for commercial cultivation, in various parts of the country in last three decades. In spite of this persistent effort by the government, there has been a continuous decline in area under cultivation in linseed from 19.51 lakh ha to 3.5 lakh ha today. The linseed cultivation is not lucrative due to low price, less market demand, lack of processing, and value addition. Linseed is an important bioeconomy crop as it is the richest source of omega-3 fatty acid and lignan. It is extremely important to promote linseed agriculture. For that, it is important to develop technologies to resource omega-3 from linseed and enrich commonly consumed food and thereby add value to linseed to provide better price to linseed growing farmer and at the same time provide omega-3 nutritional security to the people.

The efforts initiated by Dr. PDKV, Akola, Bharati Vidyapeeth Deemed University, Pune (BVDU), BAIF Development and Research Foundation, Pune (BAIF-DRF), and M/s. Ensign Diet Care, Pune, as an Industrial Partner with support from two NAIP Projects under ICAR in Component III & Component II are successful to establish public–private partnership (PPP) value chain model to create market demand, better price to farmers, thereby increasing area under linseed and sustainability under rainfed farming system.

With the introduction of high-yielding, disease-resistant linseed PKV-NL-260 developed by Dr P.B. Ghorpade (AICRP-Linseed, Nagpur), the farmers in Vidharbha are now harvesting more yield. With the linseed value addition efforts of BVDU, farmers now get buyback guarantee and good price (5 % over and above the market price). This has a positive impact on the area under linseed in Vidharbha, Maharashtra, and the farmers are finding linseed farming lucrative.

Omega-3 Fatty Acids Are Very Unstable

This has been the real bottleneck in taking omega-3 to the people. We have developed a formulation (a universal omega-3 fortifier, an emulsion completely miscible with water) in honey [48] with antioxidants that is stable for over nine months. This enables us to enrich any food product with omega-3 fatty acid. Omega-3 fortifier, as it is completely miscible in water, can be used to enrich milk and other dairy products.

Linseed Is not Readily Edible and Has Anti-nutrients

Although linseed is now regarded as super food as it contains very high amount of omega-3 fatty acid (55–60 %) and is very rich in soluble fiber, it is not readily edible as it contains high levels of anti-nutrients, such as cyanogens glycoside, linatin (anti-vitamin B-6) [49]. This problem has been successfully resolved by cold press extraction [50] of omega-3 oil free from all the above anti-nutrients. The cake formulated in omega-3 chicken feed for layers produces omega-3-enriched egg. Chicken feed [51] developed for broilers in such a way that it not only produces omega-3 chicken meat [52–54], but also gives better health to the birds [55]. So the anti-nutrients are regulated in the feed such that it does not affect the birds' performance or health.

Awareness of Importance of Omega-3 for Public Health

This is really a major hurdle. However, as the "Flax Bio-village" Concept envisages enriching the commonly consumed food including egg, milk, and chicken, it is hoped

that it would have better consumer acceptability and with the experience of health benefits to the consumer, omega-3 egg, omega-3 milk, and omega-3 chicken, will eventually become popular.

Convergence of Linseed Agriculture to Health and Wealth

Figure 2.3 depicts how FBC is able to bring about convergence of linseed agricultureto health and wealth. FBC develops methods of processing linseed to maximize the value of linseed plant and linseed. FBC provides better price to the linseed grower to increase linseed agriculture. Finally FBC provides high health value product to the consumer by processing linseed.

Many processing techniques have been found to lower the concentration of functional components in food. Omega-3 fatty acids are notoriously unstable. They are susceptible to oxidation when subjected to heat, light, or when in contact with air moisture, metal. Particular care has to be taken while extracting oil from linseed, to avoid or minimize these oxidizing factors by reducing the time of contact while processing.

Linseed has about 35–40 % oil of which 55–60 % is ALA. Omega-3 oil can be extracted by either solvent or cold press extraction. Solvent extraction is harsh but more efficient, although results in almost complete extraction of the oil. Cold press extraction is therefore preferred. The process developed by us involves cold press extraction with a cooling jacket and under inert nitrogen atmosphere. This being inefficient, only 75–80 % of oil is extracted and the rest remains in the cake. The unique innovative process has been developed to use the high-grade omega-3 oil for the production of omega-3 soft gels, omega-3 oil, and the oil is further processed to produce water miscible emulsion, i.e., omega-3 fortifier. Omega-3 fortifier is particularly suitable for enriching milk and other dairy products.

As the inefficient cold press extraction of the oil from linseed leaves ~25 % of oil still in the cake, cake can be further processed suitably for producing omega-3-enriched feed mix formulated appropriately to enrich layer feed for the production of omega-3 eggs and also for the enrichment of broiler feed for the production of omega-3 chicken.

Flax Lignan for Pharmaceutical Application

Bakke and Klosterman in 1956 isolated SDG lignan [56] from flaxseed which is also known as SECO, the aglycone of SDG, depending on the method of analysis. Apart from SDG, flaxseed also contains matairesinol, isolariciresinol, lariciresinol, demethoxy-secoisolariciresinol, and pinoresinol in smaller quantities. Apart from flaxseed lignans are present in legumes, cereals, vegetables, berries, seaweed, tea, and alcoholic beverages. SDG lignan has array of pharmacological actions.

Linseed lignan (SDG) has estrogenic [57] and strong antioxidant activities [58]. SDG exhibits cardioprotective, anti-atherosclerotic [59, 60], and anti-diabetic [61–63] activity. Linseed has about 1–3 % SDG which has cardioprotective [64], antihyperlipidemic [65] activity. Active metabolite of SDG lignan namely enterolactone has anti-metastatic activity [66]. Penumathsa et al. reported the efficacy of SDG lignan in hypercholesterolemic myocardial infarction [67]. Apart from lignan, some phenolic butanol

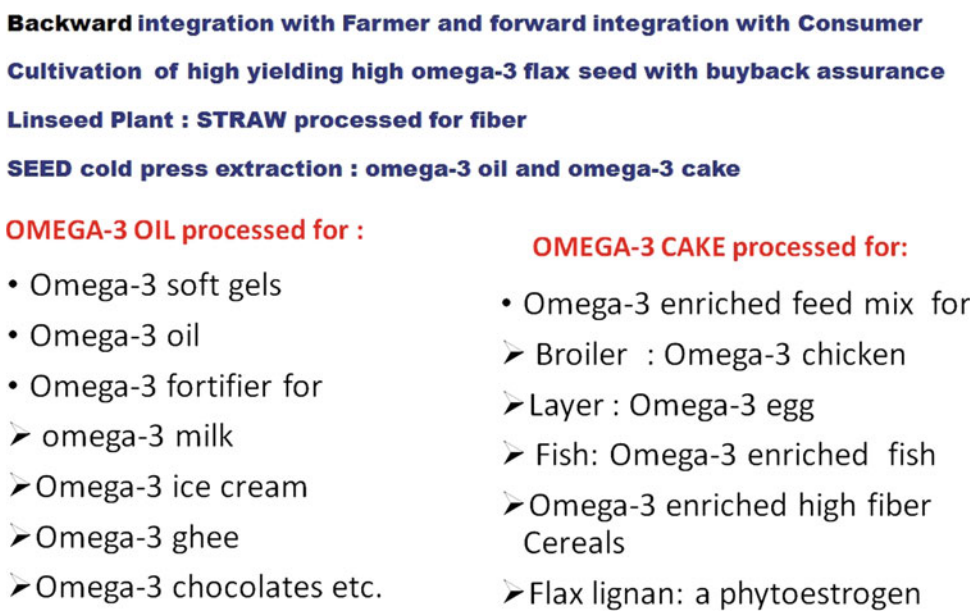

Fig. 2.3 Flax bio-village concept (FBC)

soluble non-lignan components extracted from defatted flax meal have hepatoprotective [68], immunomodulatory activities [69]. In nutshell, bioactive lignan in linseed has potential activities which further add value.

Summary

Flax Bio-village Concept envisages creating wealth to the linseed growing farmer by adding value to linseed, and at the same time, it provides technologies to develop omega-3-enriched functional food for better health of the consumer.

- FBC can revive the linseed crop and lure the farmers for linseed cultivation to meet the challenge of attaining omega-3 nutritional security.
- FBC will provide region-wise state released high-yielding omega-3 seed to the farmer and hence farmer will get higher production and also higher returns.
- FBC provides technology to cold press extract linseed under mild non-oxidizing condition to get high-quality omega-3 oil.
- FBC provides technology to tailor-made omega-3 fortifier to enrich any food products in bakery, dairy, confectionary industries
- FBC processes the cake with still leftover omega-3 in it to produce enriched feed mix (EFM) to feed layer and broiler chicks to produce omega-3-enriched egg and chicken meat.
- The birds consuming omega-3 also enjoy better health with reduced morbidity and mortality increases profitability.
- FBC aims to achieve omega-3 nutritional security and good health for all.

FBC mission is "**Harvesting wealth and cultivating Health**."

References

1. Simopolous AP. Evolutionary aspects of omega-3 fatty acids in the food supply. Prostaglandins Leukot Essen Fatty Acids. 199;60:421–429.
2. Abuajah CI, Ogbonna AC, Osuji CM. Functional components and medicinal properties of food: a review. J Food Sci Tech. 2015;52:2522–9.
3. Tur JA, Bibiloni MM, Sureda A, Pons A. Dietary sources of omega 3 fatty acids: public health risks and benefits. Br J Nutr. 2012;107 (2):S23–52.
4. Simopoulos AP. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother. 2002;56(8):365–79.
5. Goyens PL, Spilker ME, Zock PL, Katan MB, Mensink RP. Conversion of α-linolenic acid in humans is influenced by the absolute amounts of α-linolenic acid and linoleic acid in the diet and not by their ratio. Am J Clin Nutr. 2006;84(1):44–53.
6. Hussein H, Ah-Sing E, Wilkinson P, Leach C, Griffin BA, Millward DJ. Long-chain conversion of [13C] linoleic acid and-linolenic acid in response to marked changes in their dietary intake in men. J Lipid Res. 2005;46:269–80.
7. Bang HO, Dyerberg J, Sinclair HM. The composition of the Eskimo food in north western Greenland. Am J Clin Nutr. 1980;33 (12):2657–61.
8. Fumagalli M, Moltke I, Grarup N, Racimo F, Bjerregaard P, Jørgensen ME, Korneliussen TS, Gerbault P, Skotte L, Linneberg A, Christensen C, Brandslund I, Jørgensen T, Huerta-Sánchez E, Schmidt EB, Pedersen O, Hansen T, Albrechtsen A, Nielsen R. Greenlandic inuit show genetic signatures of diet and climate adaptation. Science. 2015;349(6254):1343–7.
9. Calder PC. n-3 polyunsaturated fatty acids, inflammation, and inflammatory diseases. Am J Clin Nutr. 2006;83(6):1505S–1519S.
10. Lenihan-Geels G, Bishop KS, Ferguson LR. Alternative sources of omega-3 fats: can we find a sustainable substitute for fish? Nutrients. 2013;5(4):1301–15.
11. Dulvy NK, Sadovy Y, Reynolds JD. Extinction vulnerability in marine populations. Fish Fish. 2003;4(1):25–64.
12. Worm B, Barbier EB, Beaumont N, Duffy JE, Folke C, Halpern BS, Jackson JBC, Lotze HK, Micheli F, Palumbi SR, Sala E, Selkoe KA, Stachowicz JJ, Watson R. Impacts of biodiversity loss on ocean ecosystem services. Science. 2006;314:787.
13. Strobel C, Jahreis G, Kuhnt K. Survey of n-3 and n-6 polyunsaturated fatty acids in fish and fish products. Lipids Health Dis. 2012;30(11):144.
14. Bosch AC, O'Neill B, Sigge GO, Kerwath SE, Hoffman LC. Heavy metals in marine fish meat and consumer health: a review. J Sci Food Agric. 2016;96(1):32–48.
15. Adarme-Vega TC, Lim DKY, Timmins M, Vernen F, Li Y, Schenk PM. Microalgal biofactories: a promising approach towards sustainable omega-3 fatty acid production. Microb Cell Fact. 2012;11:96.
16. Couëdelo L, Boué-Vaysse C, Fonseca L, Montesinos E, Djoukitch S, Combe N, Cansell M. Lymphatic absorption of α-linolenic acid in rats fed flaxseed oil-based emulsion. Br J Nutr. 2011;105 (7):1026–35.
17. Barceló-Coblijn G, Murphy EJ. Alpha-linolenic acid and its conversion to longer chain n-3 fatty acids: benefits for human health and a role in maintaining tissue n-3 fatty acid levels. Prog Lipid Res. 2009;48(6):355–74.
18. Davis BC, Kris-Etherton PM. Achieving optimal essential fatty acid status in vegetarians: current knowledge and practical implications. Am J Clin Nutr. 2003;78(3):640S–6S.
19. Decsi T, Kennedy K. Sex-specific differences in essential fatty acid metabolism. Am J Clin Nutr. 2011;94(6):1914S–9S.
20. Domenichiello AF, Kitson AP, Bazinet RP. Is docosahexaenoic acid synthesis from α-linolenic acid sufficient to supply the adult brain? Prog Lipid Res. 2015;59:54–66.
21. Fleming JA, Kris-Etherton PM. The evidence for linolenic acid and cardiovascular disease benefits: comparisons with eicosapentaenoic acid and docosahexaenoic acid. Adv Nutr Int Rev J. 2014;5(6): 863S.
22. Nara TY, He WS, Tang C, Clarke SD, Nakamura MT. The E-box like sterol regulatory element mediates the suppression of human delta-6 desaturase gene by highly unsaturated fatty acids. Biochem Biophys Res Commun. 2002;296(1):111–7.
23. Pan A, Chen M, Chowdhury R, Wu JH, Sun Q, Campos H, Mozaffarian D, Hu FB. α-Linolenic acid and risk of cardiovascular disease: a systematic review and meta-analysis. Am J Clin Nutr. 2012;96(6):1262–73.

24. Simopoulos AP. Human requirement for N-3 polyunsaturated fatty acids. Poult Sci. 2000;79(7):961–70.
25. Kim KB, Nam YA, Kim HS, Hayes AW, Lee BM. α-Linolenic acid: nutraceutical, pharmacological and toxicological evaluation. Food Chem Toxicol. 2014;70:163–78.
26. Hu FB, Stampfer MJ, Manson JE, Rimm EB, Wolk A, Colditz GA, Hennekens CH, Willett WC. Dietary intake of alpha-linolenic acid and risk of fatal ischemic heart disease among women. Am J Clin Nutr. 1999;69(5):890–7.
27. Albert CM, Oh K, Whang W, Manson JE, Chae CU, Stampfer MJ, Willett WC, Hu FB. Dietary alpha-linolenic acid intake and risk of sudden cardiac death and coronary heart disease. Circulation. 2005;112(21):3232–8.
28. Erkkila AT, Lehto S, Pyorala K, Uusitupa MIJ. n-3 Fatty acids and 5-y risks of death and cardiovascular disease events in patients with coronary artery disease. J Clin Nutr. 2003;78:65–71.
29. Baylin A, Kabagambe EK, Ascherio A, Spiegelman D, Campos H. Adipose tissue alpha-linolenic acid and nonfatal acute myocardial infarction in Costa Rica. Circulation. 2003;107(12):1586–91.
30. Oda E, Hatada K, Katoh K, Kodama M, Nakamura Y, Aizawa Y. A case-control pilot study on n-3 polyunsaturated fatty acid as a negative risk factor for myocardial infarction. Int Heart J. 2005;46 (4):583–91.
31. Djoussé L, Arnett DK, Carr JJ, Eckfeldt JH, Hopkins PN, Province MA, Ellison RC. Investigators of the NHLBI FHS. Dietary linolenic acid is inversely associated with calcified atherosclerotic plaque in the coronary arteries: the National Heart, Lung, and Blood Institute Family Heart Study. Circulation. 2005;111(22):2921–6.
32. Djoussé L, Pankow JS, Eckfeldt JH, Folsom AR, Hopkins PN, Province MA, Hong Y, Ellison RC. Relation between dietary linolenic acid and coronary artery disease in the National Heart, Lung, and Blood Institute Family Heart Study. Am J Clin Nutr. 2001;74:612–9.
33. Rodriguez-Leyva D, Bassett CMC, McCullough R, Pierce GN. The cardiovascular effects of flaxseed and its omega-3 fatty acid, alpha-linolenic acid. Can J Cardiol. 2010;26:489–496.
34. Ascherio A, Rimm EB, Giovannucci EL, Spiegelman D, Stampfer M, Willett WC. Dietary fat and risk of coronary heart disease in men: cohort follow up study in the United States. BMJ. 1996;313(7049):84–90.
35. Rajaram S. Health benefits of plant-derived α-linolenic acid. Am J Clin Nutr. 2014;100(Supplement 1):443S–8S.
36. Spence JD, Thornton T, Muir AD, Westcott ND. The effect of flax seed cultivars with differing content of alpha-linolenic acid and lignans on responses to mental stress. J Am Coll Nutr. 2003;22 (6):494–501.
37. Ernesto M, Cardoso AP, Nicala D, Mirione E, Massaza F, Cliff J, Haque MR, Bradbury JH. Persistent konzo and cyanogen toxicity from cassava in northern Mozambique. Acta Trop. 2002;82 (3):357–62.
38. Goya A, Sharma V, Upadhyay N, Gill S, Sihag M. Flax and flaxseed oil: an ancient medicine & modern functional food. J Food Sci Technol. 2014;51(9):1633–53.
39. Touré A, Xueming X. Flaxseed lignans: source, biosynthesis, metabolism, antioxidant activity, bio-active components, and health benefits. Compr Rev Food Sci Food Saf. 2010;9(3):261–9.
40. Adlercreutz H. Lignans and human health. Crit Rev Clin Lab Sci. 2007;44(5–6):483–525.
41. Thomas FX, Robert LS, Black TN, Olejnik N, Wiesenfeld TW, Babu UB, Bryant M, Flynn TJ, Ruggles DI. Effects of flaxseed and defatted flaxseed meal on reproduction and development in rats. Food Chem Toxicol. 2003;41:819–34.
42. Linseed annual report 2014–15. ICAR-Project coordinating unit (Linseed), C.S.A.U.A&T. campus, Kanpur-208002.
43. Hegde MV, Ghorpade PB, Hegde NG, Wagh UV, Gosavi PG, Kadam SS. Flax biovillage concept presented at world congress on oils and fats. In: 28th ISF Congress, Sydney, Australia, 27–31 Sept 2009.
44. Michaelsen KF, Dewey KG, Perez-Exposito AB, Nurhasan M, Lauritzen L, Roos N. Food sources and intake of n-6 and n-3 fatty acids in low-income countries with emphasis on infants, young children (6–24 months), and pregnant and lactating women. Matern Child Nutr. 2011;7(2):124–40.
45. Giltay EJ, Gooren LGJ, Toorians A, Katan MB, Zock PL. Docosahexaenoic acid concentrations are higher in women than in men because of estrogenic effects. Am J Clin Nutr. 2004;80 (5):1167–74.
46. Singh KK, Mridula D, Rehal J, Barnwal P. Flaxseed: a potential source of food, feed and fiber. Crit Rev Food Sci Nutr. 2011;51 (3):210–22.
47. Rodriguez-Leyva D, Bassett CMC, McCullough R, Pierce GN. The cardiovascular effects of flaxseed and its omega-3 fatty acid, alpha-linolenic acid. Can J Cardiol. 2010;26(9):489–96.
48. Hedge MV, Wagh UV, Khan SA. Omega-3 fatty acid compositions with honey. PCT/IN2005/000163.
49. Shahidi F, Wanasundara PKJPD. Cyanogenic glycosides of flaxseeds. Antinutrients and phytochemicals in food. Chapter 10, p. 171–185. ACS Symposium Series, vol. 662.
50. Kasote D, Badhe YS, Hegde MV. Effect of mechanical press oil extraction processing on quality of linseed oil. Ind Crops Prod. 2013;42:10–3.
51. Hegde MV, Bhalerao SS, Kadam SS. Composition for chicken feed for production of omega-3 chicken and method thereof. Filed Patent Application No 1971/MUM/2012. Dated 07/02/2014.
52. Bhalerao SS, Hegde MV, Ranade A, Avari P, Nikam S, Kshirsagar K, Kadam SS. Studies in production of omega-3 chicken meat II. Ind J Poultry Sci. 2010;45(3):273–9.
53. Bhalerao SS, Hegde MV, Ranade A, Avari P, Nikam S, Kshirsagar K, Kadam SS. Studies in production of omega-3 chicken meat I. Ind J Poultry Sci. 2012;45(3):273–9.
54. Bhalerao SS, Hegde MV, Katyare SS, Kadam SS. Promotion of omega-3 chicken meat production: an Indian perspective. World's Poult Sci J. 2014;70:365–73.
55. Bhalerao SS, Hegde MV, Badhe YS, Kadam SS. Omega-3 fatty acids in the feed improve broiler chick health, presented at 2012 poultry association. Annual Meeting 9–12 at University of Georgia in Athens Georgia, USA.
56. Bakke JE, Klosterman HJ. A new diglucoside from flaxseed. In: Proceedings of the North Dakota Academy of Science, Grand Forks, North Dak, vol. 10. 1956. p. 18–21.
57. Zanwar AA, Aswar UM, Hegde MV, Bodhankar SL. Estrogenic and embryo-fetotoxic effects of ethanol extract of *Linum usitatissimum* in rats. J Complement Integr Med. 2010;7(1):Article 21:1–15.
58. Hu C, Yuan YV, Kitts DD. Antioxidant activities of the flaxseed lignan secoisolariciresinol diglucoside, its aglycone secoisolariciresinol and the mammalian lignans enterodiol and enterolactone in vitro. Food Chem Toxicol. 2007;45:2219–27.
59. Prasad K, Mantha SV, Muir AD, Westcott ND. Reduction of hypercholesterolemic atherosclerosis by CDC-flaxseed with very low alpha-linolenic acid. Atherosclerosis. 1998;136:367–75.
60. Prasad K. Hypocholesterolemic and antiatherosclerotic effect of flax lignan complex isolated from flaxseed. Atherosclerosis. 2005;179:269–75.
61. Prasad K. Oxidative stress as a mechanism of diabetes in diabetic BB prone rats: effect of secoisolariciresinol diglucoside (SDG). Mol Cell Biochem. 2000;209:89–96.
62. Prasad K. Secoisolariciresinol diglucoside from flaxseed delays the development of type 2 diabetes in Zucker rat. J Lab Clin Med. 2001;1:32–9.

63. Prasad K, Mantha SV, Muir AD, Westcott ND. Protective effect of secoisolariciresinol diglucoside against streptozotocin-induced diabetes and its mechanism. Mol Cell Biochem. 2000;206: 141–50.
64. Zanwar AA, Hegde MV, Bodhankar SL. Cardioprotective activity of flax lignan concentrate extracted from seeds of *Linum usitatissimum* in isoprenalin induced myocardial necrosis in rats. Interdisc Toxicol. 2011;4(2):90–7.
65. Zanwar AA, Hegde MV, Bodhankar SL. Antihyperlipidemic effect of flax lignan concentrate from seeds of *Linum usitatissimum* in triton induced hyperlipidemic rats. Int J Pharmacol. 2012;8(5): 355–63.
66. Mali AV, Chandorkar S, Hegde MV. In vitro anti-metastatic activity of enterolactone, a mammalian lignan derived from flax lignan, and down regulation of matrix metalloproteinases in MCF-7 and MDA MB 231 cell lines. Indian J Cancer. 2011;49(1):181–7.
67. Penumathsa SV, Koneru S, Thirunavukkarasu M, Zhan L, Prasad K, Maulik N. Secoisolariciresinol diglucoside: relevance to angiogenesis and cardioprotection against ischemia-reperfusion injury. J Pharmacol Expt Ther. 2007;320:951–9.
68. Kasote DM, Badhe YS, Zanwar AA, Hegde MV, Deshmukh KK. Hepatoprotective potential of ether insoluble phenolic components from n-butanol fraction (EPC-BF) of flaxseed against CCl4 induced liver damage in rats. J Pharm Bioallied Sci. 2012;4 (3):231–5.
69. Kasote DM, Zanwar AA, Devkar ST, Hegde MV, Deshmukh KV. Immunomodulatory activity of ether insoluble phenolic components of n-butanol fraction (EPC-BF) of flaxseed in rat. Asian Pac J Trop Biomed. 2012;2:S623–S626.

http://www.springer.com/978-3-319-40456-1

Omega-3 Fatty Acids
Keys to Nutritional Health
Hegde, M.V.; Zanwar, A.A.; Adekar, S.P. (Eds.)
2016, XXI, 610 p. 95 illus., 69 illus. in color., Hardcover
ISBN: 978-3-319-40456-1