



SEEDS AS NUTRACEUTICALS, THEIR THERAPEUTIC POTENTIAL AND THEIR ROLE IN IMPROVING SPORTS PERFORMANCE

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Seeds hold an important place in the diet of an individual as well as in sports nutrition. They have excellent nutritional value and are non-conventional sources of carbohydrates, proteins, and many other important nutrients. They are also categorised under super foods or functional foods because they provide numerous health benefits in addition to providing nutrition and energy. This review provides a comprehensive overview of popular seeds that are added to athletes' diets or ordinary people's diets to enhance food's nutritional value. It focuses on their nutritional value, therapeutic value, and performance-enhancing attributes. Some of the trending seed supplements have been discussed in this review, including Chia seeds (*Salvia hispanica* L.), Flax seeds (*Linum usitatissimum*), Pumpkin seeds (*Cucurbita maxima*), Quinoa seeds (*Chenopodium quinoa* Willd.), Amaranth seeds (*Amaranthus cruentus*), Sesame seeds (*Sesamum indicum*), Hemp seeds (*Cannabis sativa* L.). These are some of the healthiest seeds that can be supplemented in regular diet according to individual health goals. The therapeutic potential of these seeds are also discussed which helps prevent many diseases. The purpose of this review is to bring together the latest research on role of seeds as nutraceuticals, therapeutics and the benefits of using them as supplements as a part of daily dietary intake for individuals as well as athletes for improving their performance.

Keywords: Functional foods, Nutraceuticals, Performance-enhancing, Seeds, Sports nutrition, Supplements, Therapeutic.

Introduction

Seeds have immense biological, medicinal, nutritional, and economic value. In other words, seeds are the bearers of life that protect, nourish the embryo, and give rise to a new young plant under suitable conditions. They have rich starch, protein, and oil reserves which helps in the proper growth and development of a plant and explains their importance as a major food source as cereals and legumes for the entire world. They are also a rich source of

nutrients, including protein, carbohydrates, essential fatty acids, fibre, vitamins, oil, minerals, and many other nutrients. Considering their nutritional benefits, this review also illustrates the importance of seeds in enhancing sports performance or exercise performance for an athlete. They have nutraceutical value because they provide an appropriate amount of energy, nutrients and also have bioactive compounds that aid in preventing diseases. Different seeds have specific medicinal or

therapeutic value in preventing or treatment of cardiovascular diseases, diabetes, hypertension, thyroid disorders, cancer, oxidative stress, and other harmful conditions. In this review, properties of Chia seeds, Flax seeds, Pumpkin seeds, Quinoa seeds, Amaranth seeds, Sesame seeds, and Hemp seeds have been discussed in detail in the context of their nutritional profile, disease-preventing attributes, and role in strength gain and performance improvement in resistance or endurance training and sports. The importance of seeds as a supplement in the human diet has gained a lot of attention recently and is expected to increase in the future to meet the nutrition demands of people throughout the world. Dietary supplementation of seeds in appropriate amounts can have a positive impact on overall human health in providing optimal nutrition, boosting energy levels, and protecting from multiple diseases.

Seeds with high nutritional value, therapeutic and performance-enhancing potential:

Chia seeds (*Salvia hispanica L.*)

Chia seeds were used as fuel by runners and warriors during long distance run or battle^{1,2}. The literal meaning of Chia is 'strength', its taken from Mayan language. Chia seeds are abundant in vitamins, omega-3 fatty acids, antioxidants and have a high nutritional value^{1,3,4}. It consists of dietary fiber, protein, omega-3 fatty acids, omega-6 fatty acids, calcium, phosphorus, copper, potassium, zinc, essential fatty acids alpha-linolenic and linoleic acid, vitamin A, B, E, and D, sulfur, iron, iodine, magnesium, manganese, thiamine, niacin^{1,3,5,6}. Aztec warriors consumed these seeds to boost their energy, increase stamina and endurance. Originally it was grown in Mexico and Central America, and was used as currency in previous times². It also has high medicinal value². Chia seeds are growing popular recently as sports nutrition supplement⁵ and are used in several sports such as marathon running, obstacle course

training, military exercises, iron man competitions, cycling, and swimming³. These seeds provide satiety and a slow release of energy which helps increase stamina to sustain energy levels for several hours without getting exhausted. It offers dynamic sports nutrition by slowly releasing energy and furnishing the body with a broad range of nutrients, antioxidants, vitamins, minerals, and omega-3 essential fatty acids^{1,2,5}. The nutrition provided by chia seeds helps increase the oxygen-carrying capability of blood, maintaining hydration and keeping athletes healthy during training and workouts³. Carbohydrate loading is one of the critical strategies used by athletes before a competition or event involving endurance sports or events lasting >90 minutes^{7,8}. It is well documented that high dietary carbohydrate intake before competition helps in increasing muscle glycogen stores resulting in performance improvement^{7,8}. In a study by Illian *et al.*, omega-3 rich chia seeds have been shown as a viable option for improving performance for endurance events and helped athletes to decrease their dietary sugar intake⁹. However, some studies contradict the performance-enhancing effect of chia seeds; a study by Nieman *et al.* reported no increase in running performance after ingestion of chia seed oil, although an increase in plasma level of alpha-linolenic acid was observed¹⁰. A recent study by Lestari *et al.*, has shown that chia seeds can be used as the main ingredient in making high-energy sports gel¹¹. Chia seeds have multiple health promoting properties as well as therapeutic applications¹²⁻¹⁴. Numerous studies have attributed these seeds with antineoplastic, analgesic, laxative, and hypotensive properties^{3,15,16}. It protects the cardiovascular system, regulates lipid metabolism, and has anticoagulant, anti-oxidative⁴ as well as anti-inflammatory properties^{3,15,17}. Considering the numerous medicinal and nutritional properties, many scientific studies are being conducted to

validate the safety and efficacy of chia seed supplementation^{12,13,15}.

Flax seeds (*Linum usitatissimum*)

Flax seeds have multiple health benefits and have nutritional and medicinal value¹⁸⁻²¹. Its medicinal uses have been described in history, such as in ancient Greek time, Hippocrates, the father of medicine, suggested flax seeds consumption for the relief of abdominal pain¹⁸. Theophrastus recommended the use of flax mucilage as a remedy for cough¹⁸. It is rich in dietary fibers, protein, omega-3 fatty acids, antioxidants, vitamins E, K, C, B1, B3, B5, B6, potassium, magnesium, calcium, iron, phosphorus and other essential nutrients^{19,20}. Flax seeds are known for its omega-3 essential fatty acid content, and therefore consumption of flax seeds helps in lowering cholesterol²², lowering the risk of cancer, reducing inflammation, improving heart health²³ and stabilising blood sugar²⁴. Its Omega-3 fatty acids also help reduce inflammation in muscles and support muscle fibre regeneration in athletes. Its consumption has also been found to aid weight loss and enhance energy levels. It also contains lignans and fiber which act as phytoestrogens and antioxidants¹⁹. It is rich in alpha linolenic acid and thus lowers the risk of many diseases such as heart disease²⁴, arthritis, Parkinson's disease and others. Its rich fiber content also helps in maintaining good gut and digestive health, improving cardiovascular health²⁵ and maintaining blood sugar levels^{26,27}. Thiamin is another important ingredient in flax seeds that supports energy yielding metabolism and maintains a healthy nervous system²⁷. Antihypertensive action of dietary flaxseed has also been observed in hypertensive patients²⁸. Many studies have shown the therapeutic and medicinal properties of flax seeds with the power to fight heart disease²³, cancer, diabetes²⁹, osteoporosis, autoimmune disorders, atherosclerosis³⁰ and many other diseases^{18,27}. In an *in vivo* study by Nounou et al., the effect of Flaxseed supplementation in combination

with muscular exercise has been shown to confer protective role against harmful effects of acute myocardial ischemia³¹. Another study by Halalkhor *et al.* elucidated the oxidative damage amelioration effect by flax seeds supplementation along with concurrent physical activity in overweight women³². Although there are some studies showing the positive effect of flax seeds supplementation with exercise or in sports, but still a lot more studies are needed to establish the scientific evidence behind its overall health and performance-enhancing activity.

Pumpkin seeds (*Cucurbita maxima*)

Pumpkin seeds contain a rich repertoire of nutrients such as proteins, magnesium, fiber, zinc, unsaturated fatty acids, phenolic acids, carotenoids and a no. of other nutrients^{6,33-35}. They have been found to exhibit antioxidative, hypoglycemic, antihypertensive³⁶, anticancer, antilipemic, cardioprotective and gynoprotective properties³³. Magnesium plays an important role in muscle protein synthesis, nerve function and blood pressure regulation which are important for athletes in training or sports³⁵. Pumpkin seeds have also been shown to have therapeutic effect for multiple diseases³⁷. An *in vivo* study by Arzoo *et al.*, showed the protective effect of Pumpkin seed supplementation in combination with other herbal agents in managing type 2 Diabetes³⁸. Its ingestion has also been found beneficial in several other diseases such as asthma and other respiratory and allergic diseases³⁹. In an *in vivo* study by Paul M. *et al.*, it was observed that pumpkin seed oil has protective effect against formaldehyde induced major organ damages⁴⁰. Another *in vivo* study by Eraslan *et al.* demonstrated the antioxidant effect of pumpkin seed oil⁴¹. It is also shown to have anti peroxidative properties and was found effective in alleviating the detrimental effects associated with protein malnutrition *in vivo*⁴². An *in vivo* study by Akomolafe *et al.*, investigated the effect of diet

supplementation with raw and roasted pumpkin seeds and found its therapeutic role in enhancing erectile function⁴³. Pumpkin seeds have also been demonstrated to possess antiplatelet activity and can prevent thrombotic events⁴⁴. It has also been found to increase satiety and control obesity⁴⁵. A study by Zirrahian *et al.* demonstrated the reduction in oxidative stress in liver tissue of rats as a result of pumpkin seeds supplementation with endurance training⁴⁶. Another study demonstrated the simultaneous effect of pumpkin seed supplementation and regular aerobic exercise training in decreasing apoptosis in heart and aorta endothelial cells in arsenic intoxicated rats⁴⁷. The antioxidant effect of pumpkin seed consumption and endurance training has been shown in cardiac muscle of rats⁴⁸. Studies on pumpkin seeds supplementation in humans are limited and more investigation is needed in this direction. Also, in context of sports nutrition, although pumpkin seeds are popular as supplements but scientific studies evaluating its efficacy are scarce and more research is needed to gain full benefits from this natural supplement.

Quinoa seeds (*Chenopodium quinoa* Willd.)

Quinoa, *Chenopodium quinoa* Willd., is an ancient edible seed indigenous to South America⁴⁹. Quinoa seeds is considered a powerful superfood with all the necessary nutrients required for an active and healthy body^{49,50}. It is a rich source of Manganese, Phosphorus, calcium, sodium, potassium, Magnesium, Folate, Thiamin, vitamin B2, B6, A, C and E, proteins, carbohydrates, fibre and other nutrients^{50,51}. It contains all essential nine amino acids making it a complete protein^{49,50}. It is a particularly good source of lysine. It takes longer to break down compared to other carbohydrates and thus provides energy source for a longer time and thus delays onset of fatigue. After an intense training or sports event, quinoa seeds can provide a good post exercise recovery food

providing the protein and carbohydrate source required for muscle restoration and regaining strength⁵². One more advantage of Quinoa is that it is gluten free and can be taken by people with gluten intolerance⁵³. Its rich in dietary fiber content can help increase longevity and reduce the risk of total mortality and several other chronic diseases^{54,55}. Quinoa is highly beneficial for human health and has prevented the risk of many chronic diseases¹⁴. It is rich in phytonutrients that have anti-inflammatory activity. It contains omega-3 fatty acids, which are healthy for heart. It has high fibre content that improves gut and digestive health and can help in managing weight. Some studies suggest that Quinoa consumption can help improve triglyceride levels and regulate blood sugar levels⁵⁶. In some studies, Quinoa seeds have also been found to exhibit prebiotic potential in the gut microbiota of human simulated digestion^{57,58}. It helps promote healthy gut microbiota which further prevents inflammation, obesity, and many other diseases⁵⁹. A study by Mohamed *et al.*, demonstrated the anticancer activity and preventive effects of quinoa seed supplementation against non-alcoholic fatty liver disease⁶⁰. Quinoa is a functional food with multiple bioactive ingredients and displays high nutritive as well as therapeutic value⁶¹. Its supplementation in diet can work wonders for good health and an active lifestyle. Scientific studies on quinoa supplementation in athletes still need a long way to go, very few studies have been conducted in sports nutrition with multiple limitations. More evidence is required to conclude the role of quinoa supplementation in boosting performance in athletes.

Amaranth seeds (*Amaranthus cruentus*)

Amaranth, which can be called as Golden crop for future has the ability to grow in dry and semi dry lands^{62,63}. Amaranth seeds have high percentage of protein, dietary fiber, carotenoids, iron, vitamin C, vitamin A, calcium, riboflavin, folic acid,

thiamine, lysine and bioactive components like tocopherol, squalene, anthocyanins and other phenolic compounds^{64,65}. It is also rich in essential fatty acids^{62,66}. It also lacks gluten, so it provides a valuable substitute for carbohydrate sources for gluten intolerance^{66,67}. In addition, it was also found to exhibit antioxidant activity^{68,69}. Amaranth seeds have been highly beneficial for health and are currently very popular in sports nutrition. It has many health benefits, including stimulating the immune system, regulating blood glucose levels, improving hypertension and hemoglobin levels^{14,69}. Amaranth seeds have also exhibited prebiotic potential in the human intestinal ecosystem⁵⁸. It also exhibits anti-inflammatory activity⁷⁰, anti-cancer activity⁶⁹, anti-diabetic activity⁷¹ and cholesterol lowering properties^{69,72}. A study by Kim *et al.*, demonstrated the positive effect of amaranth supplementation on improving the lipid and glucose metabolism in diabetic rats⁷¹. Amaranth is a rich source of phytochemicals that can induce beneficial effects in athletes when incorporated in sports nutrition⁷³. Squalene present in Amaranth confers cardiovascular protective properties⁶³. Its nitrite content can increase nitric oxide production and thus helping in enhancing endurance performance. It also has potential probiotic effect. Its protein content and amino acid profile can help in post exercise muscle recovery⁷³. A recent study by Liubert as *et al.*, has shown that long term use of dietary nitrates from Amaranth can improve aerobic capacity of physically active young people⁷⁴. Results of this study suggest that dietary nitrates from amaranth were also recommended as the optimal nutritional supplement to be taken in the last week during preparation of competition in endurance events. Another study demonstrated the performance enhancing effect of an amaranth based beverage on cycling performance⁷⁵. Only few studies have been conducted in sports

nutrition on use of Amaranth seeds as a potential supplement or ergogenic aid to improve sports performance. Therefore further research is required to validate the use of amaranth seeds as promising supplement to be used by athletes for improving performance.

Sesame seeds (*Sesamum indicum*)

Sesame seeds supplementation gives several health benefits such as improving exercise performance, lowering cholesterol⁷⁶, improving longevity, and regulating blood pressure. Its nutritional composition consists of proteins, fats, carbohydrates, fibres, calcium, iron, magnesium, phosphorus, potassium, selenium, sodium, zinc, vitamin B1, B3, B6 and vitamin E. Sesame seeds are high in essential minerals manganese, zinc and copper which help in bone health, immune health, energy and collagen production respectively. They are also rich in Iron which helps in making hemoglobin and delivering oxygen to muscle tissues. Sesame seed supplementation can help prevent lethargy and fatigue in athletes by providing essential minerals and iron in an appropriate amount. They also contain lignans and other bioactive compounds which facilitate significant antioxidant effects and thus prevent several diseases⁷⁶⁻⁷⁸. A high level of vitamin E and fats also confer a beneficial effect on the skin, protecting it from damage from harmful sun rays and improving the texture of the skin⁷⁹. It has been found to increase the levels of good cholesterol⁷⁶ and lower the levels of bad cholesterol in animal studies and therefore demonstrating the positive effect on healthy heart. Its cardioprotective effects have been observed in several studies and also prevention of formation of atherosclerotic plaques have been observed⁸⁰. In addition, the bioactive compounds sesamin and sesamol have potential neuroprotective effects⁸¹. It has been found to reduce thrombotic tendency and prevent cerebral ischemia by providing sufficient flow of oxygen and glucose to brain. It has also been found to

improve hypertension by inducing the endothelial production of nitric oxide which is the most important vascular relaxing factor in endothelium⁸². Sesame seed supplement have also been used as an alternative to the use of statins which can have side effects since sesame supplements ingestion have shown to reduce risk of cardiovascular disease and atherosclerosis⁸⁰. Sesame seeds are also rich in selenium, iron, zinc, copper which supports thyroid hormone production and good thyroid health^{83,84}. Some studies have demonstrated that sesame seed supplementation in diet can help improve aerobic exercise capacity in athletes. It also improves performance by reducing muscle fatigue and damage. In a study on soccer players, sesame seed supplementation for 28 days was found to enhance performance⁸⁵. Another study by Takemoto *et al.*, demonstrated the positive effect of Sesame seed supplementation in alleviating fatigue and oxidative stress in healthy humans⁸⁶. Sesame seeds are a good source of vital nutrients, antioxidants, and beneficial bioactive compounds, making them an important ingredient in regular diet for all people, including athletes. However, more broad research is needed to establish its performance-enhancing value for athletes in sports nutrition.

Hemp seeds (*Cannabis sativa L.*)

Hemp seeds have high nutritional and functional value and consist of protein, fibers, zinc, high magnesium, omega-6 and omega-3 fatty acids, phosphorus, potassium, sodium, sulfur, calcium, iron, zinc, vitamin B1, vitamin E and other important nutrients^{87,88}. The minerals present in Hemp seeds are easily absorbed by the body and high magnesium helps in boosting energy production and bone health⁶. They also contain vitamin E in large amount which helps in fighting oxidative damage and can be highly beneficial for endurance athletes. Hemp seeds are complete protein sources containing all essential amino acids. The presence of high level of amino acid

arginine boosts nitric oxide production on dietary supplementation of hemp seeds which protects cardiovascular health⁸⁹ and also protects against inflammation⁹⁰. It also contains a good ratio of omega-6 to omega-3 fats, and gamma-linolenic acid which has anti-inflammatory properties which can also help in improving eczema symptoms^{91,92}. Dietary supplementation of Hemp seed has been shown to exhibit potential prevention and treatment of chronic and inflammatory diseases⁹². Some *in vivo* studies have also shown that hemp seeds supplement help in blood pressure regulation⁹³ and reduce the risk of blood clot formation^{94,95}. Hemp seed supplementation was also found to play role in hormonal regulation and reducing symptoms of premenstrual syndrome (PMS) and menopause which can be attributed to its high content of gamma-linolenic acid^{96,97}. Whole hemp seeds also have high fiber content that helps in good digestive health and lowers the risk of diabetes^{98,99}. Hemp seeds have become popular recently but have been used as a staple food in many regions. They have excellent nutritional value and are rich in healthy fats, quality protein, minerals, and vitamins¹⁰⁰. If Hemp seed supplement is taken before sleeping, the protein content might help gain strength and increase muscle protein synthesis during resistance training¹⁰¹. Hemp seeds are popular supplements in athletes because of its high protein content which helps in muscle repair and growth and restores glycogen stores. It helps in increasing stamina, muscle size and recovery when taken as a supplement before training or workout or during competitive events.

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