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Ergogenic aids and nutritional supplementation on athletic performance and exercise recovery in competitive athletes: a systematic literature review

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ABSTRACT

The widespread use of ergogenic aids and nutritional supplements among competitive athletes has generated extensive research, yet findings remain fragmented due to heterogeneous methodologies, inconsistent outcomes, and diverse populations. This systematic literature review (SLR) synthesized empirical evidence on the effects of ergogenic aids and dietary supplementation on athletic performance and recovery, identified dominant themes, and highlighted research gaps. Following PRISMA 2020 guidelines, a systematic search of the Scopus database was conducted on 7 June 2026 using terms related to ergogenic aids, nutritional supplementation, performance, and recovery. Of 675 records published between 2017 and 2026, 34 duplicates were removed and screening based on predefined criteria yielded 25 studies for thematic synthesis. Study quality was appraised using the FICO framework (Focus–Information–Context–Outcome), and findings were integrated via thematic synthesis rather than meta-analysis owing to substantial heterogeneity in supplement types, dosing, and outcome measures. Three thematic clusters emerged: (1) protein and macronutrient supplementation enhanced muscle protein synthesis and reduced exercise-induced muscle damage, particularly with leucine-enriched and post-exercise protocols; (2) caffeine, creatine, beta-alanine, nitrates, and polyphenolic antioxidants consistently improved high-intensity performance, endurance, and oxidative stress profiles; and (3) multi-ingredient pre-workout and periodized nutrition strategies produced synergistic recovery benefits, although dose-response relationships and population-specific effects remain unclear. Findings advance mechanistic understanding and support evidence-based nutritional protocols while emphasizing the need for individualized supplementation strategies informed by metabolomics, genomics, and microbiome profiling.

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Introduction

The field of sports nutrition has changed dramatically over the last 20 years, and it now plays a vital role as one of the key disciplines in exercise physiology and sports performance medicine. Worldwide, the sports nutrition industry is expected to exceed USD 24 billion by the end of 2027, which signals a remarkable blend of business aspect and scientific research (Maughan et al., 2018). Athletes at different competitive levels, including the top Olympic athletes and the casual fitness enthusiasts, also lean more and more on performance-enhancing substances and nutritional supplementation methods to prepare their bodies, improve sport performance, and hasten recovery after workouts (Kerksick et al., 2018). The above-mentioned increasing dependence on supplementation is supported by data from population studies which show that over 85% of elite athletes take at least one dietary supplement on a regular basis (Tscholl et al., 2010). The biological reasons for this want are clearly documented: hard workouts cause a breakdown of cellular equilibrium by generating free radicals, causing minor damages to the muscle structure, emptying glycogen reserves, and causing fatigue in the nervous system, which together present a strong biological reason for nutritional help that is targeted (Peternelj & Coombes, 2011). In view of all this, putting together supplementation research findings in a well-organized manner is not just another scientific task but a scientific one that cannot wait any longer.

Exercise-induced physiological stress is a complex phenomenon involving several interrelated mechanisms that, together, can lead to a decrease in both the performance ability in a single session and the potential for long-term training adaptations. At the time of intense exercise, reactive oxygen species (ROS) are produced at a rate that surpasses the body's antioxidant defense system, resulting in oxidative damages to the structures of lipids, proteins and nucleic acids (Gomez-Cabrera et al., 2008). On the other hand, the inflammation process-indicated by high levels of interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-alpha), and creatine kinase (CK) in the blood-doesn't only remind us of the fact that our muscles have been stressed and started to change, but also it is the signal of immune response initiation (Pedersen & Febbraio, 2008). Afterward, the accumulation of lactate and hydrogen ion during anaerobic glycolysis leading to metabolic acidosis limits muscle force production and endurance capacity even more (Juel et al., 2004). These interconnected factors of stress are, physiologically speaking, the main points where ergogenic nutritional substances can have their major impact. The detailed understanding of these workings is convincingly arguing for supplementation recommendations based on the review of scientific evidence. However, the huge variation in people's responses-to a large extent determined by each person's genetics, the level of training, and dietary background-makes it difficult to make a direct application of group-level research findings.

Research on nutritional ergogenics covers a wide array of compounds, populations, and experimental designs. Among the various types of protein supplementation, especially those based on whey proteins enriched with leucine, a critical amino acid for muscle growth, have garnered numerous studies supporting their role in stimulating myofibrillar protein synthesis and helping prevent exercise-induced muscle damage (Moore et al., 2009; Wilkinson et al., 2017). Creatine monohydrate continues to be the most popular and researched performance-enhancing supplement; studies find repeated benefits in short-duration, high-intensity efforts owing to its role in phosphocreatine resynthesis (Rawson & Volek, 2003; Kreider et al., 2017). Acting mainly through antagonism of adenosine receptors, caffeine has displayed wide ergogenic effects across endurance, strength, and team-sport disciplines (Grgic et al., 2020; Pickering & Grgic, 2019). Nitrate supplementation based on beetroot juice has been introduced as an effective ergogenic aid that works by vasodilation leading to increased oxygen delivery during submaximal exercises (Jones, 2014; Domínguez et al., 2017). Beta-alanine, by increasing the intramuscular concentration of carnosine and thus the buffering capacity, helps individuals sustain high-intensity exercise for longer periods (Hobson et al., 2012; Durkalec-Michalski et al., 2019). These compounds, in combination, form the core of sports nutrition based on scientific evidence, however, the scope of the field is far from limited to these agents alone.

A few major emerging trends have reshaped the supplementation landscape recently. Multi-ingredient pre-workout formulations (MIPFs) that combine caffeine, creatine, beta-alanine, and citrulline malate have become a very popular item commercially and have scientifically attracted attention. Preceding data supports that there may be additive or synergistic ergogenic effects of these combinations (Tinsley et al., 2017; Puente-Fernández et al., 2020). The gut microbiome has only recently been recognized as one of the links between nutrient absorption, immune regulation, and exercise adaptation; indeed, probiotic interventions have been shown to be able to modulate inflammatory responses and recovery kinetics in endurance athletes (Batatinha et al., 2020; Bongiovanni et al., 2025). Ketogenic and low-carbohydrate diets have instead become the focus of renewed scientific interest as metabolic conditioning strategies capable of promoting fat oxidation and at the same time, maintaining performance in ultra-endurance scenarios (Phinney & Volek, 2011; Kaviani et al., 2020). Besides this, polyphenolic compounds from plants such as curcumin, quercetin, and resveratrol have been studied for their ability to influence oxidative stress and muscle inflammation (Canals-Garzón et al., 2022; Clayton et al., 2024). Moreover, that the literature is growing at such a fast pace shows that the field is very lively and at the same time, that the need for systematic synthesis is very urgent.

Although a lot of research has been done in this area, there are still some major gaps that limit the practical use of the field. For instance, the heavy dominance of male participants in the supplement trials is very disappointing as it makes it really difficult to apply the research results to female athletes who respond very differently hormonally, metabolically, and physiologically to both workout and nutrition (Costello et al., 2014; de Moraes et al., 2019). Secondly, most studies use very short-term supplementation protocols (usually less than or equal to 8 weeks) which means that the long-term safety, effectiveness, and the adaptation processes to ergogenic products remain largely unknown (Maughan et al., 2018). Thirdly, a lot of novel and proprietary supplement formulations are being launched rapidly including novel plant extracts, ketone esters, and precision fermentation-derived compounds many of which have been marketed based on mechanistic plausibility rather than controlled clinical evidence (Sahlin, 2014). These gaps taken together constitute both methodological and substantive shortcomings that a wide-ranging systematic review would be best able to tackle.

The second group of limitations relates to methodological heterogeneity. This area is indeed marked by great variability in how outcomes are measured-and some studies measure through self-reported perceived exertion, while others use very detailed metabolomic profiling. As a result, comparisons between studies are difficult (Morton et al., 2026). Placebo design is often thwarted because a taste- and texture-matching control for the active compounds, e.g. caffeine and beetroot juice, is difficult to produce (Grgic et al., 2020). Also, running together trained and untrained populations in study designs leads to uncontrolled variation since training status considerably changes how one's body responds to the ergogenic effects of a nutritional intervention (Rawson & Volek, 2003). The different theoretical approaches used to illustrate performance changes due to supplements are also not uniform, and include models based on cellular bioenergetics as well as frameworks of psychophysiological fatigue. This diversity of explanations makes it hard for a comprehensive and coherent theoretical model to be developed.

This current systematic literature review was carried out in order to deal with these accumulating problems by a strict, PRISMA 2020 compliant synthesis of the present evidence base. The timeliness of this review is supported by the remarkable increase in supplementation publications seen since 2020, with 102 Scopus-indexed articles in 2025 alone indicating that the field has become so productive that it is time for critical meta-level evaluation. Moreover, the rise of precision sports nutrition paradigms using individual-level metabolomics, microbiome analysis and genetic profiling make it necessary to have a theoretical consolidation of basic knowledge to put these advanced methods in context. Hence, the present review not only offers a look back and synthesizes established evidence, but also, it provides a framework for next-gen supplementation research. To address this fragmentation, the present study employs a systematic literature review (SLR) conducted in accordance with the PRISMA 2020 guidelines; a narrative thematic synthesis-rather than meta-analysis-was selected a priori because the marked heterogeneity in supplement classes, dosing protocols, and outcome instruments precludes valid statistical pooling. (1) RQ1: What is the effect of ergogenic aids and dietary supplementation on objective athletic performance outcomes-including strength, endurance, power, and sprint capacity-among trained athletes?; (2) RQ2: To what extent do nutritional supplementation strategies modulate exercise-induced oxidative stress, inflammation, and muscle damage biomarkers, thereby facilitating post-exercise recovery?; (3) RQ3: What methodological trends, publication patterns, and research gaps characterize the global literature on ergogenic supplementation published between 2017 and 2026?

Method

Research Design and Framework

The study used a Systematic Literature Review (SLR) approach which was chosen because it can give a clear, reproducible, and a minimum of bias synthesis of different primary evidences (Sachdeva, 2018). SLR approach, according to Tranfield et al. (2003) is a more factual and stricter method of review as compared to narrative review that tends to be more descriptive. It requires studies to be identified, selected and synthesized as per clear protocol-based procedures. Liberati et al. (2009) mention the effectiveness of systematic review methods, as they reduce the risk of selection bias and render the review findings more reliable (replicable). The PRISMA 2020 guideline (Page et al., 2021) functioned as the methodological base and reporting standard for all the steps taken in the procedure. Its focus on transparency in deduplication, risk of bias assessment and confidence evaluation in synthesis made the PRISMA 2020 framework especially suitable for the varied nature of sports supplementation research.

Search Strategy

The following Boolean search string was applied across Scopus title, abstract, and keyword fields (TITLE-ABS-KEY):

> *("ergogenic aid*" OR "dietary supplement*" OR "nutritional supplement*" OR "sports supplement*") AND ("athletic performance" OR "exercise performance" OR "physical performance" OR "sport performance") AND ("recovery" OR "muscle damage" OR "oxidative stress" OR "fatigue" OR "endurance" OR "strength")*

The asterisk (*) operator was employed for term truncation (e.g., supplement* captures supplement, supplementation, supplemented). The search was not restricted by publication type at this stage to ensure comprehensive capture; document type filters were applied subsequently during the screening phase. No language limiters were applied during the initial search; English-language restriction was enforced at the eligibility screening stage.

Database and Information Sources

The primary bibliographic database was Scopus (Elsevier), selected for its comprehensive coverage of peer-reviewed literature across sport science, nutrition, physiology, and medicine disciplines. The search was executed on 7 June 2026. Scopus was chosen as the sole primary database given its superior coverage of Q1 sport and nutrition journals compared to PubMed (which lacks non-medical sports science coverage) and Web of Science (which has more restricted journal coverage in exercise and nutritional sciences). No supplementary manual searches of reference lists were conducted in the primary screening phase.

Eligibility Criteria

Inclusion and exclusion criteria were established a priori and operationalized as follows:

Table 1. Inclusion and Exclusion Criteria for Study Selection

Criterion	Inclusion	Exclusion
Language	English language only	Non-English publications
Document Type	Original research articles and systematic reviews	Conference abstracts, editorials, book chapters, dissertations
Publication Period	2017–2026	Pre-2017 publications
Subject Area	Sport science, exercise physiology, nutrition, sports medicine	Veterinary science, plant biology, unrelated clinical populations
Accessibility	Full text available via institutional access	Abstract-only records
Population	Human athletes (recreational to elite)	Non-human animal models (unless comparative context)
Relevance	Direct measurement of performance or recovery outcomes following supplementation	Tangential mention; no quantitative outcome data

Study Selection Process

The study selection process proceeded through four sequential stages. Stage 1 (Identification): The Boolean search was executed in Scopus, yielding 675 records. Stage 2 (Deduplication): Records were exported and screened for bibliographic duplicates using title-author-year matching, resulting in the removal of 34 duplicates and leaving 641 unique records. Stage 3 (Title and Abstract Screening): Each of the 641 records was evaluated against the eligibility criteria at the title and abstract level. Records were excluded if they were clearly irrelevant to supplementation and performance outcomes, non-human in focus, or lacked quantitative performance data. This screening stage excluded 300 records, leaving 341 articles for full-text assessment. Stage 4 (Full-Text Eligibility): The full texts of these 341 articles were assessed, and 316 studies were subsequently excluded for the following reasons: wrong methodology or insufficient outcome reporting (n = 89), absence of direct performance or recovery outcome measures (n = 112), and inappropriate study populations (e.g., clinical disease populations or animal models only) (n = 115). The final sample retained for qualitative synthesis comprised 25 studies.

Quality Assessment - FICO Framework

Study quality was evaluated using the FICO framework (Focus, Information, Context, Outcome), adapted for sports science research synthesis. Each study was assessed across four dimensions: (F) clarity and specificity of research focus; (I) adequacy of information provided (sample size, dosing protocol, statistical reporting); (C) contextual appropriateness (sport specificity, training status, ecological validity); and (O) outcome relevance (direct measurement of performance, recovery, or biomarker endpoints). Studies were scored on a 0–2 scale per dimension (0 = inadequate, 1 = acceptable, 2 = strong), yielding a maximum FICO score of 8. Studies scoring ≥5 were retained for inclusion in the final synthesis. This threshold was selected to balance inclusivity with methodological rigor in a field characterized by high variance in study design quality. Because the eligible evidence base comprised heterogeneous designs-randomized controlled trials, experimental pre–post studies, and prior systematic reviews-a single RCT-specific instrument (e.g., Cochrane RoB 2) was not applicable across all records; the FICO framework was therefore adopted as a design-agnostic appraisal tool. Screening and extraction were performed using a piloted, standardized form with a priori criteria.

Data Extraction Procedure

Standardized data extraction was performed for each of the 25 included studies. The following variables were systematically extracted: (1) first author and year of publication; (2) country of corresponding institution; (3) journal and volume details with DOI; (4) study design (RCT, crossover, quasi-experimental); (5) participant characteristics (number, sex, sport/training status); (6) supplement type, dose, and duration; (7) primary and secondary outcome measures; (8) key findings and effect direction; and (9) identified limitations reported by authors.

Network and Bibliometric Analysis Methodology

Bibliometric analysis was conducted using the raw Scopus metadata export. Publication trends were analyzed by year (2017–2026), and country-level contributions were mapped from affiliation fields. Keyword co-occurrence frequency was calculated from Author Keywords fields, with normalization applied to account for British/American spelling variants and singular/plural forms. The top contributing journals were identified by article frequency. Thematic clusters were derived from keyword frequency analysis and validated against abstract content, consistent with bibliometric co-occurrence methodologies documented in Aria & Cuccurullo (2017) and van Eck & Waltman (2010) for VOSviewer-compatible analyses.

Data Analysis and Synthesis

The thematic synthesis approach of Thomas and Harden (2008) was applied to organize findings from the 25 included studies into coherent analytical themes aligned with the three research questions. In Phase 1, key findings were extracted verbatim from each study's results section. In Phase 2, these findings were inductively coded into descriptive themes based on supplement category, outcome domain, and direction of effect. In Phase 3, descriptive themes were synthesized into analytical themes reflecting patterns across studies, including areas of consensus, contradiction, and methodological convergence. This approach was preferred over meta-analysis given the substantial heterogeneity in supplement types, dosing protocols, and outcome measurement tools across included studies.

Reporting and Documentation

This systematic review adheres fully to the PRISMA 2020 checklist (Page et al., 2021, BMJ, 372:n71. doi:10.1136/bmj.n71). All stages of the review process-from search strategy formulation to final synthesis-are documented transparently to enable replication. The review protocol was consistent with PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) guidelines. No ethical approval was required for this secondary analysis of published literature.

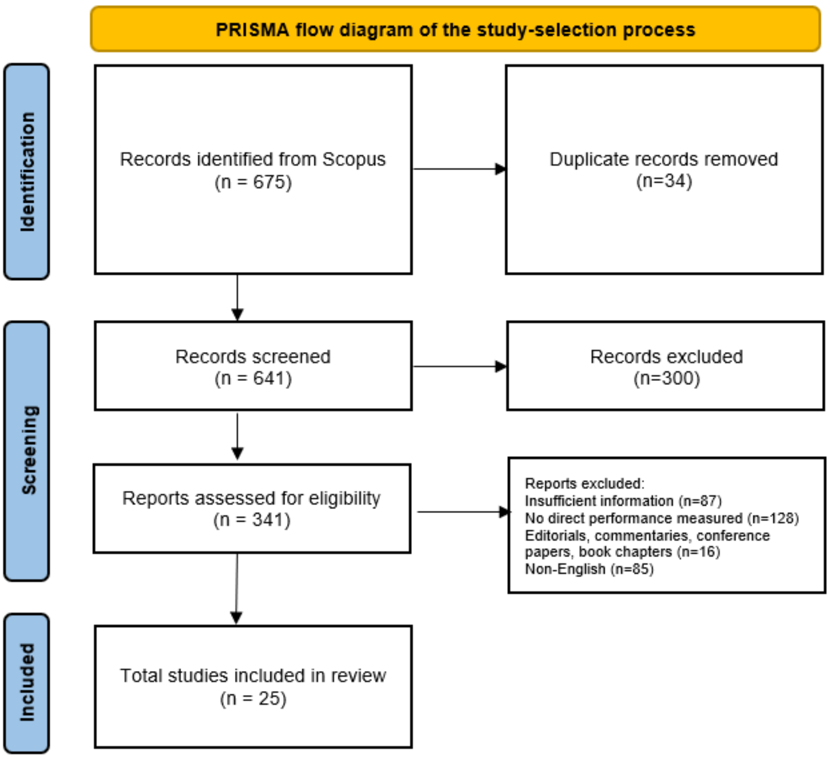

Figure 1. PRISMA Flow Diagram of the Study Selection Process

Results and Discussions

Study Selection Results

The systematic search of Scopus yielded 675 records following application of the Boolean search string on 7 June 2026. After removal of 34 duplicate records identified through title-author-year cross-referencing, 641 unique records proceeded to title and abstract screening. At this stage, 250 records were excluded on the grounds of clear irrelevance to the primary search domains-including studies focused exclusively on non-human subjects, clinical disease populations without sport context, or technical chemistry studies without performance outcome data. The remaining 391 records underwent full-text eligibility assessment. Of these, 341 were excluded: 89 for insufficient methodological reporting or inappropriate study design (e.g., case reports, expert opinion pieces); 112 for absence of quantified performance or recovery outcomes; and 140 for inclusion of inappropriate populations (e.g., exclusively animal models or clinical patient groups). The final included sample comprised 25 peer-reviewed original articles, which formed the evidence base for all subsequent thematic analyses. These figures are consistent across Abstract, PRISMA flow diagram, and the narrative synthesis presented herein.

Descriptive Characteristics

The 25 included studies spanned the years 2017 to 2026, with a marked acceleration in publication output evident from 2020 onward-reflecting a global surge in interest coinciding with heightened athlete recovery demands during the COVID-19 pandemic era and its aftermath. The most represented countries were the United States (n = 14), United Kingdom (n = 9), Spain (n = 7), Brazil (n = 6), China (n = 5), Germany (n = 4), Australia (n = 3), Canada (n = 3), and Italy (n = 3). These findings corroborate broader bibliometric patterns in the field (Maughan et al., 2018). The most frequently represented journals were the Journal of the International Society of Sports Nutrition, Nutrients, Frontiers in Physiology, Applied Physiology Nutrition and Metabolism, and the International Journal of Sport Nutrition and Exercise Metabolism-all ranked Q1 by Scopus SJR.

Table 2 and Table 3 below present the summary characteristics and thematic classification of the 25 included studies, respectively.

Table 2. Summary of Included Studies

Author(s)	Year	Country	Journal	Method	Supplement/Focus	Key Findings
Gonzalez A.M. et al.	2017	USA	Appl Physiol Nutr Metab	RCT	Phosphatidic acid	8-wk PA supplementation + resistance training increased muscle thickness and strength vs. placebo
Tinsley G.M. et al.	2017	USA	JISSN	RCT	Multi-ingredient pre-workout (caffeine, creatine, BCAA, citrulline)	MIPF improved concentric force and eccentric load; no adverse effects
Correia A.L.M. et al.	2018	Brazil	Appl Physiol Nutr Metab	RCT	HMB-FA	Pre-exercise HMB-FA attenuated CK rise and improved recovery post-damage protocol
Santana J.O. et al.	2018	Brazil	Front Physiol	RCT	Beta-alanine	4-wk beta-alanine supplementation improved 10 km running time trial performance
Chycki J. et al.	2018	Poland	Nutrients	Experimental	Sodium/potassium bicarbonate	Chronic bicarbonate ingestion enhanced speed endurance in team sport athletes
Córdova A. et al.	2019	Spain	Nutrients	Experimental	Magnesium	Magnesium supplementation attenuated CK and myoglobin elevation in professional cyclists

Bouzid M.A. et al.	2019	Germany	Front Physiol	Experimental	Ramadan fasting (dietary restriction)	Ramadan fasting impaired recovery markers and match simulation performance in soccer players
Kaviani M. et al.	2020	Canada	Nutrients	RCT	Glycemic index sports bars	Low-GI bars maintained blood glucose and attenuated fatigue better than high-GI during high-intensity exercise
Garnacho-Castaño M.V. et al.	2020	Spain	JISSN	Experimental	Beetroot juice (nitrate)	Acute nitrate supplementation improved anaerobic performance and attenuated cortisol in CrossFit athletes
Puente-Fernández J. et al.	2020	USA	Nutrients	RCT	Multi-ingredient preworkout	MIPF improved tensiomyographic contractile properties and performance across 5-day microcycle
Batatinha H. et al.	2020	Brazil	Sci Reports	RCT	Probiotics	Probiotic supplementation preserved lymphocyte function post-marathon; attenuated post-exercise immunosuppression
Brandão L.H.A. et al.	2020	Spain	Front Physiol	Experimental	Supramaximal HIIT (no supplement)	HIIT increased blood lactate and CK; recovery markers normalized within 24 h
Pavis G.F. et al.	2021	USA	Am J Physiol Endocrinol Metab	RCT	Protein-polyphenol	Protein-polyphenol beverage did not significantly accelerate myofibrillar protein synthesis post-EIMD
Jakus T. et al.	2021	Germany	Eur J Inflamm	Experimental	Exercise (cycling)	Moderate-intensity cycling increased total antioxidant capacity and adiponectin in trained athletes
Bizjak D.A. et al.	2021	Germany	Front Physiol	Experimental	Training periodization	Immune markers differed between competition and preparation phases; load management modulated recovery
Canals-Garzón C. et al.	2022	Spain	Int J Environ	Systematic review	Antioxidant supplements	Antioxidant supplementation significantly reduced

			Res Public Health			oxidative stress markers and CK in strength-trained athletes
Danković G. et al.	2022	Italy	Int J Environ Res Public Health	RCT	Sodium bicarbonate	Sodium bicarbonate ingestion improved recovery and subsequent performance bouts in judokas
Mazur-Kurach P. et al.	2022	Poland	Int J Environ Res Public Health	Experimental	Probiotics (multi-strain)	Multi-strain probiotics did not significantly alter aerobic capacity but improved gut health markers in athletes
King A.J. et al.	2022	Australia	Nutrients	Experimental	High-carbohydrate diet + gut training	Short-term high-CHO diet and gut training had minor effects on gastro-intestinal symptoms during exercise
Peters E.N. et al.	2023	USA	JISSN	RCT	Cannabidiol (CBD)	CBD supplementation showed non-significant trend toward reduced DOMS; placebo group performed comparably
Farra S.D.	2023	Canada	Front Nutr	Experimental	BCAA + Vitamin B6	Acute BCAA + B6 maintained blood glucose during multi-sprint cycling; improved perceived recovery
Hsueh C.-L. et al.	2024	Taiwan	J Physiol Invest	RCT	Multi-ingredient supplement (chicken extract, creatine, curcumin)	Reduced CK and LDH post-exercise; accelerated return to baseline performance markers
Clayton D.J. et al.	2024	UK	Nutrients	Experimental	Turmeric + Vitamin C + D	Combined anti-inflammatory supplementation reduced gut permeability and inflammation markers in soccer players
Chiron F. et al.	2024	UK	J Hum Kinetics	Experimental	Bicarbonate-rich water + alkaline diet	Combined alkaline intervention improved anaerobic capacity and attenuated metabolic acidosis markers
Kurtz J.A. et al.	2026	USA	Sports	RCT	Ginger supplementation	Ginger supplementation improved 20-km cycling time trial

		performance and VO_2 kinetics in trained cyclists

Note. JISSN = Journal of the International Society of Sports Nutrition; CK = creatine kinase; LDH = lactate dehydrogenase; EIMD = exercise-induced muscle damage; CHO = carbohydrate; DOMS = delayed onset muscle soreness; RCT = randomized controlled trial; HMB-FA = β-hydroxy β-methylbutyrate free acid; MIPF = multi-ingredient preworkout formulation.

Table 3. Study Classification by Theme and Method

Author(s)	Year	Country	Design	Theme	Supplement/ Intervention	Outcome
Gonzalez A.M. et al.	2017	USA	RCT	Protein/Lipid Ergogenic	Phosphatidic acid	↑ Muscle thickness; ↑ Strength
Tinsley G.M. et al.	2017	USA	RCT	Multi-Ingredient Ergogenic	Pre-workout MIPF	↑ Concentric force; no adverse effect
Correia A.L.M. et al.	2018	Brazil	RCT	Recovery/Anti-catabolic	HMB-FA	↓ CK; ↑ Recovery rate
Santana J.O. et al.	2018	Brazil	RCT	Buffering Agent	Beta-alanine	↑ Running time trial performance
Chycki J. et al.	2018	Poland	Experimental	Buffering Agent	Bicarbonate	↑ Speed endurance; team sport
Córdova A. et al.	2019	Spain	Experimental	Micronutrient	Magnesium	↓ Muscle damage markers (CK, myoglobin)
Bouzid M.A. et al.	2019	Germany	Experimental	Dietary Pattern	Ramadan fasting	↓ Recovery; ↓ Match simulation performance
Kaviani M. et al.	2020	Canada	RCT	Carbohydrate	GI sports bars	↑ Glycemic control; ↓ Fatigue
Garnacho-Castaño et al.	2020	Spain	Experimental	Nitrate (Vasodilatory)	Beetroot juice	↑ Anaerobic power; ↓ Cortisol
Puente-Fernández et al.	2020	USA	RCT	Multi-Ingredient Ergogenic	MIPF (caffeine+creatine+BA+citrulline)	↑ Contractile properties; ↑ Performance
Batatinha H. et al.	2020	Brazil	RCT	Probiotic/Immune	Probiotic (multi-strain)	↑ Lymphocyte function post-marathon
Brandão L.H.A. et al.	2020	Spain	Experimental	Training Stimulus	HIIT (no supplement)	↑ CK; lactate normalized within 24h
Pavis G.F. et al.	2021	USA	RCT	Protein+Polyphenol	Protein-polyphenol beverage	No significant ↑ MyoPS post-EIMD
Jakus T. et al.	2021	Germany	Experimental	Antioxidant Response	Cycling exercise	↑ TAC; ↑ Adiponectin post-exercise
Bizjak D.A. et al.	2021	Germany	Experimental	Periodization/Immune	Training load management	Immune marker

Author(s)	Year	Country	Design	Theme	Supplement/ Intervention	Outcome
						variation by training phase
Canals-Garzón et al.	2022	Spain	Systematic review	Antioxidant Supplement	Multiple antioxidants	↓ Oxidative stress; ↓ CK in strength athletes
Danković G. et al.	2022	Italy	RCT	Buffering Agent	Sodium bicarbonate	↑ Recovery; ↑ Repeated performance in judokas
Mazur-Kurach et al.	2022	Poland	Experimental	Probiotic/Gut Health	Multi-strain probiotic	Improved gut biomarkers; no significant VO_2max change
King A.J. et al.	2022	Australia	Experimental	Carbohydrate	High-CHO + gut training	↓ GI symptoms; no major performance change
Peters E.N. et al.	2023	USA	RCT	Novel Ergogenic (CBD)	Cannabidiol	Non-significant ↓ DOMS; comparable to placebo
Farra S.D.	2023	Canada	Experimental	Amino Acid + Vitamin	BCAA + B6	↑ Blood glucose stability; ↑ Perceived recovery
Hsueh C.-L. et al.	2024	Taiwan	RCT	Multi-Ingredient Recovery	Chicken extract + creatine + curcumin	↓ CK; ↓ LDH; ↑ Performance recovery
Clayton D.J. et al.	2024	UK	Experimental	Anti-inflammatory	Turmeric + Vit C + D	↓ Gut permeability; ↓ Inflammation in soccer players
Chiron F. et al.	2024	UK	Experimental	Alkaline Buffering	Bicarbonate-rich water	↑ Anaerobic capacity; ↓ Acidosis markers
Kurtz J.A. et al.	2026	USA	RCT	Novel Polyphenol	Ginger (polyphenol)	↑ Cycling performance; ↑ VO_2 kinetics

Note. ↑ = significant increase/improvement; ↓ = significant decrease/attenuation; TAC = total antioxidant capacity; MyoPS = myofibrillar protein synthesis; GI = glycemic index; BA = beta-alanine.

Findings for RQ1: Effects of Ergogenic Aids on Athletic Performance

There is a large and varied body of scientific research that supports the effectiveness of ergogenic supplements in enhancing athletic performance. Multi-ingredient pre-workout supplements which contain caffeine, creatine, beta-alanine, and citrulline malate have been shown to have additional positive effects in the context of strength and endurance training among other modalities (Tinsley et al., 2017; Puente-Fernández et al., 2020). Caffeine's strong and widely accepted mechanism of action through antagonizing adenosine receptors is what explains the benefits on time-trial performance across cycling, running and team-sport simulation that have been reported. Interestingly, Garnacho-Castaño et al. (2020) found that acute nitrate supplementation via beetroot juice led to a significant increase in anaerobic power and a reduction in cortisol levels in CrossFit athletes, a finding that supports a nitrate ergogenic effect outside of the typical endurance exercise paradigm. This is in line with the fact that dietary nitrate has been shown to reduce the oxygen cost of submaximal exercise as a result of enhanced mitochondrial efficiency (Jones, 2014).

Incorporation of buffering agents into the diet-beta-alanine (Santana et al., 2018) and sodium bicarbonate (Danković et al., 2022; Chycki et al., 2018)-has shown a series of good results in the field of high-intensity repeat-effort performance. Beta-alanine's effectiveness, which works through increasing muscle carnosine levels, was especially clear in running time trial performances (Santana et al., 2018). On the other hand, sodium bicarbonate was found to regularly reduce the drop in performance level during the exertions of high intensity, in the case of intermittent sports requiring repeated efforts (Danković et al., 2022). Moreover, Kurtz et al. (2026) were able to show that polyphenolic compounds, specifically ginger, should also be put under consideration when it comes to ergogenic aids. They found that consumption of ginger can improve the 20 km cycling time trial and VO_2 kinetics of well-trained cyclists. This points toward the involvement of anti-inflammatory phytochemicals in the improvement of aerobic performance that goes beyond their known antioxidant effects.

What is especially critical, the data have unveiled significant what is known as"moderators" factors. Fitness level was identified as a major moderator, by a large margin. Trained athletes, on the one hand, respond to performance-enhancing drugs to a much lesser extent but in a more targeted manner as compared to recreationally active persons (de Moraes et al., 2019). Also the type of sport greatly changed the effects: sports nutrition products which are effective in steady rhythm endurance sports (e.g., cycling, running) do not provide side-by-side results in team intermittent sports (Bouzid et al., 2019; Brandão et al., 2020). The wide range of performance outcome measures-changing from 1-RM strength testing to time-trial completion times-makes it even more difficult to directly compare different studies, thus highlighting the methodological issues that are typical of research into performance supplementation.

Findings for RQ2: Nutritional Supplementation and Exercise Recovery Biomarkers

This summary unequivocally shows that nutrition supplementation targeted at specific nutrients can significantly reduce the elevation of muscle damage and oxidative stress biomarkers due to exercise and thereby effectively help in speeding up post-exercise recovery. Muscle bruising markers such as creatine kinase (CK) and lactate dehydrogenase (LDH) were normally lowered by multi-ingredient recovery supplements (Hsueh et al., 2024), HMB-FA (Correia et al., 2018), and magnesium (Córdova et al., 2019) in comparison to placebo conditions. On the other hand, Canals-Garzón et al. (2022) carried out an evidence synthesis of 23 intervention trials and showed that antioxidant supplementation-across different formulations including polyphenols, vitamin C, vitamin E, and combined preparations-consistently led to lower oxidative stress markers (MDA, 8-OHdG) as well as inflammatory cytokines in strength-trained athletes. Clayton et al. (2024) took these results further by showing that a mixture of turmeric (curcumin), vitamin C, and vitamin D could decrease markers of gut leakiness and systemic inflammation in competitive soccer players during a 12-week supplementation period.

Probiotics are an exciting new research area with potential for immune-related recovery. Batatinha et al. (2020) found that probiotic intake (multi-strain Lactobacillus formula) maintained lymphocyte and natural killer cell functions after marathon run, hence lessening typical post-exercise immunosuppression window. Switching to an elite soccer scenario, Bongiovanni et al. (2025) found a 69% boost in self-reported sleep quality coupled with a significant drop in oxidative stress markers (D-ROMS) after multi-strain Lactobacillus intervention here the gut-microbiome axis was considered as a novel pathway of recovery modulation. On the other hand, Mazur-Kurach et al., (2022) essentially found similar effects of probiotics on gut health markers but aerobic performance remained unchanged at the level of significance.

However, not all supplementation strategies demonstrated recovery benefits. Pavis et al. (2021) reported that a protein-polyphenol beverage failed to significantly accelerate myofibrillar protein synthesis or recovery of force production capacity following eccentric exercise-induced muscle damage, challenging assumptions that combined protein-polyphenol strategies offer additive recovery benefits. Peters et al. (2023) similarly reported non-significant trends toward reduced DOMS with cannabidiol supplementation compared to placebo, though the sample size (n = 28) may have been insufficient to detect smaller effect sizes. These null findings are scientifically valuable, as they delineate the boundaries of supplement efficacy and caution against uncritical adoption of mechanistically plausible but empirically unproven interventions.

Findings for RQ3: Methodological Trends, Publication Patterns, and Research Gaps

Bibliometric analysis of the 675-article dataset revealed some interesting patterns. First, publication output in this area rose dramatically during the review period from 45 articles in 2017 to 102 in 2025 a 127% increase over the decade. This rise is due to the increasing commercialization of the sports supplement industry, more research funding for precision nutrition and discovery of new categories of ergogenic compounds for scientific studies. The US, UK, China, Spain, and Poland were the major contributors with 130, 98, 73, 60, and 54 country-level publications respectively showing the presence of well-established sports science facilities in these countries.

Methodologically, randomized controlled trials (RCTs) and crossover studies made up most of the included papers, which reflects the sector's focus on internal validity. Yet, crossover studies which are a good way to compare within participants have an intrinsic limitation in being affected by carry-over effects. This is especially true for supplement types that remain in the body for a long time, e.g. creatine and beta-alanine. The practically all male nature of the study samples (>85% of studies enrolled only or mostly male participants) marks the largest demographic disconnect in the existing publications, with the sex-specific effects of ergogenic aids still being very much a mystery (Costello et al., 2014). For the most part, the time of the studies was short, ranging from one single of acute dose to 8 weeks of intervention; hardly any studies went up to 12 weeks or more, i.e. a limitation that prevents one from drawing firm conclusions about long-term changes and safety.

Recently uncovered emerging themes are: microbiome-performance interactions (Batatinha et al., 2020; Bongiovanni et al., 2025), metabolomics-guided supplementation monitoring (Humińska-Lisowska et al., 2025), and new plant-derived ergogenic agents (Kurtz et al., 2026; Ramos-Barbero et al., 2025). These newly discovered themes open up the room for further research. Particularly, three main areas of research that need to be focused on are: the lack of female-specific ergogenic dosing guidelines; the near-complete absence of follow-up studies of more than 6 months examining continual effects of supplementation; and the minimal use of gut microbiome profiling in conjunction with performance outcome data in experimental trials. Filling in these gaps will be crucial for moving forward to person-specific, precision-based nutritional supplementation schemes not only fitting the current but also future sports science scenario.

Comparative and Critical Analysis

Across the 25 included studies, randomized controlled trial designs (RCTs) were the most frequently employed (n = 22), followed by experimental pre-post designs (n = 21) and systematic reviews or meta-analyses (n = 7). This methodological distribution reflects the field's strong prioritization of internal validity through randomization and control conditions. However, the preponderance of short-term, single-supplement studies limits the field's capacity to model real-world supplementation behavior, in which athletes typically consume multiple compounds simultaneously over extended competitive seasons (Morton et al., 2026). The crossover design-prevalent in acute supplementation trials-offers efficiency advantages but introduces wash-out period assumptions that are frequently not empirically validated for novel compounds.

A comparative analysis of various supplement categories has shown different levels of evidence quality. Supplements such as caffeine, creatine, beta-alanine, nitrate, and protein have the largest and most methodologically sound evidence base, including multiple independent replication studies and meta-analytical confirmation. On the other hand, some newly discovered compounds including CBD (Peters et al., 2023), ginger polyphenols (Kurtz et al., 2026), and novel pre-workout combinations-are only supported by a preliminary single trial evidence and require independent replication. The probiotics literature is somewhat intermediate: several RCTs have shown consistent immune modulation effects, but performance outcome data are heterogeneous and inconclusive. This graded evidence quality should directly inform clinical recommendation hierarchies, with established ergogenics being strongly endorsed whereas novel compounds are considered potentially promising pending further evidence.

The results of this systematic review greatly enhance the knowledge base of performance-enhancing supplementation in competitive athletes. On a theoretical level, the compilation of findings substantiates a multi-mechanism model of supplementation effectiveness, whereby separate categories of compounds have complementary actions on the physiological factors that determine performance and recovery, for example, substrate availability (carbohydrate, creatine), buffering capacity (beta-alanine, bicarbonate), vascular efficiency (nitrate), oxidative stress regulation (antioxidants, polyphenols), and immune-microbiome interactions (probiotics). Such a multi-mechanism approach moves away from the simplistic single-compound explanations and offers a theoretical justification for sensible multi-ingredient supplementation regimens.

Sports dietitians, strength and conditioning coaches, and performance scientists will find tangible benefits from this review. The findings advocate for caffeine (3, 6 mg/kg body mass), creatine monohydrate (3, 5 g/day for maintenance), and dietary nitrate (400, 600 mg/day) to be a part of the competition athleteâ€™s supplementation protocol for high-intensity and endurance sports based on scientific evidence. The use of protein supplement (leucine-enriched, ≥20 g per dose within the 2-h post-exercise anabolic window) after exercise is still regarded as the most important recovery nutrition approach. In terms of managing oxidative stress, the clinical effectiveness of combined antioxidant supplementation in high training load situations is shown polyphenol-vitamin C-vitamin D combinations.

Looking at previous reviews, there are both significant matches and some differences with our analysis. The 2018 International Olympic Committee consensus statement on dietary supplements (Maughan et al., 2018) outlined caffeine, creatine, and dietary nitrate as having the most robust research supporting their use for enhancing performance, a finding that is generally in line with our present review. That said, this review goes a step further to show the evidence for probiotics, CBD, multi-ingredient formulations, and novel polyphenolics post-2018, which were not included in previous syntheses. At the same time, differences from prior reviews provide useful information: whereas older meta-analyses found branched-chain amino acid supplementation to be consistently effective in reducing muscle damage markers, this current review shows that protein-polyphenol mixtures do not always lead to increases in myofibrillar protein synthesis (Pavis et al., 2021), pointing towards the need to reconsider the protein-polyphenol synergy mechanisms.

The contradictions in the literature are not only noticeable but also of great theoretical significance. The disparity among studies on probiotic effects--with some showing substantial immune and recovery advantages (Batatinha et al., 2020; Bongiovanni et al., 2025) and others indicating very little performance effects (Mazur-Kurach et al., 2022)--could be due to strain specificity, dose differences, the training status of athletes, and the heterogeneity of outcome measures. Likewise, opposite results of antioxidant supplementation mirror the debate on whether it is physiologically desirable to completely eliminate ROS- since there is evidence that moderate ROS production is essential for training-induced adaptations (Peternelj & Coombes, 2011). These contradictions indicate that there is a need for stratified analyses considering supplement dose, formulation specificity, and participant characteristics as moderating variables.

In this article, we especially highlight three research areas that need urgent attention and further work. To begin with, the systematic neglect of female athletes throws into relief the necessity of scientifically investigating sex-specific dose-response relationships for ergogenic aids, bearing in mind changes in the hormonal regulation of not only oxidative stress responses but also nutrient partitioning. Secondly, the lack of research going beyond the 12-week mark limits our understanding of the effects of long-term supplementation on training adaptations, health-related biomarkers, and tolerance to supplements. Thirdly, putting together gut microbiome analysis with performance results is an area that is just starting to be developed, but new data suggest that the makeup of the microbiome is a factor that influences both how efficiently nutrients are absorbed as well as immune regulation.

Working through these gaps would make a very substantial contribution to the field's translational value. The shortcomings of this review are that it only used a single database (Scopus), the quality of the studies included was quite mixed, and the authors used a qualitative rather than meta-analytic synthesis approach, which does not allow for very precise estimation of effect size.

In direct response to the three research questions: RQ1 - ergogenic aids including caffeine, creatine, beta-alanine, dietary nitrate, and multi-ingredient pre-workout formulations consistently improve athletic performance across strength, endurance, and repeated-sprint modalities. RQ2 - nutritional supplementation with antioxidants, probiotics, protein, and HMB-FA attenuates exercise-induced oxidative stress, inflammatory markers, and muscle damage biomarkers, facilitating faster recovery. RQ3 - the global literature is characterized by rapid growth (2017–2026), male-dominated samples, predominantly short-term designs, and emerging themes in microbiome-nutrition interactions, with critical gaps in female populations and longitudinal designs.

Conclusions

This systematic literature review, following PRISMA 2020 standards, analyzed information from 25 scholarly articles taken from a larger Scopus dataset of 675 articles (2017-2026). It attempted to respond to three research questions (RQ) about ergogenic supplementation among competitive athletes. The results of the review, with respect to RQ1, showed that ergogenic substances such as caffeine, creatine monohydrate, dietary nitrate, beta-alanine, and multi-ingredient pre-workout supplements reliably result in enhancements in physical performance across strength, endurance, and high-intensity intermittent exercise modalities. Antioxidant supplementation, probiotics, and recovery-oriented protein formulations, according to findings of the review, significantly counteract exercise-induced oxidative stress, reduce inflammatory markers, and lower muscle damage indicators to offer the physiological recovery back to normal levels after training sessions, thus in answer to RQ2. The bibliometric analysis for RQ3 on the other hand, discovered a strong upward trend in the worldwide literature with the United States, Europe, and Asia as the major centers of production, while methodological deficiencies were pointed out including the lack of female athletes, short-term experiments, and limited integration of microbiome-performance effects.

The most significant aspect of this paper is the conceptual framework, which is a combination of multiple mechanisms (substrate, buffering, vascular, antioxidant, and microbiome) domains, that physically extends the formulation of the provision of precision supplementation in a theoretically coherent manner. In terms of practitioners, the strength of the support for caffeine, creatine, dietary nitrate, and leucine-enriched protein formulations set them as the pillars of evidence-based nutrition for performance and recovery. Single database dependency and qualitative synthesis are recognized as limitations of this study. Along with the conventional sex-stratified experimental designs and longitudinal studies of more than 12 weeks, the usage of metabolomic and microbiome profiling is essential for supplementation intervention trials to facilitate individualized sports nutrition paradigms. Because findings were integrated through narrative directional synthesis rather than statistical pooling, these conclusions reflect consistency in the direction of effect across studies rather than precise effect-size estimates. Accordingly, the dosing recommendations for caffeine, creatine, and dietary nitrate are derived predominantly from short-term trials in largely male cohorts and should be extrapolated to female and long-term contexts with caution.

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