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Review article

Antioxidants in Sports Nutrition: Boosting Performance & Reducing Oxidative Stress

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ABSTRACT

Sports nutrition offers a wide range of benefits that directly impact an athlete's performance, recovery, and overall well-being. Proper nutrition fuels the body, providing the necessary energy for intense physical activity and helping to delay fatigue, allowing athletes to perform at their best for longer periods. This review investigates the role of antioxidants in sports nutrition, concentrating on their potential to alleviate oxidative stress, which is a typical problem for athletes due to their strenuous physical activity. It discusses the methods by which antioxidants protect cells from free radical damage and looks at significant nutrient requirements of these critical molecules. Furthermore, the paper covers supplementing options and their efficacy in improving athletic performance and recuperation. While antioxidants have numerous benefits, excessive supplementation might interfere with training adaptations and cause nutritional imbalances. So, this detailed research offers useful insights for athletes and sports nutritionists looking to improve performance while reducing oxidative stress.

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Introduction

An antioxidant can be defined as a compound that in a relatively low concentration, prevents or delays the oxidation of biomolecules and can fight oxidative stress, which may negatively impact cells. They play a crucial role in preserving cellular strength and neutralizing free radicals can set off a chain of harmful effects on cells (1). Over the last few decades, antioxidants have mostly been recognized as a nutritional approach for preventing or minimizing the negative effects of reactive oxygen and nitrogen species (RONS), which are produced during and after hard activity(2).

Antioxidant supplementation has become a widespread practice among athletes as a way to lower oxidative stress, facilitate recovery, and improve performance (3). According to researches by the American College of Sports Medicine, athletes regularly consume antioxidants as a nutritional strategy with potential benefits (4).

"Over 50% of elite endurance and male collegiate athletes consumed doses of antioxidant supplements daily that were higher than the recommended daily allowance (RDA)" (5)."It plays a crucial role in regulating ROS levels by directly scavenging free radicals, regulating ROS/RNS-producing enzymes, and/or via adaptive electrophilic processes.""Acute and chronic endurance exercise increases the expression and activity of endogenous antioxidant enzymes in skeletal muscle."

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Physical exercise is inextricably linked to the body's control of oxidative and nitrosative stress, which are critical processes involving the formation and accumulation of reactive oxygen species (ROS) and reactive nitrogen species (RNS) which are critical for cellular signaling, control, and equilibrium.When the body's ability to neutralize reactive species through its natural antioxidant defense mechanisms is exceeded, oxidative stress ensues. "The primary sources of endogenous reactive oxygen species are hydrogen peroxide and superoxide anion, which are produced as byproducts of cellular metabolism, particularly mitochondrial respiration (6).

REDUCTION OF OXIDATIVE STRESS

"Physical activity, particularly intense exercise, can produce reactive oxygen species and cause the body to experience oxidative stress."When the body's ability to neutralize reactive species through its natural antioxidant defense mechanisms is exceeded, oxidative stress ensues. Reactive Oxygen Species (ROS) generated within cells mainly originate from metabolic processes, particularly mitochondrial respiration and include superoxide anion O2- and hydrogen peroxide H2O2.

When ROS production exceeds, the capacity of antioxidant defenses, it leads to axidative stress, which can damage cellular components like protein and lipids (7). This damage can impair cellular function and lead to a variety of health complications. Antioxidants are essential for preventing oxidative stress-related damage. They neutralize free radicals, preventing them from causing damage to cells and tissues. Antioxidants neutralize free radicals by a variety of ways, including contributing electrons to stabilize them, decreasing their reactivity, or breaking them down into less dangerous compounds (8).

Traditionally, exercise is separated into aerobic and resistance training components. Aerobic exercise strengthens the cardiovascular system and decreases reactive oxygen species and several ROS-related responses dramatically as exposed in Figure 1.Therefore, it is essential to differentiate between training methods that demand a high degree of athletic capability (9).Aerobic exercise reduces exercise-induced oxidative stress because it increases antioxidant levels and antioxidant enzyme activity.

However, resistance exercise improves structural i.e., muscle fiber and neurological adaptations while increasing oxidative and inflammatory stress. Resistance exercise causes elevated levels of oxidative and

inflammatory stress, which slows recovery time. Reactive oxygen species (ROS) are now recognized as key signaling molecules that play a vital role in regulating physiological functions. In skeletal muscle, intense exercise can trigger a substantial rise in ROS and reactive nitrogen species (RNS). However, if these reactive species accumulate beyond the neutralizing capacity of antioxidant enzymes, they may become detrimental to the body. The extent of their effects depends on various factors, including the intensity, duration and frequency of physical activity, as well as individual's age, sex and overall fitness level. Indeed, in skeletal muscle, intense physical activity can generate high production of ROS and reactive nitrogen species (RNS). A large concentration of reactive species might be hazardous to the organism if it is not neutralized by the available antioxidant enzymes, depending on the activity level, duration, frequency, sex, age, and fitness.

Figure 1 ROS and antioxidant response in sports performance

Source: Clemente-Suárez et al., 2023 (10)



NUTRIENT REQUIREMENTS FOR A SPORTS PERSON

Nutrition has been recognized as a vital component for optimal athletic performance, with both the science and practice of sports nutrition evolving rapidly (11).Evidence supports a variety of nutritional practices for improving sports performance. Dietary methods for improving performance involve altering macronutrient, micronutrient, and hydration intakes, as well as their composition and timing throughout the day. The value of individualized or personalized dietary guidance is growing, with dietary methods customized for the individual athlete's sport and personal goals. Dietary supplements can improve performance, if used correctly (12).

Energy requirements

The body's energy production relies on the oxidation of macronutrients i.e, carbohydrates, protein, fats which undergoes catabolic pathways such as glycolysis, beta-oxidation, and deamination, respectively to generate ATP (the primary energy source of energy). "Balancing energy intake with energy expenditure is crucial to prevent an energy deficit or excess. Energy deficits can cause short stature, delayed puberty, menstrual dysfunction, loss of muscle mass and increased susceptibility for fatigue, injury or illness" (13). "Extra calories are needed during growth spurts and to replenish energy expended during athletic endeavours" (14).

Macronutrients: Carbohydrates, Protein, Fats

Carbohydrates

Carbohydrates seem to be the most significant energy resource for sportsmen since they supply glucose, which is needed for energy. Energy availability is optimized as the breakdown of glycogen into glucose is regulated by key enzymes such as glycogen phosphorylase, ensuring a rapid supply of ATP due to high intensity exercise."One gram of carbohydrate contains approximately four kilocalories of energy"(15).

Glucose is stored as glycogen in muscles and liver and muscle glycogen is the most readily available energy source for working muscle and can be released more quickly than other energy sources.""Carbohydrates should comprise 45% to 65% of total caloric intake for four- to 18-year-olds. Good sources of carbohydrates include whole grains, vegetables, fruits, milk and yogurt (16).

Protein

Proteins are essential for the growth and repair of muscle, hair, and skin. However, as endurance exercise increases, protein contributes to blood glucose regulation through gluconeogenesis (17). Proteins undergo digestion into amino acids which are then absorbed and utilized for physiological functions, including muscle repair and enzyme production.

During prolonged exercise, certain amino acids like alanine, contribute to gluconeogenesis in the liver, helping maintain blood glucose levels and sustain energy production. "One gram of protein provides four kilocalories of energy.""Protein should comprise approximately 10% to 30% of total energy intake for four- to 18-year-olds." Good sources of protein include lean meat and poultry, fish, eggs, dairy products, beans and nuts, including peanuts (18).

Fats

During exercise, fats undergo lipolysis, where triglycerides are broken down into glycerol and free fatty acids. This process generates acetyl CoA, which enters the citric acid cycle to produce ATP, making fats as a crucial source energy source for endurance exercise and prolonged physical activities. "It is a calorie-dense source of energy (one gram provides nine kilocalories) but is more difficult to use."

Fats should comprise 25% to 35% of total energy intake for four- to 18-year-olds.""Saturated fats should comprise no more than 10% of total energy intake.""Good sources of fat include lean meat and poultry, fish, nuts, seeds, dairy products, and olive and canola oils. Fat from chips, candy, fried foods and baked goods should be minimized (13).

Micronutrients

Although there are numerous vitamins and minerals essential for optimum health, athletes should pay special attention to ensuring that they take adequate levels of calcium, vitamin D, and iron (19). Calcium ions serve as secondary messengers in enzymatic reactions and are essential for bone health, appropriate enzyme activity, and muscular contraction for optimal athletic performance.

The recommended intake of calcium is 1000 mg/day for children aged four to eight, and 1300 mg/day for those aged nine to eighteen. Calcium-rich foods and beverages include milk, yogurt, cheese, broccoli, spinach, and fortified grain products (20).

Vitamin D is required for healthy bones and teeth and is implicated in calcium absorption and metabolism. For children aged four to eighteen, current standards indicate 600 IU per day (21). Professionals that exercise inside or in northern climates are more prone to be vitamin D deficient. So, fortified foods, such as milk, and sun exposure are forms of vitamin D which can be taken to enhance the sports performance of athletes (22).

Iron is a key component of hemoglobin in RBC's and myoglobin in muscle tissues, facilitating oxygen transport and storage for energy production. Additionally, iron is crucial for electron transfer in electron transport chain, aiding in ATP synthesis, which is essential for endurance, muscle performance and overall athletic recovery.

Increased iron is necessary throughout adolescence to maintain development, and also spike in blood quantity and lean muscle. Boys and girls aged nine to thirteen should take 8 mg per day to prevent anaemia and exhaustion of iron reserves. Youth aged 14 to 18 require more iron, up to 11 mg per day for men and 15 mg per day for women. Iron-rich diets include eggs, leafy green vegetables, fortified whole grains, and lean meats (23).

Fluids

Water, as a fundamental nutrient, is essential for athletes. The type, amount and timing of fluid consumption can significantly impact athletic performance. Proper hydration supports body temperature regulation and compensates for fluid loss through sweating during exercise(24). The amount an athlete sweats and their fluid needs are influenced by environmental factors such as temperature and humidity. Maintaining proper hydration involves consuming fluids before, during and after physical activity. Athletes should drink 400-600ml of cold water approximately 2 to 3 hours before the sports activity. During exercise, they should replenish fluids by consuming 150-300ml every 15-20 minutes (25).

ROLE OF ANTIOXIDANTS IN SPORTS NUTRITION AND ITS SUPPLEMENTATION

Antioxidants are chemicals that block the oxidation of other molecules, preventing cellular harm. "In sports, the role of antioxidants has gained considerable attention due to their potential to reduce oxidative stress, improve recovery, and enhance overall athletic performance (3).It neutralizes free radicals by donating electrons, stabilizing these unstable molecules and preventing cellular damage.

This helps to reduce the oxidative stress generated by severe physical activity. Intense exercise frequently causes inflammation as the body repairs exercise-induced muscle damage. So, antioxidants helps to reduce inflammation by preventing oxidative damage, which can exacerbate inflammatory processes."They aid in the reduction of muscle soreness and inflammation by neutralizing free radicals(26).

Antioxidants help in muscle repair by protecting muscle cells from oxidative damage and facilitating the repair process. As a result, Vitamin C is essential for collagen synthesis, which is vital for the repair and preservation of muscular tissues, tendons, and ligaments (27).Intense physical exercise may weaken the immune system, raising the risk of sickness.

Antioxidants help the immune system by shielding immune cells from oxidative damage, increasing overall immunological health and decreasing susceptibility to infections (28). Antioxidants, which counteract oxidative stress and promote cellular function, can help athletes operate at greater intensities for longer periods of time, lowering tiredness. "According to some studies, antioxidants may improve physical performance by reducing oxidative stress-induced impairments in muscle function and endurance" (29).

Antioxidants contribute to the efficiency of energy production within cells by shielding the mitochondria from oxidative damage. Healthy mitochondria are essential for maintaining high energy levels throughout extended or vigorous activity (30).

Vitamin C and other antioxidants play important roles in collagen production, which is required for muscle fiber and connective tissue repair. Faster muscle repair indicates faster recovery between training or contests. Antioxidants can reduce exercise-induced inflammation, which helps expedite recovery times. This means athletes can return to training or competition more quickly and with less downtime (31).

Antioxidant Supplementation

Intense physical activity generates free radicals, which damage cells and slow recuperation, whereas antioxidants minimize them. Consuming antioxidants like vitamin E and C may help with healing. Athletes who follow a plant-based diet, which often has higher levels of antioxidant molecules, claim that the antioxidants in plant foods help them recover faster. "Antioxidants are important in sports nutrition because they help to manage oxidative stress, reduce inflammation, and improve recovery (32)."

Ascorbic acid, also known as ascorbate, is a vital vitamin that serves a variety of biological purposes, some of which are especially critical for exercise immunology and metabolism. In addition to being a strong hydrophilic antioxidant, vitamin C is a cofactor for a number of metalloenzymes that are involved in the formation of peptide hormones, collagen, carnitine, and neurotransmitters (33).

Furthermore, because these metabolic and immune functions of vitamin C are all associated with exercise, it is possible that times of more physical activity requiring musculoskeletal growth and repair, as well as optimal immune function maintenance, will increase athlete's requirements. Individual demands and exercise intensity usually define a daily dose of 500-2000 mg of Ascorbic acid, buffered vitamin C (34).

Vitamin E is a group of lipid-soluble compounds that includes four tocopherols and four tocotrienols (α-, β-, γ-, and δ-). Although all naturally occurring vitamin E isomers and synthetic rac-α-tocopherol have similar antioxidant effects, α-tocopherol (also known as RRR-α-tocopherol) is the most physiologically active. Vitamin E, a strong scavenger of peroxyl radicals, is the principal inhibitor of the free radical-mediated chain reaction of lipid peroxidation in mammals, including humans. The relevance of this function is to maintain the integrity of long-chain polyunsaturated fatty acids in cell membranes throughout the body, therefore maintaining their structure and biological function (35). 400-800 IU per day are recommended in the form of alpha-tocopherol or mixed tocopherols. Higher doses should be monitored for potential side effects (36).

POTENTIAL HARMS OF SUPPLEMENTATION WITH HIGH DOSES OF ANTIOXIDANTS IN ATHLETES

Vigorous exercise produces high levels of reactive oxygen species (ROS) as a result of athletes consuming large volumes of O2, causing some athletes to consume antioxidants under the false suumptions that they will prevent the harmful effects of ROS (37).

High doses of antioxidant supplements, such as vitamins C and E, might disrupt physiological responses to exercise and pose health hazards in number of ways:
Regular exercise causes oxidative stress, which is essential for activating positive adaptations including mitochondrial biogenesis and increased endurance.

Excessive antioxidant supplementation may inhibit these adaptations by neutralizing reactive oxygen species (ROS), which operate as signaling molecules, potentially lowering training efficiency (38). While antioxidants aid to decrease muscle damage, an excessive intake may impair the natural inflammatory response required for muscle healing. This could result in prolonged recovery times and lower performance gains over time (39).

The body's antioxidant defense system includes enzymes such as superoxide dismutase (SOD) and glutathione peroxidase(40). High-dose supplements can suppress these natural defensive systems, leaving the body more reliant on external sources while possibly contributing to oxidative damage in the long run (41).Exercise-induced oxidative stress additionally impacts hormonal signaling, including the modulation of anabolic hormones such as testosterone and growth hormone. Excessive antioxidant intake may disrupt these hormonal responses, thereby restricting strength and muscular development (42).

CONCLUSION

Antioxidants are crucial in sports nutrition as they regulate oxidative stress, reduce inflammation, and improve recovery, making them necessary for athletes seeking optimal performance. While dietary sources along with customized supplementation can help reduce exercise-induced oxidative damage, too much supplementation can disrupt normal physiological processes, hindering training adaptations, and potentially pose health hazards. The body relies on a delicate balance of oxidative and antioxidant processes, and excessive supplementation may reduce important stress responses that promote muscular growth, endurance, and metabolic efficiency.

Athletes should prioritize consuming antioxidants from whole foods like fruits, vegetables, nuts, and seeds, which contain a diverse range of bioactive compounds that work together to enhance recovery and overall health. While supplementation may be beneficial in specific situationssuch as intensive training, recovery from injuries, or high oxidative stress, it should be used with caution and adjusted to individual needs.

Athletes can consult with sports nutritionists or healthcare professionals to assess whether supplementation is necessary while also ensuring that it does not interfere with training adaptations or long-term health. Rather than relying on high doses of isolated antioxidants, a strategic and well-balanced approach that includes both dietary antioxidants and, when necessary, appropriate supplementation is the most effective way to improve performance, speed up recovery, and maintain long-term athletic potential.

By focusing on a nutrient-dense diet, monitoring training reactions, and changing supplementation as needed, athletes may maintain an optimal balance that promotes endurance, strength, and general well-being. A complete approach that respects the body's natural processes and encourages insignificant, long-term performance improvements will eventually lead to higher results, sports longevity, and general health.

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