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Flaxseed and Sports Nutrition – A Winning Combination

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Fitness trainers advise that a good diet can help in achieving fitness and sports results. It would appear that this message is being embraced not only by hard-core sports enthusiasts but increasingly by mainstream consumers. Euromonitor International attributes the ever growing sports nutrition market – globally valued at over $10 billion at the end of 2014 - to a continued rise of protein as a "super-nutrient" and consumer awareness of the need to incorporate exercise into a healthy lifestyle[1].

In 2014, the U.S. sports nutrition market, the largest in the world, represented about $5.95 billion. According to Euromonitor, products with the sports nutrition segment are expected to have strong growth with a CAGR 9%.

Moving into mainstream and 'beyond the athlete' is how Innova Market Insights views the sports nutrition market. These products are not "just for athletes, it's about healthy living" was how Innova described the growth in this segment. In fact, sports nutrition, that is "Beyond the Athlete", is identified as one of Innova's "10 Key Food & Beverage Trends to Watch for 2016[2].

Flaxseed – A Long history of Fitness use

Flaxseed and flaxseed oil are used by sports enthusiasts, professional and amateur athletes for muscle building and exercise endurance. Hollywood recognized the importance of the essential fatty acids (EFAs) in flaxseed when Oscar winner Hilary Swank (in the 2005 film "Million Dollar Baby") was challenged to transform her 110 lbs., 5'71/2" frame into that representative of a Women's World Boxing Champion. Swank put in many hours at the gym and in the boxing ring to get the desired result; but there was another key component to her success – flaxseed oil. On a post Oscar appearance on *The Tonight Show* with Jay Leno, Swank acknowledged that flaxseed oil was responsible for a significant part of her success in achieving the look she did for her role in the film.

Fast forward a decade and flaxseed continues to grow in popularity with sports enthusiasts and can now be found in sport nutrition products including foods, beverages

[1] Euromonitor International. December 2015. "Trends and Developments in Sports Nutrition". http://www.nutraingredients-usa.com/Markets/5.9-bomega-US-sports-nutritioomega-market-unlocking-mass-appeal-Euromonitor (Accessed January 25, 2016)

[2] Innova Market Insights. Top Ten Trends list for 2016. The Innova Database. www.innovadatabase.com. (Accessed January 25, 2016)

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and supplements. There are a number of nutritional constituents within this incredible seed that make it ideal for sports nutrition applications.

Essential Fatty Acids Required for Muscle Building

Essential fatty acids (EFA) are required in the diet as they cannot be made by humans. The two EFAs found in flaxseed are linoleic acid (C18:2, LA) which is an omega-6 fatty acid, and the omega-3 fatty acid alpha-linolenic, ALA (18:3, omega-3) – omega refers to different chemical characteristics of the fatty acids.

LA and ALA are components of cellular membranes and act to increase membrane fluidity. These fatty acids are necessary for cell membrane function, as well as for the proper functioning of the brain and nervous system[3,4]. Flaxseed is the richest dietary source of ALA. The oil constitutes 32-45% of the composition of flaxseed, of which 51-57% is ALA.

ALA plays an important role in growth and development, reproduction and vision; in maintaining healthy skin and cell structure; in the metabolism of cholesterol and in gene regulation; and in supporting heart health[5].

ALA is converted to the long-chain omega-3 fatty acids, eicosapentaenoic acid (EPA) and docosapentaenoic acid (DPA), and to some extent to docosahexaenoic acid (DHA), fatty acids that naturally occur in fish and fish oil. Similarly, LA is converted to long-chain omega-6 fatty acids, in particular arachidonic acid (AA), by the same series of desaturation and elongation enzymes that metabolize ALA (Figure 1).

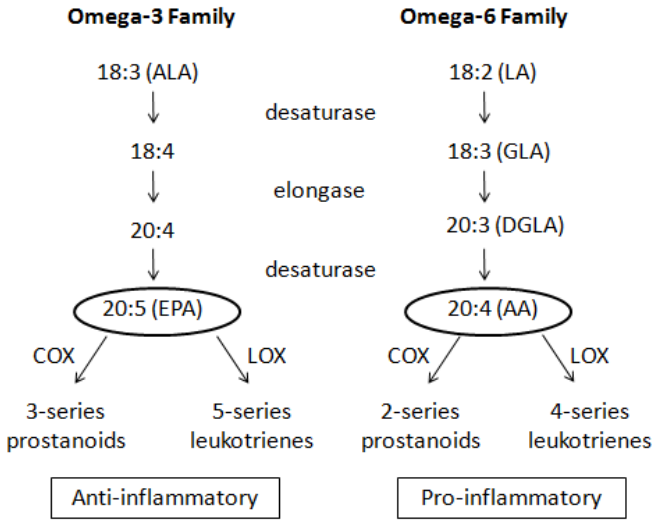
The metabolism of omega-3 fatty acids depends on other nutrients, particularly omega-6 fatty acids due to the competition for the same enzymes[6]. High levels of omega-6 fatty acids reduce the amount of omega-3 fatty acids incorporated into lipids that comprise human tissues as well as the conversion of ALA to the longer chain omega-3 fatty acids.

Higher amounts of dietary ALA as well as decreased LA increase the conversion of ALA to EPA and DHA[6,7]. The rate of conversion is fairly limited in humans, but ALA appears to provide health benefits on its own unrelated to conversion of the longer chain fatty

[3] Davis, B.C., Kris-Etherton, P.M. *Am J Clin Nutr;* 2003. 78(Suppl): 640S-660S.
[4] Harper, C.R. and Jacobson, T.A. *Arch Intern Med*; 2001. 161. 2185 – 2192
[5] Fleming JA, Kris-Etherton PM. *Adv. Nutr.* 2014;5(6):863S-876S.
[6] Brenna JT, et al. *Prostaglandins Leukot Essent Fatty Acids* 2009;80:85-91.
[7] Goyens PL, et al. *Am J Clin Nutr* 2006;84:44-53.

acids.[5] A gender difference in the conversion rate appears to exist, with estrogen increasing conversion in women compared to men.[8]

Figure 1. Overview of pathways for conversion of α- linolenic acid and linoleic acid to eicosanoids[5,9]



Abbreviations: ALA, alpha-linolenic acid; EPA, eicosapentaenoic acid; LA, linoleic acid; GLA, gamma-linolenic acid; DGLA, dihomo-gamma-linolenic acid; AA, arachidonic acid; COX, cyclooxygenase; LOX, lipooxygenase.

Eicosanoids, such as prostanoids and leukotrienes, are hormone-like substances that affect inflammation. They are produced from both ALA (less inflammatory) and LA (mostly pro-inflammatory; Figure 1). AA, derived from LA, is the starting point of the eicosanoid inflammatory cascade that affects a wide array of body functions.[10]

Inflammation can occur following intense bursts of exercise or long-term muscle strain[11]. A diet that is high in LA and low in ALA skew eicosanoid production towards a more inflammatory profile. Increasing dietary ALA intake from flaxseed can help a healthy body guard against inflammation.[12]

[8] Childs CE, et al. *Nutr J* 2014;13:113.
[9] Calder PC. *Am J Clin Nutr* 2006;83:1505S-1519S.
[10] Anand R, et al. *Inflammation* 2014;37:1297-1306.
[11] Sim, M et al. *European J Appl Physio.* 2012; 112(6):1889-1898.
[12] Caligiuri SP, et al. *Exp Gerontol* 2014;59:51-57.

α-linolenic Intake is Below Recommendations

The Institute of Medicine (IOM) recommended dietary intake of ALA is 1.6 g/day for men and 1.1 g/day for women, or 0.6-1.2% of energy intake, with a dietary omega-6 to omega-3 ratio of 5:1 to 10:1.[13] However, the consumption of omega 3 fatty acids is very inadequate in North America. Data from the 2003-2008 National Health and Nutrition Examination Survey (NHANES) in the U.S. showed that 40.8% of adults aged ≥19 years were not meeting the recommended dietary intake for ALA.[14]

The Importance of an Optimal Omega-6 to Omega-3 Ratio

A proper balance of the EFAs in the diet is important for the maintenance of good health and in sports – for optimum muscle development and overall physical performance. The activity of the omega-6 and omega-3 derived eicosanoids impacts proper cell function and the growth of tissues such as muscle. The eicosanoids influence the inflammatory process and the ability of the body to heal – both of which will affect exercise, endurance and athletic training.

For optimal health, Health Canada recommends an omega-6:omega-3 fatty acid dietary ratio of 4:1 to 10:1[2]. The U.S. Food and Drug Administration has yet to set an official recommendation in this area, although as mentioned the IOM recommends an omega-6:omega-3 ratio of 5:1 to 10:1.

In the past, dietary intake of omega-6 and omega-3 fatty acids were approximately equal, but modern diets have significantly changed resulting in very high omega-6 to omega-3 ratios (16:1 or higher).[15] Not only are people eating less omega 3, the overall availability of omega-6 LA in the food supply has increased from about 2.79% to 7.21% of energy from 1909 to 1999. The level of ALA in the food supply has only increased from 0.39% to 0.72% of energy due mostly to modifications in food processing. These changes resulted in the ratio of LA to ALA increasing from 6.4:1 in 1909 to 10.0:1 in 1999.[16]

Overall, we are consuming too much LA and not enough ALA. Studies indicate that a high intake of LA shifts the physiologic state to one that is prothrombotic and proaggregatory, characterized by increases in blood viscosity, vasospasm, and

[13] Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, D.C. National Academy Press, 2005.
[14] Papanikolaou Y, et al. *Nutr J* 2014;13:31.
[15] Liu J, et al. *Nutrients* 2014;6:5184-5223.
[16] Blasbalg TL, et al. *Am J Clin Nutr* 2011;93:950-962.

vasoconstriction, decreases in bleeding time and, of significance to exercise physiology – an inflammatory state[5,12].

ALA helps the healthy body combat the inflammatory state. It also aids with maintaining normal blood flow and viscosity; assists in maintaining a healthy heart rhythm; and helps normal blood vessel function[5].

Excessive free radical formation that occurs with cellular oxidation, and trauma during high-intensity exercise leads to an inflammatory state that is made worse by the increased amount of omega 6 fatty acids in Western diets[17]. This can be counteracted by the omega 3 fatty acids, in particular ALA and EPA.

For the majority of athletes, including those at the leisure level, ALA from flax is a crucial component for enhanced performance and general good health. In addition, flaxseed can help to improve LA to ALA ratios since it contains more than three times as much omega-3 as omega-6 fatty acids. Flaxseed enrichment in sports nutrition can provide healthier fatty acid profiles.

ALA and Sports Nutrition

About "Million Dollar Baby" – Flaxseed oil allowed Hilary Swank not only to reach her physical goals, but far surpass them. Her diet during training consisted of mostly proteins (egg whites, fish, etc.), almost no carbohydrates (except for some fibrous vegetables and controlled high-glycemic carb snacks), and flax oil (for its EFAs). The bulk of her caloric intake came from protein (for muscle and repair of muscle tissue after workouts) and flax oil (for continued growth). Flax oil provided her with nearly 1000 calories a day, a quarter of her daily intake. Without an abundance of carbohydrates, her body began accessing stored fat to use as energy. For athletes and in sports nutrition, one of the most important benefits of ALA, in this regard, is the role that it plays in optimizing energy reserves in the body[18].

ALA improves the metabolism of fats which is especially helpful with endurance sports, such as marathons. When a runner "hits the wall" and their glycogen stores are used up, the body begins burning fat[19]. In this case, efficient burning of fats makes a difference in performance.

[17] Simopoulos AP. 2007. *Curr Sports Med Rep.* 6(4):230-6.
[18] Ayre KJ, Hulbert AJ. 1997. *Lipids.* 32(12):1265-70.
[19] De Sousa, MV, et al. *European J Appl Physio*. 2007; 99(1):57-63.

ALA improves response time. Electrical impulses move from the brain to muscles across cell membranes which as indicated earlier are rich in ALA when consumed in the diet.[20] Omega-3 fatty acids, such as ALA, are the most efficient fatty acids in allowing these electrical impulses to move from cell to cell. Thus, response time is improved.

ALA aids in muscle repair at the cellular level. Omega 3 fatty acids present on the cell membrane significantly effect the speed and quality of tissue repair.

ALA and Inflammation

ALA is particularly helpful with the normal inflammation and the swelling that often accompanies serious training. ALA interferes with the conversion of omega-6 LA to AA and blocks the conversion of AA to its pro-inflammatory eicosanoids including thromboxane A_2 (TXA_2) and leukotriene B_4 (LTB_4). TXA_2 is one of the most potent promoters of platelet aggregation known. LTB_4 increases the release of reactive oxygen species and cytokines like tumor necrosis factor α (TNF-α), interleukin 1β (IL-1β), IL-6 and IL-8.

Early research identified ALA as the regulator of LA and AA metabolism. ALA acts to competitively inhibit the conversion of LA to AA resulting in decreased amounts of substrate available for the production of proinflammatory eicosanoids[21]. In human clinical research, ALA has been shown to reduce the proinflammatory TXA_2[22] and LTB_4[23]. Diets rich in ALA have also been shown to significantly decrease the concentration of AA in neutrophils[24], and in serum[25],[26].

Inverse relationships between dietary omega-3 fatty acids, highly related to ALA intake, and muscle mass have recently been reported, suggesting that omega-3 intake may be a regulator of muscle mass and protein metabolism[27]. A higher dietary ratio of omega-6:omega-3 fatty acids seemed to be associated with a reduced muscle mass. The investigators speculated that a reduction in inflammatory cytokines as a result of ALA intake may mitigate anabolic resistance of muscle protein synthesis.

The anti-inflammatory properties of ALA can reduce the incidence of exercise-induced bronchoconstriction (EIB) which is a condition characterized by transient airway

[20] Lowery, LM. *J Sports Sci Med.* 2004; 3:106-117
[21] Budowski, P. and Crawford, M. A. 1985. *Proceedings o fthe Nutrition Society*. 44. 221-229.
[22] Caughey GE, et al. 1996. *Am. J. Clin. Nutr*. 63: 116-122.
[23] Matsuyama W, et al. 2005. *Ches*t 128: 3817-3827.
[24] Healy DA, et al. 2000. *Lipids*; 35: 763-768.
[25]Zhao G, et al. 2004. *J. Nutr*. 134: 2991-2997.
[26] Zhao G, et al. 2007. *Am. J. Clin. Nutr*. 85: 385-391.
[27] Wong, TC, et al. *PLoS One*. 2015; 10(10):e0140402.

narrowing during or after exercise, resulting in decrements in post-exercise pulmonary function[28]. A high prevalence of EIB and asthma-like symptoms, such as wheezing, chest tightness, abnormal breathlessness, cough, and/or sputum production have been reported in elite athletes and increasingly in "weekend warriors" – individuals who exercise strenuously on an irregular basis[29].

EIB appears to involve multiple mechanisms. It has been suggested that transient dehydration of the airways activates the release of inflammatory mediators, such as AA metabolites (leukotrienes and prostaglandins), from airway cells, resulting in bronchial smooth muscle contraction[30]. Omega-3 fatty acids have been reported to improve pulmonary function and reduce several proinflammatory markers in athletes with EIB[28].

Flaxseed - An Excellent source of Protein

Flaxseed can be considered a very nutritious plant protein due to its composition of amino acids (AA), the building blocks of protein. The protein content of flaxseed varies from 20 to 30 %[31] constituting approximately 80% globulins and 20 % glutelin[32]. Flaxseed contains no gluten.

Protein is an essential nutrient required in the diet for growth and development and the maintenance of cellular structures, organs and muscle mass. It is especially critical for muscle building and normal exercise recovery.

There are nine essential amino acids: isoleucine, leucine, lysine, threonine, tryptophan, methionine, histidine, valine and phenylalanine. Non-essential amino acids are those that the body can manufacture and include: glutamic acid, alanine, aspartic acid, asparagine, glutamine, arginine, proline, serine, tyrosine, cysteine, and glycine.[13]

Proteins can be synthesized when there are sufficient quantities of all necessary AA available. If essential amino acids (EAA) are lacking, the body will be unable to make proteins and will have to break down muscle proteins to meet requirements.

Proteins from animal sources such as meat, poultry, fish, eggs, milk, cheese and yogurt, provide all nine EAA and are referred to as "complete" proteins. Plant proteins (from grains, pulses, nuts, seeds, and vegetables) are low in one or more specific EAA.

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[28] Mickleborough TD, et al. 2003. *Am. J Respir. Crit. Care Med.* 168(10):1181-9.
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[31] Oomah BD, Mazza G. *Food Chem* 1993:48:109-114.
[32] Hall C, et al. *Adv Food Nutr Res.* 2006;51:1-97.

The amino acid profile of flax is similar to that of other oilseeds (Table 1) and especially to that of soybeans[33]. Whole and milled flaxseed, oil-extracted flaxseed meals, and isolated flax proteins have high levels of glutamic acid/glutamine, arginine, and branched-chain amino acids (valine and leucine) and are low in aromatic amino acids (tyrosine and phenylalanine)[32].

Flax protein is limited in the EAA lysine[33] but can be combined with pulses to achieve a complete protein. EAA requirements can be met exclusively by plant proteins if a variety of plant sources are consumed to meet energy needs.[34]

Table 1. Protein and amino acid content of select oilseeds[32]

	Flaxseed	Soybean	Chia	Corn, yellow
	g/100 g	g/100 g	g/100 g	g/100 g
Protein	19.29	16.64	16.54	9.42
Tryptophan*	0.297	0.242	0.436	0.067
Threonine*	0.766	0.723	0.709	0.354
Isoleucine*	0.896	0.807	0.801	0.337
Leucine*	1.235	1.355	1.371	1.155
Lysine*	0.862	1.108	0.970	0.265
Methionine*	0.370	0.224	0.588	0.197
Cysteine	0.340	0.268	0.407	0.170
Phenylalanine*	0.957	0.869	1.016	0.463
Tyrosine	0.493	0.630	0.563	0.383
Valine*	1.072	0.831	0.950	0.477
Arginine	1.925	1.291	2.143	0.470
Histidine*	0.472	0.449	0.531	0.287
Alanine	0.925	0.784	1.044	0.705
Aspartic acid	2.046	2.093	1.689	0.655
Glutamic acid	4.039	3.224	3.50	1.768
Glycine	1.248	0.770	0.943	0.386
Proline	0.806	0.974	0.776	0.822
Serine	0.970	0.965	1.049	0.447

*Essential amino acids

[33] U.S. Department of Agriculture. USDA national nutrient database for standard reference. http://ndb.nal.usda.gov/ 2011. Accessed January 25, 2015.
[34] Craig WJ, Mangels AR. *J Am Diet Assoc* 2009;109:1266-1282.

The protein in flaxseed can make an important contribution to overall protein intake, particularly for vegetarians, people trying to consume less animal products and as a source of protein in sports nutrition and weight loss diets.

Protein Requirements and Sports Performance

The Recommended Dietary Allowance (RDA) of high quality protein (i.e., complete and/or complementary proteins) for both men and women is 0.80 g per kg body weight per day.[13] The Acceptable Macronutrient Distribution Range (AMDR) is "the range of intake for a particular energy source that is associated with reduced risk of chronic disease while providing intakes of essential nutrients". For protein, the AMDR is 10-35%.[13]

Physical activity is a powerful stimulus to promote net muscle protein anabolism (synthesis) which is important for all age groups. Resistance-type exercise in particular can effectively increase muscle strength and mass which can improve physical performance and functional capacity[35].

During the early 20th century, science evolved on the role of protein, fat and carbohydrates in athletic performance[36]. Among professional athletes, protein became an important nutrient in the diet to enhance muscle mass. In the 1950's and 1960's, athletes focused on milk and beef for their protein intake. Later in the 1970's, isolated protein powders and amino acids were introduced.

Increased protein synthesis rates following exercise can last for up to 16 hours in trained and 24–48 hours in untrained individuals[37]. Muscle protein breakdown is also stimulated following exercise, but to a lesser extent than protein synthesis[38]. Both exercise and nutrition are required to obtain a positive protein balance and as such to build muscle.

Research suggests that protein requirements may be somewhat higher than the levels established by the Institute of Medicine,[39] especially in athletes. However, this evidence has not yet prompted a revision of protein recommendations.

In studies comparing elite bodybuilders and endurance athletes with sedentary controls, nitrogen balance data revealed that bodybuilders required 1.12 times[40] (1.2 – 1.4 g/kg

[35] Evans, WJ. 1995. *J Gerontol A Biol Sci Med Sci* 50:147–150.
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[39] Elango R, et al. *Curr Opin Clin Nutr Metab Care* 2010;13:52-57.
[40] Tipton, KD and Wolfe, RR. 2004. *J Sports Sci*. 22:65–79

bw/day) and endurance athletes required 1.67 times (1.2 – 1.8 g/kg bw/day) more daily protein than sedentary controls[41].

Recovery products are prominent in sports nutrition, and one of the most efficient pathways to improved recovery is through high-quality protein (such as found in flaxseed) and carbohydrates. Consuming these macronutrients stimulates the release of insulin, a potent anabolic hormone that facilitates muscle uptake of amino acids and stimulates muscle protein synthesis. Dietary carbohydrate and protein also inhibit protein degradation and enable net muscle protein accretion.

Ingesting protein and/or amino acids prior to, during, and/or following exercise can enhance recovery, immune function, and growth and maintenance of lean body mass (LM). Consequently, protein and amino acid supplements can serve as a convenient way to ensure a timely and/or adequate intake for athletes[42].

Due to the importance of adequate and high-quality protein to the fitness regimes, this macronutrient has become the most lucrative category within sports nutrition, with global sales up 10% to reach $8.1 billion in 2014[1].

Branched Chain Amino Acids and Protein Synthesis

Increasing training induced gains through improving skeletal muscle regeneration is a focus of sports research. One such intervention has been to increase intakes of the branched chain amino acids (BCAAs), leucine, isoleucine, and valine, which make up more than one third of muscle protein[43]. The levels of BCAA in flaxseed (3.24 g/100g) are higher than those of soybean (2.96 g/100g) and chia (3.12 g/100g) (See Table 1).

BCAAs reduce fatigue and enhance exercise performance. One study has shown that BCAA supplementation enhances exercise capacity and lipid oxidation (for use as energy substrates) in glycogen-depleted subjects[44].

BCAAs are metabolized directly in the muscle and can be converted into energy to prevent muscle catabolism. BCAA consumption has been found to reduce or prevent the breakdown of muscle tissue for energy. And the use of BCAAs during and after exercise has been reported to produce a significant reduction of muscle breakdown during

[41] Tarnopolsky. MA, et al. 1988. *J Applied Physiol*. 64(1):187-193
[42] Kreider RB, Campbell B. 2009. *Phys Sportsmed.* 37(2):13-21.
[43] Phillips SM. 2012. *Br J Nutr*. 12(Suppl 2):S158–S167.
[44] Gualano AB,, et al. 2011. *J Sports Med Phys Fitness.*51(1):82.

exercise[45]. BCAAs may also stimulate skeletal muscle protein synthesis (MPS) to a similar degree as all 9 EAAs[46].

Plant-based proteins contain approximately 6–8% leucine and in low doses, they do not increase MPS compared to animal-based proteins, which contain approximately 8–11% leucine. However, if leucine is added to a plant-based protein, MPS rates are not significantly different from animal-based proteins[47].

Arginine and Exercise

Arginine functions as a precursor to nitric oxide, a potent vasodilator that allows increased blood flow. Nutritional manipulation to increase nitric oxide could influence oxygen kinetics and exercise performance. Flaxseed has a higher level of arginine than does soybean (1.925 g/100g vs. 1.291 g/100g).

Large doses of L-arginine appear to have positive effect on increasing vascular function which can improve exercise efficiency and enhance performance. Arginine supplementation may improve exercise capacity through the stimulation of MPS[48].

In exercising adults, arginine supplementation (6g/day) reduced the amount of oxygen required to perform exercise - that is, the same exercise load was completed, but with less energy expended[49]. Arginine supplementation also increased time to exhaustion by 26% during high intensity cycling.

Arginine has been shown to improve performance-related outcome variables. During a 5 wk. progressive strength training program, volunteers were given a placebo or supplement containing 1 g arginine and 1 g ornithine each day. The results suggest that arginine and ornithine taken in conjunction with a high intensity strength training program can significantly increase muscle strength and LM[50].

Flaxseed as a Source of Antioxidants

The Institute of Medicine (IOM) recommends that diets contain antioxidants. In addition to its high level of omega 3 and protein, flaxseed contains a wealth of antioxidant compounds. Antioxidants are important for sports nutrition applications.

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[45] Blomstrand, E, et al. 1991. *Euro J Applied Physiol Occup Physiol* 63(2):83-88.
[46] Gleeson M. 2005. *J Nutr.* 135(6 Suppl):1591S-5S.
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[50] Elam, R. P., et al. 1989. *J. Sports Med. Phys. Fitness* 29:52-56.

Increased aerobic metabolism during exercise is a potential source of oxidative stress. Working out increases oxygen consumption which will precipitate the production of reactive oxygen species (ROS). ROS occur as a result of processes necessary to sustain life, including breathing which generates approximately 90% of cellular ROS[51]. When there is an imbalance between the levels of ROS and antioxidants, oxidative stress can cause damage to cells.

The IOM defines an *antioxidant* as a substance in food that significantly decreases the adverse effects of reactive species on normal physiological functions in humans[52]. Antioxidants can "neutralize" ROS before they are able to damage cellular components. The body does have complex defense mechanisms that are supported by the consumption of antioxidant-containing foods.

Strenuous exercise increases oxygen consumption and causes disturbance of intracellular pro-oxidant–antioxidant homeostasis. ROS pose a serious threat to the cellular antioxidant defense system, such as diminished reserve of antioxidant vitamins and increased tissue susceptibility to oxidative damage. The cellular balance between pro-oxidants and antioxidants suggests that supplementation of antioxidants may be desirable for physically active individuals by providing a larger protective margin[53].

Flaxseed – Rich in Antioxidants

Flaxseed contains a number of antioxidants that can alleviate normal exercise induced oxidative stress which can be associated with decreased physical performance, muscular fatigue, muscle damage, and overtraining.

Lignans

Flaxseed is one of the richest sources of lignans providing 75-800 times higher levels than other plant sources. Depending on the method used for measuring lignans in foods, flaxseed contains 0.82-10.55 mg SDG/g of flaxseed. Whole seed and ground flaxseed typically contain between 0.7 and 1.9% SDG which is equivalent to approximately 77-209 mg SDG/tbsp of whole seed or 56-152 mg SDG/tbsp of ground flaxseed.[54]

[51] Goszcz K, et al. *Front Cardiovasc Med*. 2015;2:29.
[52] Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Institute of Medicine. Dietary Reference Intakes: Vitamin C, Vitamin E, Selenium, and Carotenoids. Washington, DC: National Academy Press, 2000. pp. 35-57, 364.
[53] Ji, LL. *Exp Biol Med (Maywood)*. 1999; 222(3):283-292
[54] Thompson, LU, et al. 2006. *Nutr. Cancer*, 54(2):184–201.

Lignans have been reported to be effective antioxidants against DNA damage and lipid peroxidation. These unique compounds show antioxidant efficacy against free radical promoters 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,20-azo-bis(2-amidinopropane) dihydrochloride (AAPH)-initiated peroxyl radical plasmid DNA damage and phosphatidylcholine liposome lipid peroxidation[55].

Phenolic acids

Phenolics are also antioxidants found in flaxseed. They consist of a wide variety of subgroups, including phenolic acids, flavonoids, stilbenes, coumarins, and tannins. Flaxseed contains about 8 to 10 g of total phenolic acids per kilogram (kg)[56]. Phenolic acids show significant protection against oxidation.

Ferulic acid is a phenolic phytochemical that possesses high antioxidant activity, and has anti-inflammatory properties[57].

Flavonoids

Flavonoids bind certain metals, interact with enzymes and have anti-oxidant actions. Flaxseed contains about 35-70 milligrams (mg) of flavonoids/100g[58].

Conclusions

There is no doubt that products for sports enthusiasts are increasing in nutritional sophistication and in popularity with a wide range of consumers. Flaxseed offers a number of unique compounds that make it ideal for muscle building and exercise endurance. It is the highest plant based source of the essential omega 3 fatty acid, alpha-linolenic acid (ALA), is a rich source of high quality protein, and contains a mixture of antioxidants including lignans.

As this article indicates, a proper balance of dietary essential fatty acids is important for the maintenance of good health and in sports – for optimum muscle development and overall physical performance. The eicosanoids derived from omega 6 and omega 3 fatty acids influence to different degrees the inflammatory process and the ability of the body to heal – both of which will affect exercise, endurance and athletic training. ALA helps the healthy body combat the inflammatory state and helps maintain healthy blood flow as well as a healthy heart and blood vessels.

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[58] Oomah BD, Mazza G. 1998. Functional Foods: Biochemical & Processing Aspects, ed Mazza G, Technomic Publishing, Lancaster, PA, pp. 91-138.

Excessive free radical formation that occurs with cellular oxidation and trauma during high-intensity exercise leads to an inflammatory state that is made worse by the increased amount of omega 6 fatty acids in Western diets. This can be counteracted by ALA as well as the high levels of anti-oxidants found in flaxseed.

ALA also improves athletic performance by stimulating the metabolism of fats which is especially helpful with endurance sports, such as marathons. Omega-3 fatty acids, such as ALA, are the most efficient fatty acids in allowing electrical impulses to move from cell to cell, which improves response and recovery time. And ALA within the cell membrane significantly aids in the speed and quality of tissue repair.

The amino acid profile of flax is ideal for sports nutrition products with its high levels of glutamic acid/glutamine, arginine, and branched-chain amino acids (valine and leucine). In particular, BCAAs reduce fatigue and enhance exercise performance. Recovery products are prominent in sports nutrition, and one of the most efficient pathways to improved recovery is through high-quality protein. Using flaxseed as a source of protein consumed prior to, during, and/or following exercise can enhance recovery, immune function, muscle development and the maintenance of lean body mass.

Strenuous exercise increases oxygen consumption and causes disturbance of intracellular pro-oxidant–antioxidant homeostasis. Flaxseed contains a number of antioxidants that can alleviate exercise induced oxidative stress which can be associated with decreased physical performance, muscular fatigue, muscle damage, and overtraining.

Mainstream consumers—from weekend warriors to emerging lifestyle fitness types—are interested in sports nutrition products to support everyday health and more active lifestyles. Flaxseed is recognized and valued by all groups of consumers looking for whole, real “clean” foods. And for the increasing number of people who are moving away from animal products - from part-time vegetarians (“flexitarians”) to vegans – flaxseed can provide the essential fatty acids and plant-based proteins required for products targeted at this segment. Sports nutrition products loaded with the healthy bioactives that flaxseed provides can meet both old and new market trends.

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