



Flaxseed and Sports Nutrition – A Winning Combination

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There is an increasing awareness of the importance of nutrition among athletes both young and old. The message that a healthy diet is instrumental to meeting fitness goals is being embraced by hard-core muscle builders, athletes, coaches, trainers and “everyday” fitness enthusiasts.

Physical activity reduces the risk of developing or dying from some of the leading causes of illness and death in the Western world. Regular exercise can provide protection from heart disease and stroke, high blood pressure, noninsulin-dependent diabetes, obesity, back pain, osteoporosis, and can improve mood and help with stress management. Flaxseed contains omega 3 fatty acids, protein and antioxidants that support not only health and wellness but effective sports performance.

Despite COVID-19 challenges, the global sports nutrition market size is expected to grow at a compound annual growth rate (CAGR) of 9% to 12% from 2020 to 2027. In 2019, the industry was valued at USD 15.6 billion with North America accounting for over 60% of the market¹. Rising disposable income, rapid urbanization and an increase in the number of gyms and health and fitness centres is influencing market growth.

The continued interest in protein as a “super-nutrient” and consumer awareness of the need to incorporate exercise into a healthy lifestyle are important drivers of the sports market².

So too are the growing segment of active seniors. In 2015, close to 9% of people worldwide (617 million) were aged 65 and over, and this is projected to increase to 17% of the global population by 2050 (1.6 billion)³. America’s 65-and-over population will nearly double over the next three decades, from 48 million to 88 million by 2050⁴. The proportion of the Canadian population who are seniors is increasing. By 2056 it is estimated that one quarter of the population (13 million) will be aged 65 years and

¹ Grandview Research. Feb 2020. “Sports Nutrition Market Size, Share & Trends”. Sports Nutrition Market Size & Growth Report, 2020-2027 (grandviewresearch.com)

² Omega 3 sports drink to fight muscle damage (nutritioninsight.com)

³ An Aging World: 2015 (census.gov)

⁴ www.seniorcare.com/featured/aging-america/



older⁵. With these statistics, attention to diet and nutrition for active living as well as for healthy aging in general, will only increase.

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., 5’7 1/2” frame into that representative of a Women’s World Boxing Champion. Swank put in many hours at the gym to achieve 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 to today where flaxseed continues to grow in popularity in nutritional and sports products including foods, beverages 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 (C18:3, ALA). 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^{6,7}. Flaxseed is the richest dietary source of omega-3 ALA. The oil constitutes 32-45% of the composition of flaxseed, of which 51-57% is ALA (Table 1).

⁵ The Chief Public Health Officer's Report on the State of Public Health in Canada 2014 – Changing demographics, aging and health - Canada.ca

⁶ Davis, B.C., Kris-Etherton, P.M. *Am J Clin Nutr*; 2003. 78(Suppl): 640S-660S.

⁷ Harper, C.R., Jacobson, T.A. *Arch Intern Med*; 2001. 161. 2185 – 2192



Table 1. Average content of α -linolenic acid in select food sources^{8,9,10}

Food Item	Average content (%)
Flaxseed oil	53
Flaxseed	23
Chia seed	18
Hempseed	17
Walnuts, English	9
Canola oil	9
Soybean oil	7
Corn oil	7
Olive oil	1
Sunflower oil	1
Kale	0.2
Spinach	0.1

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 health¹¹.

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 enzymes¹². High levels of omega-6 fatty

⁸ Kim KB, et al. *Food Chem Toxicol* 2014;70c:163-178.

⁹ Rajaram S. *Am J Clin Nutr* 2014;100:443s-448s.

¹⁰ Goldberg EM, et al. *J Food Sci* 2012;77:S153-160.

¹¹ Fleming JA, Kris-Etherton PM. *Adv Nutr* 2014;5(6):863S-876S.

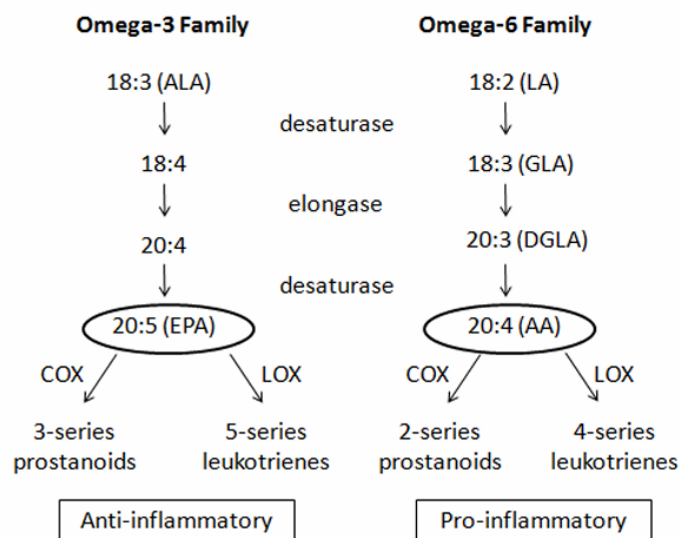
¹² Brenna JT, et al. *Prostaglandins Leukot Essent Fatty Acids* 2009;80:85-91.



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^{12,13}. The rate of conversion is somewhat limited in humans, but ALA appears to provide health benefits on its own unrelated to conversion to the longer chain omega-3 fatty acids¹¹. A gender difference in the conversion rate appears to exist, with estrogen increasing conversion in women compared to men.¹⁴

Figure 1. Overview of pathways for conversion of α -linolenic acid and linoleic acid to eicosanoids^{11,15}



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).

¹³ Goyens PL, et al. *Am J Clin Nutr* 2006;84:44-53.

¹⁴ Childs CE. *Proc Nutr Soc* 2020;79(2):219-224.

¹⁵ Calder PC. *Am J Clin Nutr* 2006;83:1505S-1519S.



AA, derived from LA, is the starting point of the eicosanoid inflammatory cascade that affects a wide array of body functions.¹⁶ Inflammation can occur following intense bursts of exercise or long-term muscle strain¹⁷. 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.¹⁸

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 10:1.¹⁹ However, intake greater than 2 g/day may be needed to provide the greatest protection against cardiovascular disease¹¹.

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.²⁰ More recent data from the NHANES show that average ALA intake had only increased slightly from 1.59 g/day in 2003-2004 to 1.82 g/day in 2011 2012.²¹

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.

¹⁶ Anand R, et al. *Inflammation* 2014;37:1297-1306.

¹⁷ Sim, M et al. *European J Appl Physio* 2012;112(6):1889-1898.

¹⁸ Caligiuri SP, et al. *Exp Gerontol* 2014;59:51-57.

¹⁹ 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.

²⁰ Papanikolaou Y, et al. *Nutr J* 2014;13:31.

²¹ Petersen K, et al. *Curr Dev Nutr* 2020;4(10):1-11.



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).²² 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 1999.²³ The shift in the LA to ALA ratio is concerning because evidence suggests that a high ratio may inhibit the conversion of ALA to EPA.²⁴

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 pro aggregatory, characterized by increases in blood viscosity, vasospasm, and vasoconstriction, decreases in bleeding time and, of significance to exercise physiology – an inflammatory state.^{11,18}

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.²⁵

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 diets²⁶. 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 flaxseed 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.

²² Liu J, et al. *Nutrients* 2014;6:5184-5223.

²³ Blasbalg TL, et al. *Am J Clin Nutr* 2011;93:950-962.

²⁴ Greupner T, et al. *Food Funct* 2018;9(9):4742-4754.

²⁵ Stupin M, et al. *Front Physiol* 2019;10:1129.

²⁶ Simopoulos AP. *Curr Sports Med Rep* 2007;6(4):230-6.



ALA and Sports Nutrition

For athletes and in sports nutrition, one of the most important benefits of ALA is the role that it plays in optimizing energy reserves in the body²⁷.

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 fat²⁸. In this case, efficient burning of fats makes a difference in performance.

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.²⁹ 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 affect the speed and quality of tissue repair. Significant increases in lean mass were observed in older adults supplemented during a 12-week resistance training program with 14 g/ day of ALA from flaxseed oil³⁰. While this study cannot delineate the impact of ALA supplementation versus exercise training in the increase in lean mass, it nonetheless suggests an effect on enhancing lean tissue growth. The mechanism by which diets high in ALA lead to enhanced nutrient partitioning towards increased lean mass deposition in humans is largely unknown, although ALA may promote muscle anabolism by increasing protein synthesis and decreasing protein degradation³¹.

ALA and Inflammation

ALA is particularly helpful with the normal inflammation and 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 A2 (TXA2) and leukotriene B4 (LTB4). TXA2 is one of the most potent promoters of platelet aggregation known. LTB4 increases the release of reactive oxygen species and cytokines like tumor necrosis factor α (TNF- α), interleukin 1 β (IL-1 β), IL-6 and IL-8.

²⁷ Ayre KJ, Hulbert AJ. *Lipids* 1997;32(12):1265-70.

²⁸ De Sousa, MV, et al. *European J Appl Physio* 2007;99(1):57-63.

²⁹ Lowery, LM. *J Sports Sci Med* 2004; 3:106-117

³⁰ Cornish SM, Chilibeck PD. *Appl Physiol Nutr Metab.* 2009;34(1):49-59.

³¹ Monnard CR, Dulloo AG. *Obes Rev.* 2021 Mar;22 Suppl 2:e13197. doi: 10.1111/obr.13197.



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 eicosanoids³². In human clinical research, ALA has been shown to reduce the proinflammatory TXA₂ and LTB₄. Diets rich in ALA have also been shown to significantly decrease the concentration of AA in neutrophils³⁵ and in serum^{36,37}.

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 metabolism³⁸. 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 narrowing during or after exercise, resulting in decrements in post-exercise pulmonary function³⁹. 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 basis⁴⁰.

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 contraction⁴¹. Omega-3 fatty acids have been reported to improve pulmonary function and reduce several proinflammatory markers in athletes with EIB²⁸.

³² Budowski, P. and Crawford, M. A. *Proc Nutr Soc* 1985;44: 221-229.

³³ Caughey GE, et al. *Am J Clin Nutr* 1996;63: 116-122.

³⁴ Matsuyama W, et al. *Chest* 2005;128:3817-3827.

³⁵ Healy DA, et al. *Lipids* 2000;35:763-768.

³⁶ Zhao G, et al. *J. Nutr* 2004;134: 2991-2997.

³⁷ Zhao G, et al. *Am J Clin Nutr* 2007;85:385-391.

³⁸ Wong, TC, et al. *PLoS One*. 2015;10(10):e0140402.

³⁹ Mickleborough TD, et al. *Am J Respir Crit Care Med* 2003;168(10):1181-9.

⁴⁰ Paul DW, et al. 1993. *Int J Sports Med*. 14:433-436.

⁴¹ Karjalainen EM, et al. *Am J Respir Crit Care Med* 2000;161:2086-2091.



ALA and Immunity

The COVID pandemic has led to higher numbers of consumers seeking nutritional tools as a way to support their immune health. These trends have carried over to the sports nutrition segment where the use of omega-3 fatty acids such as ALA in fitness bars, beverages and in supplements is on the rise^{42,43}.

The immune system protects the body from invading pathogens, such as viruses or bacteria. It comprises a unique group of cells as well as cell-independent mechanisms. Immune cells include a wide array of compounds such as macrophages, neutrophils, eosinophils, basophils, mast cells and natural killer cells which are the first cellular line of defense⁴⁴.

Research supports the role that dietary ALA can play in building a strong immune system. ALA in 30 g/day of flaxseed administered for one-month periods provided positive enhancement of immune cells in an immune-compromised population with systemic lupus erythematosus⁴⁵ and in morbidly obese patients⁴⁶. In adipose tissue macrophages, higher levels of immune stimulating resolving compounds (IL-4, IL-10 and arginase 1) were reported following ALA supplementation in mice⁴⁷. Similar positive effects were noted on the immune biomarkers, phospholipase A2, IgE, interferon gamma (INF- γ) and the INF- γ /IL4 ratio in immune-suppressed rats following ALA administration⁴⁸.

Dietary flaxseed ALA works as both a mitigator and protector of the various cells associated with immune responses to virus, bacteria etc. Enhancing immunity is an important quality for sports nutrition products. With “exercise as medicine,” “fitness for older adults,” and “exercise for lifestyle medicine” ranking among the top global sports nutrition trends for 2021, according to the American College of Sports Medicine, immune-boosting sports support products are becoming an impressive market segment⁴⁹.

⁴² Louca, P, et al. 2020. medRxiv. <https://www.medrxiv.org/content/10.1101/2020.11.27.20239087v1>

⁴³ Hamulka, J, et al. *Nutrients* 2021, 13, 54. <https://dx.doi.org/10.3390/nu13010054>

⁴⁴ Gutiérrez S, et al. 2019. *Int. J. Mol. Sci.* 20, 5028.

⁴⁵ Clark WF, et al. 1995. *Kidney Inter* 48:475-480.

⁴⁶ Faintuch J, et al. 2007. *Obesity Surg* 17:341-347.

⁴⁷ Bashir S, et al. *PLoS One*. 2019. *PLoS One*. Oct 17;14(10):e0223070. doi: 10.1371/journal.pone.0223070.

⁴⁸ Kavesh M, et al. 2019. *Iran J Basic Med Sci.* Mar;22(3):255-261. doi: 10.22038/ijbms.2019.27381.6684

⁴⁹ Worldwide Survey of Fitness Trends for 2021: ACSM's Health & Fitness Journal (lww.com)



Flaxseed - An Excellent Source of Protein

Flaxseed can be considered a very nutritious plant protein due to its composition of amino acids, the building blocks of protein. The protein content of flaxseed varies from 20 to 30%⁵⁰ constituting approximately 80% globulins and 20% glutelin⁵¹. 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 (EAA, Table 2). Non-essential amino acids are those that the body can manufacture.

Proteins can be synthesized when there are sufficient quantities of all necessary amino acids available. 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.

The amino acid profile of flax is similar to that of other oilseeds (Table 2) and especially to that of soybeans⁵².

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)^{48,49}.

Flax protein is limited in the EAA lysine^{48,49} 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.⁵³

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

⁵⁰ Oomah BD, Mazza G. *Food Chem* 1993;48:109-114.

⁵¹ Hall C, et al. *Adv Food Nutr Res* 2006;51:1-97.

⁵² U.S. Department of Agriculture. USDA national nutrient database for standard reference. <http://ndb.nal.usda.gov/> 2011. Accessed March 6, 2021.

⁵³ Craig WJ, Mangels AR. *J Am Diet Assoc* 2009;109:1266-1282.



Table 2. Protein and amino acid content of select oilseeds^{48,49}

	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

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.¹⁹ 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%.¹⁹



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 capacity⁵⁴.

During the early 20th century, science evolved on the role of protein, fat and carbohydrates in athletic performance⁵⁵. 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 individuals⁵⁶. Muscle protein breakdown is also stimulated following exercise, but to a lesser extent than protein synthesis⁵⁷. 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,⁵⁸ especially in athletes. However, this evidence has not yet prompted a revision of protein recommendations.

Protein intake is particularly important for bodybuilders to promote muscle growth. For muscle hypertrophy, protein intake between 1.4 g/kg/day to 2.0 g/kg/day is recommended, though some evidence indicates that even higher protein intake (≥ 3.0 g/kg/day) may support greater muscle development.⁵⁹ For optimal protein utilization, intake should be distributed evenly throughout the day as part of 3-6 meals, including within 1-2 hours before and after training.⁶⁰

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.

⁵⁴ Evans, WJ. *J Gerontol A Biol Sci Med Sci* 1995;50:147–150.

⁵⁵ Applegate E., Grivetti L. *J Nutr* 1997;127: 5, 869S–873S.

⁵⁶ Tang JE, et al. *Am J Physiol Regul Integr Comp Physiol* 2008;294: R172–R178.

⁵⁷ Phillips SM, et al. *Am J Physiol Endocrinol Metab* 1997;273: E99–E107.

⁵⁸ Elango R, et al. *Curr Opin Clin Nutr Metab Care* 2010;13:52–57.

⁵⁹ Ribeiro AS, et al. *Sports Med* 2019;49(10):1481–1485.

⁶⁰ Iraki J, et al. *Sports (Basel)* 2019;7(7):154.



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. Consequently, protein and amino acid supplements can serve as a convenient way to ensure a timely and/or adequate intake for athletes⁶¹.

Due to the importance of adequate and high-quality protein in fitness regimes, this macronutrient has become the most lucrative category within sports nutrition. In 2020, the global protein supplement market was estimated to be worth US\$18.91 billion and is expected to grow 8.4% annually from 2021 to 2028.⁶²

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 protein⁶³. 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 2).

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 subjects⁶⁴.

BCAAs are metabolized directly in the muscle and can be converted into energy to prevent muscle catabolism. BCAA consumption has been found to reduce exercise induced muscle damage and accelerate recovery in athletes.⁶⁵ BCAAs may also stimulate skeletal muscle protein synthesis (MPS) to a similar degree as all 9 EAAs⁶⁶.

⁶¹ Kreider RB, Campbell B. *Phys Sports Med* 2009;37(2):13-21.

⁶² Grand View Research, Inc. 2021. <https://www.grandviewresearch.com/industry-analysis/protein-supplements-market>.

⁶³ Phillips SM. *Br J Nutr* 2012;12(Suppl 2):S158–S167.

⁶⁴ Gualano AB, et al. *J Sports Med Phys Fitness* 2011;51(1):82.

⁶⁵ Bongiovanni T, et al. *Eur J Appl Physiol* 2020;120(9):1965-1996.

⁶⁶ Gleeson M. *J Nutr* 2005;135(6 Suppl):1591S-5S.



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 proteins⁶⁷.

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 soybean (1.925 g/100g vs. 1.291 g/100g) and other plant-based proteins.

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 MPS⁶⁸.

In exercising adults, arginine supplementation (6 g/day) reduced the amount of oxygen required to perform exercise - that is, the same exercise load was completed, but with less energy expended⁶⁹. 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-week progressive strength training program, volunteers were given a placebo or supplement containing 1 g arginine and 1 g ornithine each day. Ornithine may help maintain arginine levels and increase levels of anabolic hormones. The results suggest that arginine and ornithine taken in conjunction with a high intensity strength training program can significantly increase muscle strength and lean body mass⁷⁰.

Flaxseed as a Source of Antioxidants

The Institute of Medicine (IOM) defines antioxidants as substances in foods that significantly decrease the adverse effects of reactive oxygen and nitrogen species on normal physiological functions.⁷¹ In addition to its high level of omega-3 and protein,

⁶⁷ Norton LE, et al. *Nutr Metab* 2012;9(1):67.

⁶⁸ Paddock-Jones D, et al. *J Nutr* 2004;134(10 Suppl):2888S-2894S

⁶⁹ Luiking, YC, et al. *Curr Opin Clin Nutr Metab Care* 2010;13(1): 97–104.

⁷⁰ Elam, R. P., et al. *J Sports Med Phys Fitness* 1989;29:52-56.

⁷¹ Institute of Medicine. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, D.C. National Academy Press, 2000.



flaxseed contains a wealth of antioxidant compounds. Antioxidants are important for sports nutrition applications.

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 ROS⁷².

Antioxidants can “neutralize” ROS before they are able to damage cellular components. The body has complex defense mechanisms that are supported by the consumption of antioxidant-containing foods, but when there is an imbalance between the levels of ROS and antioxidants, oxidative stress can cause damage to cells.

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 margin⁷³.

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. Secoisolariciresinol diglucoside (SDG) is a lignan in flaxseed that has been associated with protection against chronic diseases, including cardiovascular disease, diabetes, and cancer.⁷⁴ 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.⁷⁵

⁷² Goszcz K, et al. *Front Cardiovasc Med* 2015;2:29.

⁷³ Ji, LL. *Exp Biol Med* (Maywood) 1999;222(3):283-292.

⁷⁴ Kezimana P, et al. *Front Genet* 2018;9:641.

⁷⁵ Thompson, LU, et al. *Nutr. Cancer* 2006;54(2):184–201.



Lignans are very effective antioxidants against DNA damage and lipid peroxidation. Lignans provide protection against free radical promoters 1,1-diphenyl-2-picrylhydrazyl

(DPPH) and 2,20-azo-bis(2-amidinopropane) dihydrochloride (AAPH)-initiated peroxy radical plasmid DNA damage and phosphatidylcholine liposome lipid peroxidation⁷⁶.

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)⁷⁷. Phenolic acids show significant protection against oxidation. Ferulic acid is a phenolic phytochemical in flaxseed that possesses high antioxidant activity, and has anti inflammatory properties⁷⁸.

Flaxseed and the Gut Microbiome

The gut microbiome is gaining recognition for playing a significant role in human health. It has been known for some time that flaxseed lignans, such as SDG, need to be metabolized by intestinal bacteria in order to be absorbed into circulation and function as antioxidants.⁷⁹

Research is now emerging in animals that suggests that flaxseed may also have positive effects on the composition of the gut microbiota, possibly due to the fibre and/or oil found in flaxseed, and exercise may augment the effect. For example, a study in rats found that high-intensity interval training and ALA supplementation helped to prevent weight gain by modulating the intestinal microbiota.⁸⁰ In addition, flaxseed lignans may modulate the gut-brain axis⁸¹ – the two-way communication between the gut microbiota and the brain – which is only starting to be understood in the research community and has enormous potential for improving human health.

⁷⁶ Hu C, et al. *Food Chem Toxicol* 2007;45:2219–2227.

⁷⁷ Velioglu YS, et al. *J. Agric. Food Chem* 1998;46, 4113–4117.

⁷⁸ Herrera E, et al. *Nutr Rev* 2009;67 Suppl 1:S140–14.

⁷⁹ Parikh M, et al. *Nutrients* 2019;11:1171.

⁸⁰ Plissonneau C, et al. *Nutrients* 2021;13:788

⁸¹ Senizza A, et al. *Molecules* 2020;25:5709.



Conclusions

Athletes and active adults seek the same benefits - performance, recovery and improved overall health. These common goals have shifted the sports nutrition category to a broader consumer base and a more mass-market focus including the typical weekend warriors as well as a growing number of 'casual consumers' interested in exercise to improve overall wellness.

Flaxseed offers a unique combination of nutrients that make it ideal for muscle building, exercise endurance and everyday work-outs. It is the highest plant-based source of the essential omega-3 fatty 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 combat the inflammatory state and helps maintain healthy blood flow as well as a healthy heart and blood vessels.

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.

Excessive free radical formation that occurs with cellular oxidation and trauma during 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.

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 antioxidants 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.

Contact us to learn more.