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Role of nutrition in performance enhancement and postexercise recovery: An overview

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Abstract
Nutrition plays a fundamental role in athletic performance, exercise adaptation, and postexercise recovery. Adequate intake of macronutrients, micronutrients, fluids, and bioactive compounds supports energy production, muscle function, immune defense, and tissue repair during and after physical activity. Carbohydrates are essential for maintaining glycogen stores and delaying fatigue, whereas proteins contribute to muscle protein synthesis and recovery. Fats serve as an important energy source during prolonged exercise and support hormonal balance. Hydration and electrolyte management are equally critical in maintaining thermoregulation and preventing dehydration-related performance decline. Recent advances in sports nutrition emphasize individualized dietary strategies based on exercise intensity, duration, and athlete-specific goals. Nutritional interventions such as nutrient timing, supplementation, and recovery-focused diets have gained attention for improving endurance, strength, and recovery outcomes. This review discusses the role of nutrition in enhancing physical performance and accelerating postexercise recovery, highlighting current evidence-based recommendations and practical applications in sports and exercise settings.

Keywords: Sports nutrition, performance enhancement, exercise recovery, carbohydrates, protein, hydration, supplementation

Introduction

Nutrition is one of the most important determinants of athletic performance and exercise recovery (Dhiman and Kapri, 2023) [10]. Physical activity increases energy expenditure and metabolic demands, requiring optimal nutritional support to sustain performance and physiological adaptation. Athletes and physically active individuals depend on balanced nutrition to maximize endurance, strength, power, and recovery while reducing the risk of injury and fatigue (Burke *et al*., 2026) [20].

Exercise induces physiological stress, including depletion of glycogen stores, muscle damage, oxidative stress, and fluid loss (Muchtar *et al*., 2026) [31]. Appropriate nutritional strategies can minimize these adverse effects and enhance adaptation to training. Scientific evidence demonstrates that dietary intake before, during, and after exercise influences performance outcomes, muscle recovery, immune function, and overall health (Hossain *et al*., 2026) [4].

Sports nutrition has evolved significantly over the past decades with growing understanding of nutrient timing, individualized diets, and ergogenic aids. Modern sports nutrition focuses not only on meeting energy requirements but also on optimizing metabolic efficiency and recovery processes. Nutritional interventions are now considered essential components of training programs for both elite athletes and recreational exercisers (Kerksick *et al*., 2026) [17].

This review provides an overview of the role of nutrition in performance enhancement and postexercise recovery, emphasizing macronutrients, micronutrients, hydration, supplementation, and recovery nutrition strategies.

Energy Requirements in Exercise

Energy requirements during exercise vary depending on factors such as exercise intensity, duration, body composition, age, sex, and training status (Burke *et al*., 2026) [6]. Athletes and physically active individuals need adequate caloric intake to maintain energy balance, support metabolic functions, and sustain physical performance (Fiorini, 2026) [4]. During exercise, the body utilizes three major energy systems: the adenosine triphosphate-phosphocreatine (ATP-PC) system for immediate short bursts of high-intensity activity, anaerobic glycolysis for moderate-duration intense exercise, and aerobic oxidative metabolism for prolonged endurance activities. Short-duration, high-intensity exercises such as sprinting and weightlifting primarily depend on carbohydrate metabolism because carbohydrates can rapidly produce energy (Xu and Zhang, 2026) [6]. In contrast, long-duration endurance activities such as marathon running and cycling rely on both carbohydrates and fats as major energy substrates. Proper nutritional intake is therefore essential to replenish energy stores, delay fatigue, and enhance exercise performance and recovery (Zhang *et al*., 2026) [4].

Low energy availability can negatively affect:

- Muscle function
- Hormonal balance
- Immune response
- Bone health
- Recovery capacity

Therefore, meeting energy demands through proper nutrition is essential for maintaining performance and preventing overtraining.

Role of Macronutrients in Performance Enhancement

1. Carbohydrates

Carbohydrates are the primary source of energy during moderate- to high-intensity exercise and play a crucial role in maintaining athletic performance. Muscle glycogen stores significantly influence endurance capacity, exercise intensity, and resistance to fatigue. Adequate carbohydrate intake helps maintain blood glucose levels, preserve muscle glycogen, delay the onset of fatigue, and enhance endurance

performance during prolonged physical activity. Preexercise carbohydrate loading is an effective strategy to maximize glycogen storage and improve performance in endurance events lasting longer than 90 minutes. During extended exercise sessions, consuming carbohydrates helps sustain energy availability, maintain cognitive function, and support optimal muscle performance. Following exercise, carbohydrate intake is also essential for replenishing depleted glycogen stores and promoting faster recovery, particularly in athletes undergoing repeated training sessions or competitions (Noakes *et al*., 2026) [26].

Postexercise carbohydrate consumption is important for glycogen replenishment. Rapid restoration of glycogen is essential when recovery time between training sessions is limited (Saha *et al*., 2026) [31].

Recommended Intake

- Moderate exercise: 5–7 g/kg/day
- Endurance training: 7–12 g/kg/day

Common carbohydrate-rich foods include:

- Rice
- Bread
- Pasta
- Fruits
- Sports drinks
- Energy gels

2. Proteins

Proteins play a vital role in muscle repair, recovery, and physiological adaptation following exercise (Puspitasari and Arfajah, 2026) [29]. Physical activity, especially resistance and strength training, increases muscle protein breakdown and turnover, thereby increasing the body's requirement for dietary protein to support muscle protein synthesis (Sánchez *et al*., 2026) [31]. Adequate protein intake contributes to muscle tissue repair, increased lean body mass, improved recovery, reduced muscle soreness, and enhanced immune function. High-quality proteins rich in essential amino acids, particularly leucine, are highly effective in stimulating muscle protein synthesis and promoting muscle adaptation after exercise (Calderón *et al*., 2026) [31]. Consuming protein both before and after exercise can optimize recovery and support training adaptations by enhancing muscle rebuilding and reducing exercise-induced muscle damage. Common sources of high-quality protein include dairy products, eggs, fish, poultry, soy products, legumes, and protein supplements such as whey protein (Inanlar and Capanoglu, 2026) [15].

Protein Timing

Consuming protein within the postexercise recovery window supports muscle recovery and adaptation.

Recommended Intake

- General athletes: 1.2–2.0 g/kg/day
- Strength athletes may require higher intake

Common protein sources:

- Milk
- Eggs
- Fish
- Poultry
- Soy
- Legumes
- Whey protein

3. Fats

Dietary fats are an important source of concentrated energy and play a significant role in supporting exercise performance, recovery, and overall health. During prolonged low- to moderate-intensity exercise, fats become a major fuel source as glycogen stores gradually decline. In addition to providing energy, fats are essential for hormone production, absorption of fat-soluble vitamins, maintenance of cell membrane integrity, and proper nervous system function. Healthy fats contribute to improved endurance performance, anti-inflammatory effects, joint health, and hormonal regulation, all of which are important for athletes and physically active individuals. Sources of healthy fats include nuts, seeds, olive oil, fatty fish, and avocado, which are rich in unsaturated fatty acids and omega-3 fatty acids. Adequate fat intake also supports recovery by reducing inflammation and maintaining immune function. However, excessive restriction of dietary fat may negatively affect hormonal balance, energy availability, and recovery processes, ultimately impairing athletic performance and overall health (Banerjee *et al*., 2026) [4].

Micronutrients and Athletic Performance

1. Iron

Iron is an essential micronutrient that plays a critical role in oxygen transport, energy metabolism, and athletic performance (Wang *et al*., 2026) [4]. It is a major component of hemoglobin and myoglobin, which are responsible for transporting oxygen to working muscles during exercise. Adequate iron levels are necessary for maintaining endurance capacity, reducing fatigue, and supporting efficient energy production. Iron deficiency can impair aerobic performance, decrease work capacity, and increase feelings of tiredness and weakness, particularly in athletes engaged in intense training (Izumi *et al*., 2026) [16]. Female athletes, endurance athletes, and vegetarians are at greater risk of iron deficiency due to factors such as menstrual blood loss, increased iron turnover during prolonged exercise, and lower intake of highly bioavailable iron sources (Luna *et al*., 2026) [19]. Dietary sources of iron include red meat, spinach, legumes, and fortified cereals. Consuming vitamin C-rich foods along with plant-based iron sources can enhance iron absorption and help maintain optimal iron status in physically active individuals.

2. Calcium and Vitamin D

Calcium and vitamin D are essential nutrients that play important roles in bone health, muscle function, and immune support, particularly in athletes and physically active individuals (Książek *et al*., 2019) [18]. Calcium is necessary for maintaining bone density, muscle contraction, nerve transmission, and proper cardiovascular function, while vitamin D enhances calcium absorption and contributes to muscle strength and immune regulation (Pfeifer *et al*., 2002) [27]. Deficiency of calcium and vitamin D may increase the risk of stress fractures, bone weakness, muscle cramps, and impaired muscle performance, especially in athletes undergoing intense training. Adequate intake of these nutrients is therefore critical for maintaining skeletal integrity and optimizing physical performance. Major dietary sources of calcium and vitamin D include dairy products, fish, fortified foods, and sunlight exposure, which stimulates vitamin D synthesis in the skin. Maintaining sufficient levels of these nutrients supports recovery, reduces injury risk, and promotes overall athletic health (Alcock *et al*., 2024) [1].

3. Antioxidants

Exercise-induced oxidative stress leads to increased production of free radicals, which can cause cellular damage, muscle fatigue, and inflammation if not properly controlled (Powers *et al*., 2011) [28]. Antioxidants play a crucial role in neutralizing these free radicals and protecting the body from oxidative damage associated with intense physical activity. Vitamins C and E are among the most important antioxidants that help support immune function, reduce muscle damage, and enhance postexercise recovery. Adequate antioxidant intake may also help decrease inflammation and improve recovery time following strenuous exercise (Bailey *et al*., 2011) [3]. Natural dietary sources of antioxidants include fruits, vegetables, nuts, and green tea, which contain various bioactive compounds such as polyphenols, flavonoids, and carotenoids. Regular consumption of antioxidant-rich foods contributes to overall health, supports exercise adaptation, and helps maintain optimal athletic performance (Tkaczenko and Kurhaluk, 2025) [37].

Hydration and Electrolyte Balance

Hydration is essential for maintaining athletic performance, thermoregulation, cardiovascular stability, and overall physiological function during exercise (Batista and dos Santos, 2020) [5]. Even mild dehydration can negatively affect endurance, muscular strength, cognitive function, and postexercise recovery. During physical activity, the body loses fluids and electrolytes through sweating, particularly sodium and potassium, which are important for maintaining fluid balance and normal muscle and nerve function. Proper hydration strategies before, during, and after exercise are therefore necessary to prevent dehydration and optimize performance. Athletes are advised to consume adequate fluids approximately 2–4 hours before exercise to ensure proper hydration status. During exercise, fluid losses should be replaced regularly, and sports drinks containing carbohydrates and electrolytes may be beneficial during prolonged or intense activities. After exercise, rehydration with fluids and electrolytes is important for restoring fluid balance, supporting recovery, and preventing muscle cramps and fatigue. Electrolytes play crucial roles in muscle contraction, nerve impulse transmission, and maintaining cellular fluid balance, making them essential components of sports nutrition and recovery management (Muchtar *et al*., 2026) [20].

Nutrient Timing

1. Preexercise Nutrition

Preexercise nutrition plays a vital role in providing sufficient energy, maintaining blood glucose levels, and preventing hypoglycemia during physical activity (Rothschild *et al*., 2020) [30]. A well-balanced preexercise meal helps improve endurance, delay fatigue, and enhance overall exercise performance. Ideally, preexercise meals should be rich in carbohydrates to supply readily available energy, contain moderate amounts of protein to support muscle function, and be low in fat and fibre to reduce gastrointestinal discomfort and promote faster digestion. Consuming meals or snacks approximately 2–4 hours before exercise allows adequate time for digestion and nutrient absorption. Appropriate preexercise nutrition also helps optimize glycogen stores, improve concentration, and support sustained performance during training or competition. Common preexercise meal options include fruits, oatmeal, yogurt, whole-grain bread, rice, and lean protein sources (Naderi *et al*., 2023) [22].

2. Nutrition During Exercise

Nutrition during exercise is important for maintaining energy availability, delaying fatigue, and supporting optimal athletic performance, especially during prolonged physical activity lasting more than 60 minutes. During extended exercise sessions, the body gradually depletes its glycogen stores, making carbohydrate intake essential for sustaining blood glucose levels and preserving muscle energy reserves. Consuming carbohydrates during exercise helps improve endurance, maintain exercise intensity, and reduce both physical and mental fatigue. Sports drinks, energy gels, fruits, and carbohydrate-rich snacks are commonly used to provide easily digestible sources of energy during activity. The recommended carbohydrate intake during prolonged exercise is approximately 30–60 grams per hour, depending on exercise intensity and duration. Adequate fluid intake along with carbohydrate consumption also supports hydration, electrolyte balance, and overall exercise performance (Casazza *et al*., 2018) [9].

3. Postexercise Nutrition

Postexercise nutrition is essential for promoting recovery, restoring energy reserves, and supporting muscle adaptation following physical activity. The primary goals of postexercise nutrition include glycogen replenishment, muscle repair, and rehydration. After exercise, muscle glycogen stores become depleted and muscle tissues undergo microscopic damage, making timely nutrient intake important for effective recovery. An ideal recovery meal should contain carbohydrates to restore glycogen levels, protein to stimulate muscle protein synthesis and tissue repair, as well as fluids and electrolytes to replace sweat losses and maintain hydration balance (Smith-Ryan *et al*., 2020) [36]. The combination of carbohydrates and proteins is particularly beneficial because it enhances glycogen synthesis, improves muscle recovery, and reduces exercise-induced muscle damage. Consuming recovery nutrition within the early postexercise period can accelerate recovery, reduce fatigue, and improve readiness for subsequent training sessions or competitions (Alghannam *et al*., 2018) [2].

Role of Supplements in Performance Enhancement

1. Creatine

Caffeine is one of the most widely used ergogenic aids in sports nutrition due to its ability to enhance physical and mental performance (Guest *et al*., 2021) [13]. It acts as a central nervous system stimulant and may help reduce the perception of fatigue, improve alertness, increase concentration, and enhance endurance performance during exercise. Caffeine stimulates the release of adrenaline and increases neural activity, which can improve reaction time, focus, and exercise capacity. It is particularly beneficial during prolonged endurance activities, where it may help athletes maintain performance and delay exhaustion. Additionally, caffeine has been shown to improve power output and reduce feelings of effort during high-intensity exercise. Common dietary sources of caffeine include coffee, tea, energy drinks, and certain sports supplements. However, excessive caffeine intake may cause side effects such as nervousness, insomnia, increased heart rate, and

gastrointestinal discomfort, making individualized intake recommendations important for athletes (Sharma *et al*., 2023) [34].

2. Branched-Chain Amino Acids (BCAAs)

Branched-chain amino acids (BCAAs), which include leucine, isoleucine, and valine, are essential amino acids that play important roles in muscle metabolism and exercise recovery. BCAAs are commonly used as sports supplements because they may help reduce exercise-induced muscle soreness, decrease muscle protein breakdown, and support muscle recovery following intense physical activity. Leucine, in particular, is known to stimulate muscle protein synthesis and promote muscle repair. Some studies suggest that BCAA supplementation may improve recovery, reduce fatigue, and support endurance performance, especially during prolonged or high-intensity exercise. However, scientific evidence regarding their effectiveness remains mixed, and the benefits may vary depending on exercise type, training status, and overall dietary protein intake. Despite these limitations, BCAAs continue to be widely used among athletes and physically active individuals to support recovery and maintain muscle health (Nie *et al*., 2018) [24].

3. Beta-Alanine

Beta-alanine is a non-essential amino acid commonly used as an ergogenic supplement to improve athletic performance during high-intensity exercise. It works by increasing muscle carnosine concentrations, which help buffer the accumulation of hydrogen ions and delay the onset of muscular fatigue caused by acid buildup during intense physical activity. By reducing muscle acidity, beta-alanine supplementation may enhance exercise capacity, improve muscular endurance, and support performance in activities involving repeated bouts of high-intensity effort such as sprinting, cycling, and resistance training. Regular supplementation has also been associated with improved training volume and reduced fatigue during prolonged anaerobic exercise. Therefore, beta-alanine is widely used among athletes seeking enhanced performance and better tolerance to intense exercise conditions (Zanella *et al*., 2016) [41].

Nutrition and Postexercise Recovery

Nutrition plays a crucial role in postexercise recovery by helping restore physiological balance and promoting adaptation following physical activity (Naderi *et al*., 2025) [23]. Intense exercise leads to depletion of glycogen stores, muscle tissue damage, fluid loss, and increased inflammation, making appropriate recovery nutrition essential for optimal performance and long-term athletic development. The primary goals of recovery nutrition are to replenish glycogen stores, repair muscle damage, restore hydration, and reduce inflammation. Consuming carbohydrates after exercise helps restore muscle glycogen, while protein intake supports muscle protein synthesis and tissue repair. Fluids and electrolytes are necessary to replace sweat losses and maintain hydration balance. Recovery foods such as chocolate milk, yogurt with fruits, smoothies, rice with lean protein, and specialized recovery shakes provide a balanced combination of carbohydrates, proteins, and fluids that support efficient recovery (Casazza *et al*., 2018) [9]. In addition to proper nutrition, adequate sleep is equally important, as sleep and nutrition together enhance muscle recovery, reduce fatigue, and improve overall exercise adaptation and performance outcomes.

Special Considerations in Sports Nutrition

1. Female Athletes

Female athletes often have increased nutritional requirements due to the combined effects of intense physical activity, hormonal fluctuations, and physiological demands. Nutrients such as iron, calcium, and vitamin D are particularly important for maintaining optimal performance, bone health, and overall well-being. Iron is essential for oxygen transport and energy production, and female athletes are at greater risk of iron deficiency because of menstrual blood loss and high training loads. Calcium and vitamin D are critical for maintaining bone density, muscle function, and reducing the risk of stress fractures. Inadequate energy intake or chronic energy deficiency can contribute to menstrual dysfunction, decreased bone mineral density, fatigue, and impaired athletic performance, a condition often associated with the Female Athlete Triad or Relative Energy Deficiency in Sport (RED-S). Therefore, balanced nutrition, sufficient caloric intake, and proper micronutrient support are essential for the health, recovery, and long-term performance of female athletes (Sims *et al*., 2023) [10].

2. Vegetarian and Vegan Athletes

Vegetarian and vegan athletes can successfully achieve high levels of athletic performance when their diets are properly planned and nutritionally balanced (Venderley and Campbell, 2006) [38]. However, plant-based athletes should pay special attention to certain nutrients that may be limited or less bioavailable in vegetarian and vegan diets. Protein quality is important because some plant proteins may lack one or more essential amino acids, making it necessary to consume a variety of protein sources such as legumes, soy products, nuts, seeds, and whole grains. Vitamin B12 is another critical nutrient, as it is primarily found in animal-based foods, and deficiency may impair energy metabolism and neurological function (Niklewicz *et al*., 2023) [25]. Iron, zinc, and omega-3 fatty acids also require careful monitoring because their intake and absorption may be lower in plant-based diets. Adequate consumption of fortified foods, supplements when necessary, and diverse nutrient-rich plant foods can help vegetarian and vegan athletes maintain optimal performance, recovery, immune function, and overall health (Naderi *et al*., 2025) [23].

3. Adolescent Athletes

Adolescent athletes have increased nutritional requirements due to the combined demands of growth, physical development, and athletic training. Adeate nutrition during adolescence is essential to support normal growth, bone development, muscle formation, hormonal changes, and training adaptation. Insufficient intake of energy, protein, vitamins, and minerals can negatively affect physical performance, recovery, immune function, and overall health (Shao *et al*., 2021) [33]. Carbohydrates provide energy for training and sports participation, while proteins support muscle growth and tissue repair. Important micronutrients such as calcium, iron, and vitamin D are especially crucial during adolescence for bone strength, oxygen transport, and proper physiological development. Proper hydration and balanced dietary habits also contribute to improved

endurance, concentration, and recovery. Therefore, adolescent athletes require well-planned and nutrient-dense diets to support both athletic performance and healthy growth and development (Everett, 2025) [11].

Conclusion

Nutrition plays a crucial role in optimizing athletic performance and postexercise recovery. Adequate intake of carbohydrates, proteins, fats, micronutrients, and fluids supports energy production, muscle repair, immune function, and recovery processes. Nutrient timing and individualized dietary strategies further enhance exercise adaptation and reduce fatigue. Evidence-based supplementation may provide additional benefits when used appropriately. A well-balanced and scientifically planned nutritional approach is essential for athletes and physically active individuals seeking improved performance, faster recovery, and long-term health.

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