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OPTIMIZING ATHLETIC PERFORMANCE THROUGH EVIDENCE-BASED NUTRITIONAL SUPPLEMENTATION: UPDATED EVIDENCE AND PRACTICAL APPLICATIONS

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Abstract

Optimizing athletic performance and post-exercise recovery necessitates a comprehensive approach that integrates dietary strategies with training demands and physiological responses. Athletes commonly use dietary supplements, although their usefulness varies depending on the supplement type, sport features, and individual reactivity. This narrative review critically assesses evidence from randomized controlled trials, systematic reviews, and meta-analyses published between 2015 and 2024, with a focus on supplements commonly used in individual sports. The findings show that creatine monohydrate consistently improves high-intensity power output and neuromuscular adaptation, whereas protein and essential amino acids help with muscle remodeling and recuperation.

Caffeine and β-alanine enhance cognitive focus, absorption capacity, and prolonged high-intensity performance. The importance of dietary nitrates and omega-3 fatty acids in lowering inflammation, accelerating healing, and improving cardiovascular function is further supported by new research. Notwithstanding these benefits, problems with optimal dosage, scheduling strategies, inter-individual variability, supplement quality, and regulatory compliance still exist. This study emphasizes the need for individualized, evidence-based supplementation plans that consider training phase, safety requirements, and sport specificity.

Keywords: *ergogenic nutrition, dietary supplements, sport performance, recovery strategies, creatine, amino acids, caffeine, omega-3 fatty acids, nitrates, individualized nutrition*

Introduction

Optimal physiological adaptation and competitive performance are becoming increasingly vital in modern sports, where modest gains can determine success. As training demands rise across all athletic disciplines,

nutritional supplementation has emerged as an important strategy for increasing performance and recovery. Supplement use among athletes has skyrocketed over the last two decades, owing mostly to emerging scientific data confirming the efficacy of certain compounds *(Maughan et al., 2018, Peeling et al., 2018)*. This increase reflects the rising recognition that nutrition is critical for exercise adaptation, metabolic efficiency, and post-exercise recovery *(Beck, 2015)*. However, despite widespread adoption, translating research into practice remains inconsistent, which is compounded by differences in study designs, demographic variables, and sport-specific demands on athletes *(Amawi, 2024)*.

The evidence for certain ergogenic compounds has been strengthened by recent systematic reviews, study designs, and systematic meta-analyses. Across a variety of demographics, it has been demonstrated that creatine, whey protein, essential amino acids, β-alanine, caffeine, and dietary nitrates enhance athletic performance or recovery *(Fernández Lázaro, 2024; Scapec, 2024; Morton, 2018; Saunders, 2016)*. One of the most researched supplements, creatine monohydrate, has been shown time and time again to enhance resistance training adaptations and high-intensity exercise performance *(Kreider, 2017; Wax, 2021)*. It has also been demonstrated that protein and essential amino acid supplements enhance muscle hypertrophy, strength, and recuperation *(Morton, 2018)*.

Caffeine *(Grgic, 2019; Pickering & Grgic, 2019; Scapec, 2024)* and β-alanine *(Saunders, 2016; Suszter, 2020)* are two supplements with evidence-based ergogenic potential. Caffeine improves strength, muscular endurance, and repeated-sprint ability, while β-alanine improves high-intensity performance through increased muscle carnosine availability. Omega-3 fatty acids, branched-chain amino acids (BCAAs), leucine, and various antioxidants have also received attention for their potential roles in reducing inflammation, oxidative stress, and muscle damage, thereby aiding recovery *(Clemente Suárez, 2023; Fernández Lázaro, 2024; Fouré & Bendahan, 2017; Martinho, 2022; Plotkin, 2021; Thielecke & Blannin, 2020)*. However, the evidence for these recovery-oriented supplements is more diverse and frequently constrained by methodological discrepancies or small study numbers.

Important uncertainties still exist despite advancements in the scientific literature. These include long-term safety concerns (*Garthe & Ramsbottom, 2020*), timing in relation to training, interindividual responsiveness (*Pickering & Grgic, 2019*), and optimal dosing protocols *(Ribeiro, 2021)*. Athletes must conform to international anti-doping regulations, therefore regulatory issues continue to be crucial to applied practice *(World Anti-Doping Agency, WADA, 2024*). These difficulties highlight the necessity of thorough, current, and sport-specific evidence syntheses.

Therefore, **the goal of this review** is to gather and analyze high-quality research that has been published between 2015 and 2024, with a focus on controlled trials, systematic reviews, and meta-analyses that look into nutritional supplements for athletic performance and recuperation. Dose-response correlations, sport-specific applications, interindividual variation, molecular pathways, and regulatory compliance are the main topics of discussion. In order to help practitioners, coaches, and athletes take nutritional supplements safely and effectively in sports, the review attempts to offer a thorough, evidence-based framework.

Research Methodology

This study was conducted as a narrative review using systematic search procedures to collect high-quality data on dietary supplements and athletic performance. The PubMed/MEDLINE, Scopus, Web of Science, and SportDiscus databases were searched extensively for publications published between January 2015 and December 2024.

Only systematic reviews, meta-analyses, and randomized controlled trials with competitive, well-trained, or healthy athletes were included. Eligible studies had to demonstrate objective performance or recovery outcomes, as well as well-specified supplementation protocols. Studies that used observational methodologies, clinical populations, multi-ingredient supplements without distinguishing individual effects, or had no performance-related outcomes were ex-

cluded. To locate more relevant articles, reference lists for relevant reviews and position statements were manually reviewed.

Supplement-Specific Evidence

Creatine monohydrate continues to be the most common ergogenic aid. Numerous meta-analyses and research studies reveal significant improvements in maximal strength, peak power, repeated sprint ability, and lean mass gains when combined with resistance training. *(Kreider et al., 2017; Mielgo-Ayuso et al., 2019; Wax et al., 2021)*. Lower dose regimens may have longer-term benefits, although effective protocols typically include a loading phase (≈20 g/day for 5–7 days) followed by maintenance (3–5 g/day) *(Ribeiro et al., 2021)*. According to position statements *(Kreider et al., 2017),* no consistent adverse effects have been detected at recommended doses, indicating long-term safety in healthy populations. Supplementing with protein, particularly whey or premium complete proteins, promotes muscle protein synthesis, recuperation, and adaptability in strength. *(Jäger et al., 2017; Beck et al., 2015)*.

Consuming 20–40 g of protein right after exercise improves the anabolic response. Protein supplementation is especially helpful during energy shortage or high-volume training stages. According to *Plotkin et, al* (2021), total daily protein consumption continues to be the dominant determinant for maximal hypertrophy or strength improvements, but isolated BCAA supplementation gives a slight benefit. Supplementing with beta alanine boosts intramuscular carnosine, improving buffering capacity and postponing tiredness during one to four minutes of high-intensity exercise *(Saunders et al., 2016; Suszter et al., 2020)*. Usually, protocols give 4–6 g daily for 4–8 weeks. Anaerobic and repeated sprint workouts yield the greatest advantages, whereas endurance activities yield mixed results. The most frequently reported side effect is mild paresthesia; in healthy people, there are no major adverse events.

Caffeine's ergogenic and neuromodulator characteristics have been extensively explored. Acute doses of 3–6 mg/kg administered 30–60 minutes before exercise consistently enhance anaerobic power, reaction time, perceived effort, and endurance performance *(Grgic et al., 2019)*. Recent RCTs *(Scapec et al., 2024)* suggest additional benefits for power output and muscle endurance. Variations in reaction between individuals may be influenced by genetic variants (such as CYP1A2), habitual intake, and stimulant sensitivity *(Pickering & Grgic, 2019)*. Long-term omega-3 supplementation (1–2 g/day EPA + DHA) supports anti-inflammatory responses, improves joint health, reduces muscular soreness, and may improve recovery *(Fernández Lázaro et al., 2024; Thielecke & Blannin, 2020)*.

Similarly, exercise-induced oxidative stress may be reduced by antioxidants and polyphenols, but excessive consumption may impair adaptive signaling *(Clemente Suárez, et al., 2023)*. There is little proof that omega-3 directly improves performance, but it is consistent for long-term musculoskeletal health and recuperation.

Particularly in recreational or lightly trained athletes, recent research indicates modest gains in time-trial performance and fatigue resistance. Supplementing with nitrate may be particularly helpful during multi-day tournaments or high-volume endurance training.

Results and Discussion

This review clearly demonstrates that, despite the wide availability of nutritional supplements marketed to enhance athletic performance, only a limited number are supported by strong and consistent scientific evidence. The results of the literature analysis indicate that **creatine monohydrate, caffeine, protein/essential amino acids, and β-alanine** currently represent the supplements with the most robust ergogenic support, whereas other supplements show moderate or context-dependent effects. Creatine monohydrate emerges as the most extensively researched and reliable ergogenic aid in sports nutrition. Experimental studies and expert consensus statements consistently report significant improvements in maximal strength, power output, and repeated high-intensity exercise performance. These benefits are primarily attributed to increased intramuscular phosphocreatine stores, enhanced ATP resynthesis, and

improved training quality over time *(Kreider et al., 2017; Wax et al., 2021)*. Collectively, these findings support the use of creatine as a foundational supplement, particularly in strength- and power-based sports. Protein intake and essential amino acids play a central role in supporting exercise-induced muscle hypertrophy and post-exercise recovery. Evidence indicates that **total daily protein intake** is a more critical determinant of adaptation than precise timing or isolated amino acid supplementation. Meta-analytical findings confirm that protein supplementation, when combined with resistance training, significantly enhances muscle mass and strength gains, especially in physically active and trained individuals (*Morton et al., 2018; Jäger et al., 2017)*. Caffeine demonstrates consistent ergogenic effects across a wide range of performance outcomes, including endurance capacity, muscular strength, power output, and reductions in perceived exertion. These effects are largely mediated through central nervous system stimulation, increased motor unit recruitment, and altered pain perception. However, substantial inter-individual variability exists, influenced by genetic factors, habitual caffeine intake, and dosing strategies, underscoring the importance of individualized supplementation protocols *(Grgic et al., 2019; Pickering & Grgic, 2019)*. β-Alanine supplementation has been shown to improve performance in high-intensity efforts lasting approximately 1–10 minutes by increasing intramuscular carnosine concentrations and enhancing buffering capacity against exercise-induced acidosis. The magnitude of these benefits depends on supplementation duration, total dose, and baseline carnosine levels, indicating that structured loading protocols are essential to maximize its ergogenic potential *(Saunders et al., 2016)*. Dietary nitrates, commonly consumed as beetroot juice, demonstrate moderate improvements in exercise economy and endurance performance, particularly in recreational and sub-elite athletes. These effects are attributed to increased nitric oxide bioavailability and improved mitochondrial efficiency. However, evidence in elite populations remains inconsistent, likely due to ceiling effects associated with already optimized physiological systems *(Peeling et al., 2018)*. Omega-3 fatty acids and antioxidant supplements primarily influence recovery-related outcomes, including inflammation, muscle soreness, and cellular stress, rather than directly enhancing performance. While these supplements may be beneficial during periods of intensified training or rehabilitation, emerging evidence suggests that chronic high-dose antioxidant supplementation may blunt training-induced physiological adaptations by attenuating exercise-related oxidative signaling pathways *(Clemente Suárez et al., 2023)*. Branched-chain amino acids (BCAAs) and isolated leucine are frequently promoted for muscle hypertrophy and recovery; however, current evidence indicates that their effects are inferior to those of complete protein sources containing all essential amino acids. Whole-protein supplementation more effectively stimulates muscle protein synthesis and supports long-term hypertrophic adaptations, particularly in resistance-trained individuals *(Fouré & Bendahan, 2017; Plotkin et al., 2021)*. Overall, **the findings of this review** confirm that nutritional supplementation can meaningfully enhance athletic performance only when grounded in strong scientific evidence, appropriate dosing, and sport-specific application. A major challenge remains the translation of laboratory-based findings into applied sport settings, where inter-individual variability, training status, and competitive demands substantially influence supplementation outcomes *(Amawi et al., 2024)*. Persistent misconceptions regarding supplement timing and synergistic combinations continue to exist, despite evidence suggesting that **total intake and chronic adaptation** are often more influential than acute timing strategies *(Ribeiro et al., 2021)*. Regulatory compliance also represents a critical consideration, as contamination risks and evolving anti-doping regulations pose ethical and career-threatening risks for athletes. Consequently, supplementation strategies should prioritize third-party tested products and evidence-based selection *(Maughan et al., 2018; WADA, 2024)*. **Although** this review synthesizes high-quality evidence, methodological heterogeneity across studies limits direct comparison and generalizability. Future research should place greater

emphasis on underrepresented populations, including female athletes, youth and master athletes, long-term safety outcomes, and precision nutrition approaches that account for individual genetic responsiveness.

Conclusions

This review confirms that only a limited number of nutritional supplements provide consistent and meaningful ergogenic benefits. **Creatine monohydrate, caffeine, protein/essential amino acids, and β-alanine** demonstrate the strongest evidence for enhancing strength, power, endurance, and training adaptations when appropriately dosed and applied. Other supplements show moderate or context-dependent effects, with limited direct influence on performance, and chronic high-dose antioxidant use may impair long-term adaptations. Overall, supplementation should support – not replace – sound nutrition and training practices and must be individualized according to sport demands and athlete characteristics. Given the potential risks related to contamination and anti-doping regulations, evidence-based selection and third-party testing remain essential for safe and effective supplement use.

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