BALNEO RESEARCH Balneo and PRM Research Journal
English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Melatonin in Athletic Recovery: Effects on Sleep, Oxidative Stress, Metabolism, and Performance

Onu Ilie [1,2], Daniel Andrei Iordan [2,3,*], Carmina Liana Mușat [4,+], Simona Steliana Tudor [4], Lucian Nicolescu – Seusan [5,*], Nicoleta-Daniela Stanca [6] , Adela Bădău [7,+] and Ancuta Elena Tupu [4]

1 Department of Biomedical Sciences, Grigore T. Popa University of Medicine and Pharmacy Iasi, 700454 Iasi, Romania;
2 Center of Physical Therapy, Rehabilitation and Wellness, "Dunarea de Jos" University of Galati, 800008 Galati, Romani;
3 Faculty of Physical Education and Sport, "Dunarea de Jos" University of Galati, Galati, Romania;
4 Faculty of Medicine and Pharmacy, "Dunarea de Jos" University of Galati, Galati, Romania;
5 1 Decembrie 1918 University of Alba Iulia, 510009 Alba Iulia, Romania;
6 Physical therapy clinic Kineto Dema, 060758 Bucuresti, Romania;
7 Department of Motor Performance, Transylvania University of Brasov, 500036 Brasov, Romania

* Correspondence: daniel.iordan@ugal.ro (D.A.I); nicolescu.lucian@uab.ro (N.S.L)
+ These authors contributed equally to this work

Citation: Ilie O., Iordan D.A., Mușat C.L., Tudor S.S., Lucian N.S., Stanca N.D., Bădău A., Tupu A.E. - Melatonin in Athletic Recovery: Effects on Sleep, Oxidative Stress, Metabolism, and Performance
Balneo and PRM Research Journal **2026**, *17(1): 962*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 07.02.2026
Published: 31.03.2026

Reviewers:
Andreea Iulia Vladulescu Trandafir
Mihail Hoteteu

Abstract: Melatonin is a hormone that regulates circadian rhythm and promotes sleep, both essential for physiological recovery. It also exerts antioxidant and anti-inflammatory effects, contributing to cellular protection against oxidative stress (OS). Through modulation of energy metabolism, melatonin may support restoration of energy substrates and metabolic homeostasis after exertion. In addition, it influences physical and mental readiness and next-day physical and cognitive performance, suggesting a potential integrative role in recovery and rehabilitation. This narrative review critically examines current evidence on mechanisms through which melatonin supports key physiological processes related to performance and health. Methodology: A comparative narrative review included 32 studies published between 2010 and 2025. Literature searches were conducted in PubMed, Google Scholar, PEDro, and ScienceDirect using keywords related to melatonin, sleep, circadian rhythm, recovery, inflammation, OS, glycogen, and athletic performance. Studies were thematically grouped into four domains. Results: Evidence suggests that melatonin supplementation may represent a potential nutritional aid supporting recovery in high-performance sport. Most studies report improved sleep onset, duration, and quality, particularly after late evening training or circadian disruption. Melatonin may also support next-day readiness and help maintain anaerobic or maximal performance. Its antioxidant and anti-inflammatory actions appear to reduce exercise-induced OS and support cellular protection, potentially improving tolerance to high training loads, although evidence for direct metabolic recovery remains limited. Collectively, these findings suggest that melatonin may support re-covery primarily through improvements in sleep quality, circadian regulation, and antioxidant defense. Conclusions: Melatonin represents a promising strategy to enhance recovery and support performance, especially when sleep and circadian alignment are compromised (e.g., nighttime training, sleep restriction, congested competition, artificial light exposure). Further controlled studies are required to clarify optimal dosing, timing, and long-term safety in athletic populations.

Keywords: melatonin, sleep, circadian rhythm, inflammation, oxidative stress, metabolic recovery, glycogen replenishment, readiness (next-day performance)

1. Introduction

Recovery is a key determinant of sport performance, shaping an athlete's ability to sustain high training loads while limiting performance decline, injury risk, and maladaptation. In elite sport, where physiological and psychological stressors are chronically elevated, optimizing recovery is central to preserving training adaptations and functional availability ("readiness").

Sleep is considered the primary driver of recovery, supporting neuromuscular restoration, endocrine balance, cognitive performance, and immune function. However, elite athletes frequently report insomnia-like symptoms, including prolonged sleep latency, fragmented sleep, reduced efficiency, non-restorative sleep, and daytime fatigue.

A systematic review up to April 2016 identified a high prevalence of sleep complaints across sports, largely linked to heavy training, competition stress, and long-distance travel, with mechanisms involving cognitive arousal and voluntary or imposed sleep restriction [1]. Modern schedules and travel also increase exposure to artificial light, potentially disrupting circadian rhythms and impairing sleep quality and energy metabolism [2].

Within this context, melatonin supplementation has gained attention due to its sleep-promoting and circadian phase-shifting properties, alongside broader biological effects relevant to recovery. Secreted mainly at night by the pineal gland under suprachiasmatic nucleus (SCN) control and suppressed by light, melatonin is a reliable peripheral marker of circadian phase, measurable in serum, saliva, or via urinary 6-sulfatoxymelatonin [3]. Physiologically, it acts as a chronobiotic through MT1 and MT2 receptors, facilitating circadian entrainment and reducing sleep onset latency, particularly in circadian-related disorders [4,5].

Beyond circadian regulation, melatonin exerts antioxidant, anti-inflammatory, and immunomodulatory actions, supported by its amphiphilic structure and widespread receptor distribution. Extra-pineal synthesis in multiple tissues suggests functions extending beyond circadian control [6]. In sport recovery, these properties may help attenuate exercise-induced oxidative stress (OS), modulate inflammation, and reduce delayed onset muscle soreness (DOMS). However, post-exercise inflammation is also essential for tissue remodeling and training adaptation; excessive suppression may impair long-term physiological gains. Moreover, uncertainties persist regarding melatonin's influence on glucose metabolism and muscle glycogen resynthesis—critical for recovery in high-intensity or congested competition settings [2,3].

Recent research has explored possible ergogenic effects, yet a systematic review and meta-analysis indicate that melatonin does not significantly improve aerobic or strength performance in healthy individuals. Its primary benefit appears related to recovery, particularly improved antioxidant status [7]. Melatonin is now recognized as a central circadian regulator synchronizing the master clock with peripheral oscillators across organs. Circulating levels remain among the best markers of circadian timing, and reviews detail its pharmacology and potential roles in bone metabolism, reproduction, immunity, cardiovascular function, and body mass regulation, with proposed relevance in neurological, gastrointestinal, psychiatric, cardiovascular, and some tumor-related conditions [8]. Nonetheless, many broad clinical claims remain hypothetical and supported by limited evidence, highlighting the need for scientific rigor and caution, especially with high-dose use and in vulnerable populations [9].

Accordingly, this review critically evaluates melatonin in athletic recovery from four perspectives:

(1) sleep and circadian regulation;
(2) oxidative stress and inflammation;
(3) metabolic recovery and energy substrate restoration;
(4) readiness and next-day performance.

2. Materials and Methods

2.1 Study Design.

A comparative narrative literature review was conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations to evaluate the role of melatonin in athletic recovery. Studies published between 2010 and 2025 were considered, focusing on the effects of melatonin on sleep and circadian regulation, OS and post-exercise inflammation, metabolic recovery, and functional readiness (Figure 1)

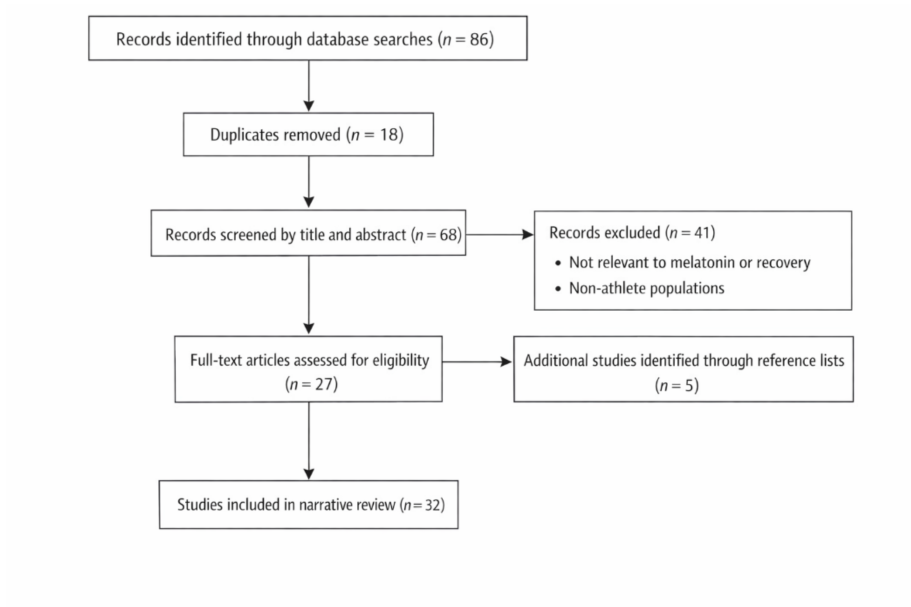

Figure 1. PRISMA-style flow diagram of the study selection process. A total of 86 records were identified through database searches. After removing 18 duplicates, 68 studies were screened by title and abstract, and 41 were excluded. Twenty-seven full-text articles were assessed for eligibility, and five additional studies were identified through reference screening. In total, 32 studies were included in the final narrative review.

2.2 Data Sources and Search Strategy

Electronic searches were performed in PubMed, ScienceDirect, and Google Scholar databases relevant to sports medicine and exercise physiology. Search strategies were adapted for each database using Boolean operators (AND). Representative search strings included: (“melatonin” AND “exercise” AND “recovery”); (“melatonin” AND “athletes” AND “sleep”); (“melatonin” AND “circadian” AND “jet lag” AND “sport”); (“melatonin” AND “inflammation” AND “muscle damage”); (“melatonin” AND “oxidative stress” AND “DOMS”); (“melatonin” AND “performance” AND “readiness”).

2.3 Eligibility Criteria

Studies were included if they met at least one of the following: (1) human participants, preferably athletes or trained individuals; (2) investigation of acute and/or chronic melatonin administration in relation to exercise, sleep, or recovery; (3) reporting outcomes relevant to sports recovery (sleep parameters, inflammatory/oxidative markers, muscle damage indices, metabolic measures, functional performance, and/or readiness indicators); (4) controlled trials, meta-analyses, or reviews addressing recovery and sleep optimization in active populations. Exclusion criteria were: animal-only studies (except those used to explain biological mechanisms, discussed separately), absence of recovery-related outcomes, and lack of accessible full text preventing adequate data extraction.

2.4 Study Selection

Screening was performed in two stages: (1) title and abstract review for relevance and (2) full-text eligibility assessment. Duplicates were removed before full-text evaluation. A total of 32 studies met the inclusion criteria and were retained for analysis.

The literature search initially identified 86 records across the selected databases. After removal of 18 duplicates, 68 records remained for title and abstract screening. Following this stage, 41 studies were excluded because they did not address exercise-related recovery outcomes, melatonin supplementation, or athlete populations. The remaining 27 articles underwent full-text assessment. An additional 5 studies were identified through reference list screening and were included due to their relevance to the predefined domains. In total, 32 studies met the eligibility criteria and were included in the final narrative synthesis.

2.5 Data Extraction and Synthesis

The following data were extracted: study design, participant characteristics, melatonin protocol (dose, timing, duration), exercise modality, and outcomes. Studies were synthesized thematically into four domains: (1) Melatonin–Sleep–Circadian Rhythm; (2) Melatonin–Inflammation–Oxidative Stress; (3) Melatonin–Metabolic/Glycogen Recovery; and (4) Melatonin–Readiness/Next-Day

3. Results

3.1. Effects of Melatonin on Sleep and Circadian Rhythm (Regulation Mechanism).

Recent literature summarizes the effects of melatonin on sleep and circadian rhythm (Table 1). In adolescent athletes, post-exercise evening melatonin improved sleep and short-term performance. In a randomized, double-blind, placebo-controlled crossover study (n = 10; mean age 15.4 years), participants performed exhaustive evening exercise (Yo-Yo Intermittent Recovery Test Level 1, ~8:00 PM) and received 10 mg melatonin or placebo. Polysomnography (10:15 PM–7:00 AM) and next-morning testing showed improved sleep quality and quantity, better well-being, and enhanced cognitive and some physical outcomes (Yo-Yo test, five-jump), without effects on handgrip or jump performance [10].

Nighttime melatonin also improved next-day short-term maximal performance in football players. In a placebo-controlled crossover study (n = 12 professionals; mean age 22.9 ± 1.3 years), melatonin was administered before sleep, and testing occurred the following morning. Measures included well-being, reaction time, alertness, handgrip, squat jump, agility T-test, and Wingate anaerobic capacity, alongside subjective sleep quality, lactate, glucose, and perceived exertion, showing favorable effects on next-day performance and psychocognitive status [11].

Another study evaluated four weeks of melatonin on circadian rhythms in endurance athletes using a two-group interventional design (melatonin vs placebo) with 7-day pre/post monitoring. Athletes received 100 mg/day, 30 minutes before bedtime, for four weeks. Exercise induced a phase advance in melatonin secretion, with changes observed in salivary melatonin rhythmicity, wrist temperature, motor activity, and body position [12].

Melatonin also improved psychomotor and physical performance after sleep deprivation in student-athletes. In a randomized, double-blind, placebo-controlled repeated-measures study (n = 10 males, 20 ± 2 years), 6 mg melatonin was given 30 minutes before balance, reaction time, and anaerobic tests under normal sleep and after 4 and 24 hours of deprivation. Sleep loss impaired performance, especially after 24 hours, whereas melatonin improved balance, reaction time, anaerobic power, and post-exercise lactate under deprivation, with no effect during normal sleep [13].

Table 1. Scientific articles presenting studies on the effects of melatonin on sleep and circadian rhythm (regulatory mechanisms).

Type of intervention	Year	Author	Participants	Main results
Acute melatonin administration: 10 mg, single evening dose after exercise; sleep assessed by polysomnography	2018	Cheikh M. [10]	10 adolescent athletes	Improved sleep quality and duration, with positive effects on well-being and on certain indicators of cognitive and physical performance.
Acute administration before sleep (dose not specified); testing the following morning	2024	Ghattassi K. [11]	12 professional football players	Improved maximal performance and several psychocognitive and physical indicators the next day.
Chronic administration: 100 mg/day for 4 weeks, 30 min before bedtime	2015	Leonardo-Mendononça R.C. [12]	Endurance athletes	Influenced circadian rhythm markers; exercise was associated with a phase advance of melatonin secretion.
Acute administration: 6 mg 30 min before testing, under two experimental conditions: normal sleep vs. sleep deprivation	2021	Paryab N. [13]	10 student-athletes	Reduced the negative effects of sleep deprivation on balance, reaction time, and anaerobic power, attenuating performance decline.

3.2. The role of melatonin in oxidative stress and inflammation (cellular protection).

Recent literature outlines the role of melatonin in OS and inflammation (Table 2). Melatonin exerts protective effects by reducing OS and preserving biological membrane fluidity, limiting lipid peroxidation, and maintaining normal cellular function [14]. As a potent antioxidant, it neutralizes reactive oxygen and nitrogen species and stimulates antioxidant enzymes, particularly within the glutathione system. Its small amphipathic structure allows diffusion into subcellular compartments, supporting membrane stability and influencing aging and disease processes [14].

Melatonin, a tryptophan-derived molecule present in most organisms, has complex metabolism involving enzymatic and free-radical–driven pathways. Evolutionarily, its primary function was antioxidant defense, later expanding to signaling roles such as photoperiodism and endocrine regulation. Its high antioxidant efficiency derives from cascade reactions generating active metabolites and from its inducible increase under moderate OS [15].

Exercise can alter melatonin secretion, and intense effort increases OS and inflammation while reducing antioxidant capacity. Evidence indicates that melatonin supplementation improves antioxidant status and lowers biochemical markers of exercise-induced OS [16]. In muscle injury related to trauma or strenuous exercise, melatonin's antioxidant and anti-inflammatory actions may reduce cytokine-mediated inflammation and muscle degradation, potentially supporting recovery [17].

Pre-exercise melatonin (6 mg) in young football players reduced OS, improved antioxidant defense, lowered triglycerides, and increased immunoglobulin A after intense exercise, suggesting beneficial metabolic and immune effects [18]. However, contrasting evidence from adults with obesity in a weight-loss program showed that melatonin (2 mg/day) increased OS markers post-exercise and blunted reductions in interleukin-6, indicating possible context-dependent or pro-oxidant effects and potential interference with cardiometabolic benefits [19].

Melatonin also influences skeletal muscle and aging by reducing mitochondrial OS and protecting muscle cells, potentially limiting frailty and preserving performance, with emerging links to the gut–muscle axis and microbiota [20]. Beyond sport, melatonin shows antioxidant and immunomodulatory effects in conditions associated with OS, including cardiovascular, neurodegenerative, metabolic, and inflammatory diseases [21].

Physiologically, melatonin synchronizes circadian rhythms and supports cellular protection, immune regulation, neuroprotection, cardiovascular and reproductive functions; reduced secretion is associated with sleep disorders and chronic disease risk, while therapeutic uses include sleep disorders and jet lag [20]. In musculoskeletal medicine, melatonin promotes bone formation, protects cartilage, and may support muscle and tendon recovery through antioxidant and anti-inflammatory mechanisms, although large clinical trials are still required [22]. Finally, melatonin exerts diverse physiological effects beyond circadian control, including mitochondrial support, metabolic regulation, and cardiovascular protection, with evidence highlighting the need to distinguish physiological from pharmacological actions [23].

Table 2. Scientific articles on the role of melatonin in oxidative stress and inflammation (cellular protection).

Main results	Year	Author	Conclusion
Effects of melatonin on OS and the fluidity of biological membranes	2014	García J. J. [14]	Melatonin reduces OS, limits lipid peroxidation, preserves membrane fluidity, neutralizes ROS/RNS, and stimulates antioxidant enzymes.
Melatonin as a powerful and inducible endogenous antioxidant: synthesis and metabolism	2015	Tan D.-X. [15]	Major endogenous antioxidant; cascade reaction with antioxidant metabolites; levels increase during moderate OS → inducible antioxidant.
Exercise-induced OS and melatonin supplementation: current evidence	2021	Kruk J. [16]	Intense exercise increases OS and inflammation; melatonin supplementation improves antioxidant status and reduces oxidative/inflammatory markers.
Melatonin therapy in blunt trauma and intense physical exercise: involvement of inflammatory cytokines	2018	Maarman G. J. [17]	Melatonin reduces inflammation and muscle degradation by modulating inflammatory cytokines; potential use in sports medicine.
Administration of melatonin before intense physical exercise: effects on OS, immunity, and lipid metabolism	2012	Maldonado M. D. [18]	Clinical study: 6 mg melatonin before exercise → reduced OS, increased antioxidant defense; lower triglycerides; increased IgA.
Effects of melatonin on post-exercise OS in adults with obesity in a weight-loss program	2024	Rigamonti A. E. [19]	2 mg/day: associated with increased post-exercise oxidative markers and inhibition of IL-6 decrease; possible pro-oxidant effect under certain conditions.
The impact of melatonin on skeletal muscle and physical exercise: implications in aging	2020	Stacchiotti, A. [20]	Reduces mitochondrial OS and protects muscle; may reduce muscle frailty and maintain physical performance.
Melatonin in OS diseases: efficacy, safety, and adverse effects	2020	Ferlazzo N. [21]	Stimulates antioxidant enzymes, reduces inflammation by regulating gene expression; used in multiple chronic diseases associated with oxidation.
Physiological and pharmacological perspectives of melatonin	2022	Samanta S. [20]	Cellular protection through free-radical detoxification; immunomodulatory and neuroprotective role; possible clinical applications.
Therapeutic potential of melatonin in musculoskeletal medicine	2025	Migliorini F. [22]	Antioxidant and anti-inflammatory effects in bone/cartilage/muscle; promising preclinical results, large clinical studies needed.
Melatonin beyond circadian regulation: diverse physiological roles and therapeutic potential	2025	Jia M. [23]	Antioxidant, anti-inflammatory, and mitochondrial effects; authors recommend distinguishing between physiological and pharmacological

3.3. The Influence of Melatonin on Metabolic Recovery and the Restoration of Energy Substrates (Metabolic Recovery).

Table 3 summarizes current evidence on melatonin and metabolic recovery, particularly its influence on the restoration of energy substrates. Administration of melatonin before intense physical exercise may attenuate OS, support immune function, and favorably modulate lipid metabolism. In a study involving 16 young football players, 6 mg of melatonin administered 30 minutes before high-intensity continuous exercise resulted in lower lipid peroxidation levels compared with placebo. Total antioxidant capacity was higher in the melatonin group, especially after 60 minutes, while triglyceride concentrations were reduced at both 15 and 60 minutes post-exercise. In addition, immunoglobulin A increased only in the melatonin group after 60 minutes, suggesting improved immune and metabolic responses that may contribute to more efficient recovery [18].

Circadian regulation, strongly influenced by environmental light, plays a critical role in metabolic homeostasis. Modern exposure to artificial light at inappropriate times—particularly at night—can disrupt sleep–wake cycles, physical activity patterns, thermoregulation, and energy metabolism, thereby increasing the risk of metabolic dysfunction such as obesity and diabetes. Light characteristics, including intensity, duration, timing, and wavelength, modulate metabolism through circadian mechanisms, with melatonin acting as a central hormonal mediator linking circadian timing to metabolic regulation [2].

Recovery from fatigue is essential for maintaining athletic performance, and melatonin has been investigated as a potential recovery-support supplement. In a randomized study including fifteen elite female athletes performing intermittent high-intensity training, 6 mg melatonin did not significantly improve immediate or short-term physical recovery, alertness, cognitive performance, perceived exertion, or thermoregulation. Nevertheless, melatonin supplementation reduced blood lactate and glucose concentrations following exercise, indicating a modulatory effect on substrate utilization and metabolic processing rather than a direct enhancement of functional recovery. These findings suggest that melatonin may influence metabolic pathways involved in recovery, even in the absence of measurable improvements in performance outcomes [24].

Table 3. Scientific articles investigating the influence of melatonin on metabolic recovery and energy substrate replenishment (metabolic restoration).

Type of intervention	Year	Author	Participants	Main results
Administration of 6 mg melatonin 30 minutes before intense exercise	2012	Maldonado M.D. [18]	16 young football players	Melatonin administration may reduce OS and improve lipid metabolism, thereby supporting post-exercise metabolic recovery processes.
Review analysis: light – circadian rhythm – melatonin	2023	Ishihara A. [2]	Narrative review	Melatonin may indirectly contribute to metabolic recovery through circadian rhythm regulation and the optimization of physiological processes associated with recovery.
Administration of 6 mg melatonin following high-intensity intermittent training	2018	Farjallah M.A. [24]	15 elite female athletes	Melatonin may accelerate the normalization of post-exercise metabolic markers (e.g., blood lactate and glucose levels), contributing to enhanced metabolic recovery.

3.4. The impact of melatonin on readiness and next-day performance

Table 4 synthesizes evidence on melatonin, readiness, and next-day performance. In a placebo-controlled crossover study of 12 trained men, evening administration of 6 mg melatonin did not improve sleep or blood biomarkers but enhanced repeated sprint performance (greater total distance, delayed fatigue) and improved perceived recovery, with reduced delayed-onset muscle soreness (DOMS) up to 72 hours post-exercise [25].

In professional soccer players, daily supplementation with 5 mg melatonin during a 6-day intensive training period increased antioxidant enzyme activity, limited OS and tissue damage markers (renal, muscular, hepatic), and attenuated performance decline in sprint and jump tests, suggesting protective and performance-maintaining effects under heavy training loads [26].

A systematic review of studies in professional soccer players (5–8 mg doses) reported reductions in OS, inflammation, and muscle damage markers, although consistent improvements in direct performance outcomes were not demonstrated, highlighting the need for larger, standardized trials [27]. Similarly, a systematic review of randomized controlled trials in highly trained athletes (5–100 mg) showed improved antioxidant and inflammatory profiles, reduced muscle and liver damage markers, and moderate metabolic effects, with indirect rather than definitive performance benefits [28].

Circadian rhythm plays a crucial role in athletic performance, influencing physiological and behavioral functions through factors such as body temperature, hormonal fluctuations (cortisol, testosterone, melatonin), light exposure, and jet lag. Aligning training and competition with individual chronotype may optimize performance, although findings remain heterogeneous [29].

Broader integrative models emphasize the interaction between sleep, nutrition, exercise, and stress in regulating the gut–brain–muscle axis. The "SPARKS" model (adequate sleep, regular activity, balanced nutrition) is associated with improved recovery, cognitive function, and performance, whereas the "SMOULDER" model (sleep deprivation, stress, overtraining, microbiota imbalance) is linked to impaired recovery and reduced performance [30].

Sleep quality remains fundamental for athletic performance and recovery, supporting muscle repair, hormonal balance, adaptation to training, and injury prevention. Evidence suggests that nutrition, supplementation, and optimized sleep strategies—partly mediated by melatonin and circadian regulation—can improve sleep duration and quality, although further research is needed to clarify long-term performance effects [31].

Table 4. Scientific studies investigating the effects of melatonin on readiness and next-day performance

Main results	Year	Author	Melatonin dose	Conclusion
Significant improvements in sprint performance, alongside reductions in perceived fatigue and post-exercise muscle soreness	2025	Mahdi N. [25]	6 mg/day	Melatonin supplementation may enhance anaerobic performance and facilitate post-exercise recovery.
Lower OS markers and a smaller decline in performance following high-intensity exercise	2022	Farjallah M.A. [26]	5 mg/day	Melatonin may help preserve physical performance during periods of intense exertion, possibly through antioxidant effects.
Enhanced physiological recovery indicators, while performance-related outcomes remain uncertain	2023	Almendros-Ruiz A. [27]	5–8 mg/day	Melatonin appears beneficial for biological recovery; however, evidence regarding performance enhancement remains inconsistent.
Reduced inflammation and muscle damage biomarkers, with no conclusive performance improvements	2024	Celorrio San Miguel A.M. [28]	5–100 mg/day	Melatonin may improve biomarkers linked to readiness and recovery, yet current evidence does not strongly support direct improvements in performance.

4. Discussion

4.1. Effects of Melatonin on Sleep and Circadian Rhythm (Regulatory Mechanism).

Findings from the reviewed literature consistently support the idea that melatonin may represent an effective strategy for improving sleep parameters in athletes, particularly in contexts characterized by late training sessions, increased physiological stress, and disruptions to circadian rhythmicity.

Melatonin is recognized as a central biological marker of the circadian rhythm and a key mediator in synchronizing the central biological clock with sleep-wake behaviors. In sports, this function becomes highly relevant as evening training sessions, nighttime competitions, or time zone changes frequently cause a delay in the circadian phase, directly impacting sleep quality and next-day performance. Cheikh et al. [10] show that melatonin ingestion after exhaustive late-evening exercise improves both sleep quality and quantity, suggesting increased efficiency in reducing post-exercise hyperactivation and facilitating sleep onset. These effects are particularly important in adolescents, a group that naturally tends toward delayed circadian phases, further exacerbated by artificial light exposure and nighttime training. Similarly, highlighted that nighttime melatonin intake not only enhances sleep but may also positively impact short-duration maximal performance the following day, suggesting that melatonin's benefits extend beyond sleep itself and into neurophysiological recovery. This relationship may be explained by the fact that consolidated sleep contributes to the restoration of neuromuscular excitability and regulation of endocrine processes involved in recovery. Regarding medium-term circadian adaptations, Leonardo-Mendonça et al. [12] demonstrate that four weeks of melatonin treatment can optimize circadian patterns in strength athletes, indicating a potential realignment of biological rhythmicity. This is relevant since chronic circadian misalignment is associated with reduced sleep efficiency and impaired recovery capacity. Furthermore, in sleep deprivation contexts, Paryab et al. [13] reported improvements in psychomotor and physical performance following melatonin supplementation, reinforcing the hypothesis that melatonin can mitigate the negative effects of sleep loss on cognitive and motor functions essential for athletes. Mechanistically, the effects can be attributed both to melatonin's chronobiotic role (phase realignment) and its impact on sleep architecture (increased proportion of deep/REM sleep) and reduced sleep onset latency. Therefore, melatonin can act as a circadian regulatory agent in sports, facilitating sleep initiation after late exertion, stabilizing sleep-wake rhythmicity, and enhancing the efficiency of nocturnal recovery.

4.2. Role of Melatonin in Oxidative Stress and Inflammation (Cellular Protection).

Another major aspect highlighted in current literature is the role of melatonin in attenuating exercise-induced OS and in modulating post-exercise inflammatory responses. Elite sports involve repeated episodes of intense physiological stress, which increase the production of reactive oxygen and nitrogen species, leading to damage of membrane lipids, proteins, and DNA. While moderate OS is a physiological component of exercise adaptations, chronic or excessive exposure is linked to delayed recovery, tissue microtrauma, and decreased performance. Melatonin is considered a major endogenous antioxidant, capable of directly neutralizing free radicals and indirectly stimulating antioxidant enzymes. García et al. [14] describe melatonin's protective effects on membrane fluidity and reduced lipid peroxidation, while Tan et al. [15] emphasize its "inducible" antioxidant capacity, suggesting melatonin acts through both immediate mechanisms and metabolic/mitochondrial regulation. In sports, this is especially relevant as intense exercise produces mitochondrial OS, particularly in intermittent and anaerobic efforts. Kruk et al. [16] synthesized evidence that melatonin supplementation can reduce markers of exercise-induced OS, although effects depend on dosage, timing, and the athletes' profiles. Moreover, melatonin exhibits anti-inflammatory effects by influencing cellular signaling pathways.

Maarman et al. [17] described a possible role of melatonin in modulating cytokines and mechanisms such as NF-κB and Akt, suggesting involvement in controlling muscle catabolism and reducing degradation of contractile proteins—processes amplified by intense exertion or mechanical trauma. From a practical standpoint, Maldonado et al. [18] demonstrated that melatonin administered immediately before intense exercise may reverse OS, enhance immune defense, and positively influence lipid metabolism in football players. This indicates potential for acute protection against exercise-induced oxidative imbalances. In a metabolically vulnerable population, Rigamonti et al. [19] also reported beneficial effects of melatonin on exercise-associated OS in obese adults, indicating that its antioxidant effects manifest across varied physiological contexts. Recent literature also confirms the growing interest in melatonin as a pleiotropic agent for the musculoskeletal system. Samanta et al. [20] discuss its impact on skeletal muscle and its relationship with exercise, while broader reviews emphasize its extended therapeutic potential [21,22,23].

Overall, melatonin may reduce the oxidative and inflammatory burden of intense physical effort, contributing to cellular protection and faster functional recovery. However, it is crucial to distinguish between beneficial effects (e.g., reduction of excessive OS) and the possibility that excessive ROS neutralization could impair adaptive training processes.

4.3. Influence of Melatonin on Metabolic Recovery and Energy Substrate Restoration (Metabolic Replenishment).

Metabolic recovery after exercise includes re-establishing energy homeostasis, restoring muscle and liver glycogen, regulating lipid metabolism, and normalizing endocrine and autonomic responses. Sleep is a central element of this process, and melatonin may influence metabolic recovery both indirectly (via sleep improvement) and directly (via effects on metabolism, inflammation, and OS). The study by Farjallah et al. [24] analyzed the impact of melatonin ingestion on performance and metabolic responses after intermittent training, suggesting that melatonin can modulate post-exercise recovery. Maldonado et al. [18] reported improvements in metabolic and lipid parameters following melatonin administration before intense exercise. These results support the idea that melatonin may reduce the metabolic cost associated with OS and preserve mitochondrial function. Additionally, the relationship between light, melatonin, and metabolism must be considered. The analysis by Gupta et al. [1] emphasizes the complexity of light's effects on human metabolism, implying that disruption of nocturnal light signals (and consequently, natural melatonin secretion) may affect energy homeostasis. In athletes, this is relevant because frequent exposure to artificial light during late hours may amplify post-exercise metabolic disruptions and delay recovery. Thus, melatonin administration may support metabolic recovery by reducing nocturnal physiological stress, improving sleep architecture, and possibly optimizing post-exercise metabolism. However, the exact mechanisms (e.g., influence on insulin sensitivity, lipid oxidation, or glycogen resynthesis) remain insufficiently clarified in athletic populations and warrant further investigation.

4.4. Impact of Melatonin on Readiness and Next-Day Performance.

The concept of "readiness" reflects an athlete's ability to perform the next day and is influenced by sleep quality, physiological stress, neuromuscular recovery, and inflammatory status. Recent evidence suggests melatonin may enhance readiness, particularly under conditions of competitive stress, intense training, and circadian disruption. In a placebo-controlled crossover study, Mahdi et al. [25] showed that melatonin supplementation improved high-intensity exercise performance and recovery the next day in trained men. These results align with Ghattassi et al. [11], who reported that nighttime melatonin ingestion improved next-day maximal short-duration performance in football players. Furthermore, Farjallah et al. [26] found that melatonin may reduce cellular damage and performance decline during intensive training periods in professional football players, suggesting it acts as an adjunct in cumulative recovery during high-load phases. This is highly practical, as congested competition periods are associated with increased fatigue, injury risk, and performance drop. These individual study results are supported by synthesis works, including systematic reviews focused on elite athletes. Almendros-Ruiz et al. [27] highlight melatonin's effects on football performance, while Celorrio San Miguel et al. [28] analyze melatonin's impact on performance and circulating biomarkers in trained athletes, reinforcing the idea that the benefits are most likely mediated by improved sleep and reduced biological stress. In a broader context, the recent mini-review by Pradhan et al. [29] indicates that interventions optimizing brain health and sleep can impact athletic performance [30,31]. Melatonin, through its chronobiotic and neuroprotective functions, emerges as a relevant candidate for integration into nutritional strategies aimed at performance optimization—especially in sports with evening competitions or frequent travel. In conclusion, melatonin appears to enhance athletes' readiness through a multifactorial mechanism: improving sleep, regulating circadian phase, reducing OS, and attenuating post-exercise inflammation. Nevertheless, there remains a need for standardized protocols regarding dosage, timing, and supplementation duration, as well as evaluations of long-term effects on training adaptations.

5. Conclusions

Based on the available evidence, melatonin emerges as a nutritional adjunct with relevance in high-performance sports, particularly through its effects on sleep, circadian rhythm, and post-exercise recovery. The studies reviewed indicate that melatonin supplementation can improve both sleep quality and quantity, especially after late evening training sessions or in situations involving circadian disruption. Concurrently, melatonin appears to enhance functional readiness and help maintain anaerobic/maximal performance the following day, suggesting that its benefits extend beyond sleep regulation alone. From a physiological perspective, melatonin presents a complex mechanistic potential, acting as an endogenous antioxidant and modulator of inflammatory responses. These properties may reduce exercise-induced OS and support cellular protection, with possible favorable effects on recovery and tolerance to high training loads. In conclusion, melatonin may be considered a promising strategy for optimizing recovery and performance in athletes, particularly when circadian rhythm disturbances are present (e.g., late-night training, sleep deprivation, competition congestion, exposure to artificial light). However, results should be generalized with caution due to the heterogeneity of protocols and populations in existing studies.

6. Practical Implications

Available results suggest several relevant applications in the context of elite sports: Sleep support after evening training: Melatonin may be helpful for athletes training late at night who experience difficulty falling asleep or fragmented sleep, facilitating the transition to sleep and improving its efficiency; Enhanced readiness the next day: Nighttime administration may help improve short/maximal performance and lead to better readiness the following day, especially in intermittent sports (e.g., football/soccer); Potential strategy during intensive periods: During demanding microcycles (e.g., competition congestion, training camps, increased volume), melatonin may mitigate cumulative fatigue through its effects on cellular stress markers and recovery; Management of circadian disruption: Melatonin should be integrated into combined circadian hygiene strategies: reducing blue light exposure in the evening, maintaining stable sleep routines, and managing ambient lighting; Individualized intervention: Tailoring supplementation to chronotype, individual sensitivity, and sport type is essential, along with assessing the risk of residual sleepiness in some athletes.

7. Limitations and Future Directions

7.1. Limitations. Protocol heterogeneity: The doses used, timing of administration (pre/post-exercise, evening/night), duration of supplementation, and pharmaceutical forms vary significantly across studies, limiting comparability and preventing standardized recommendations; Large differences between populations: Studies involve adolescents, collegiate athletes, professionals, or individuals with obesity; training status, age, and metabolic health may influence the response to melatonin; Small sample sizes: Many studies have small samples, limited statistical power, and a high risk of false-positive/negative results; Incompletely controlled outcome variables: Factors like evening artificial light exposure, caffeine intake, psychological stress, screen use, chronotype, or sleep schedule may act as confounders that are insufficiently controlled; Limited sleep measurements: Some studies rely primarily on subjective tools (e.g., questionnaires), while standardized use of polysomnography or actigraphy is still relatively limited; Possible effects on training adaptations: While melatonin reduces OS, there is ongoing debate in the literature about whether excessive ROS reduction might interfere with adaptive signaling to exercise—this aspect is underexplored for melatonin.

7.2. Future Directions. Establishing optimal protocols: Randomized studies comparing doses (e.g., 0.5 mg vs. 3 mg vs. 5 mg), timing (pre-sleep vs. post-exercise), and duration (acute vs. chronic); Integrating individual chronobiology: The inclusion of chronotype and circadian markers (e.g., DLMO – dim light melatonin onset) is needed to personalize interventions and differentiate chronobiotic from sedative effects; Evaluating performance in real-world competitive settings: More ecological studies across seasons/championships, with monitoring of sleep, load, performance, and injuries; Long-term effects: Investigations into repeated supplementation throughout a season (months), including tolerance, endocrine effects, and long-term sleep quality; Relationship with training adaptation: Studies explicitly monitoring chronic adaptations (strength, hypertrophy, VO_2max, mitochondrial adaptations) to determine whether melatonin influences adaptive processes positively, neutrally, or negatively; Interactions with other recovery strategies: Combined effects with post-exercise nutrition (carbs/protein), creatine, magnesium, red light, or interventions like cold-water immersion or compression therapy.

7.3. Final Paragraph. Overall, current evidence suggests that melatonin supplementation may represent a promising strategy for elite athletes, particularly through improving sleep quality, optimizing circadian regulation, and supporting post-exercise recovery. Reported benefits on sleep parameters and next-day performance indicate that melatonin could enhance readiness, especially in contexts involving late-night training, sleep deprivation, or high training loads. However, interpretation and generalization of findings should be made cautiously, given the heterogeneity in protocols (dose, timing, duration), small sample sizes, and incomplete control of confounding factors (chronotype, light exposure, caffeine, stress). Additional randomized trials with larger samples and standardized designs are needed, integrating objective circadian markers (e.g., DLMO), validated sleep assessments (actigraphy/polysomnography), and sport-relevant outcomes (performance, inflammatory/oxidative biomarkers, neuromuscular recovery). Furthermore, future research should clarify the effects of chronic supplementation on training adaptations and establish optimal protocols across different sports, ensuring melatonin use is safe, individualized, and effective in athletic practice.

Funding. This research received no external funding.
Acknowledgments. All authors have equally contributed to this article as senior authors.
Conflicts of Interest. The authors declare no conflict of interest.

References

1. Gupta, L.; Morgan, K.; Gilchrist, S. Does Elite Sport Degrade Sleep Quality? A Systematic Review. Sports Med. 2017, 47, 7, 1317-1333. https://doi.org/10.1007/s40279-016-0650-6
2. Ishihara, A.; Courville, A.B.; Chen, K.Y. The Complex Effects of Light on Metabolism in Humans. Nutrients. 2023, 15, 1391. https://doi.org/10.3390/nu15061391
3. Claustrat, B.; Leston, J. Melatonin: Physiological effects in humans. Neurochirurgie. 2015, 61, (2-3):77-84. https://doi.org/10.1016/j.neuchi.2015.03.002
4. Pevet, P.; Challet, E.; Felder-Schmittbuhl, M.P. Melatonin and the circadian system: Keys for health with a focus on sleep. Handb Clin Neurol. 2021, 179, 331-343. https://doi.org/10.1016/B978-0-12-819975-6.00021-2
5. Vasey, C.; McBride, J.; Penta, K. Circadian Rhythm Dysregulation and Restoration: The Role of Melatonin. Nutrients. 2021, 13, 3480. https://doi.org/10.3390/nu13103480
6. Amaral, F.G.D.; Cipolla-Neto, J. A brief review about melatonin, a pineal hormone. Arch Endocrinol Metab. 2018, 62, 4, 472-479. https://doi.org/10.20945/2359-3997000000066
7. Drummond, F.R.; Drummond, L.R.; Campos, H.O.; Fernandes, J.G.R.P.; da Costa Monteiro, M., Lara, H.F.G.; de Almeida Mafra, T.C.; Lavorato, V.N.; Pereira, A.B.; Leite, L.H.R.; Poletini, M.O.; Coimbra, C.C. Is melatonin as an ergogenic hormone a myth? a systematic review and meta-analysis. Endocrine. 2024, 83, (2), 302-321. https://doi.org/10.1007/s12020-023-03498-1
8. Tordjman, S.; Chokron, S.; Delorme, R.; Charrier, A.; Bellissant, E.; Jaafari, N.; Fougerou, C. Melatonin: pharmacology, functions and therapeutic benefits. Curr Neuropharmacol. 2017, 15, (3):434–443. https://doi.org/10.2174/1570159X14666161228122115
9. Boutin, J.A.; Kennaway, D.J.; Jockers, R. Melatonin: Facts, Extrapolations and Clinical Trials. Biomolecule. 2023, 13, (6):943. https://doi.org/10.3390/biom13060943
10. Cheikh, M.; Hammouda, O.; Gaamouri, N.; Driss, T.; Chamari, K.; Cheikh, R.B.; Dogui, M.; Souissi, N. Melatonin ingestion after exhaustive late-evening exercise improves sleep quality and quantity, and short-term performances in teenage athletes. Chronobiol Int. 2018, 35, (9):1281-1293. https://doi.org/10.1080/07420528.2018
11. Ghattassi, K.; Farjallah, M.A.; Graja, A.; Romdhani, M.; Boudhina, N.; Guimard, A.; Driss, T.; Souissi, N.; Chtourou, H.; Hammouda, O. Nocturnal Melatonin Ingestion Improves Soccer Players' Short-Term Maximal Performances on the Following Day. Res Q Exerc Sport. 2024, 95, (3):751-758. https://doi.org/10.1080/02701367.2024.2303457
12. Leonardo-Mendonça, R.C.; Martinez-Nicolas, A.; de Teresa Galván, C.; Ocaña-Wilhelmi, J.; Rusanova, I.; Guerra-Hernández, E.; Escames, G.; Acuña-Castroviejo, D. The benefits of four weeks of melatonin treatment on circadian patterns in resistance-trained athletes. Chronobiol Int. 2015, 32, (8):1125-34. https://doi.org/10.3109/07420528.2015.1069830
13. Paryab, N.; Taheri, M.; H'Mida, C.; Irandoust, K.; Mirmoezzi, M.; Trabelsi, K.; Ammar, A.; Chtourou, H. Melatonin supplementation improves psychomotor and physical performance in collegiate student-athletes following a sleep deprivation night. Chronobiol Int. 2021, 38, (5):753-761. https://doi.org/10.1080/07420528.2021
14. García, J.J.; López-Pingarrón, L.: Almeida-Souza, P.; Tres, A.; Escudero, P.; García-Gil, F.A.; Tan, D.X.; Reiter, R.J.; Ramírez, J.M.; Bernal-Pérez, M. Protective effects of melatonin in reducing oxidative stress and in preserving the fluidity of biological membranes: a review. J Pineal Res. 2014, 56, (3):225-37. https://doi.org/10.1111/jpi.12128.
15. Tan, D.-X.; Manchester, L.C.; Esteban-Zubero, E.; Zhou, Z.; Reiter, R.J. Melatonin as a Potent and Inducible Endogenous Antioxidant: Synthesis and Metabolism. Molecules. 2015, 20, :18886–18906. https://doi.org/10.3390/molecules201018886
16. Kruk, J.; Aboul-Enein, B.H.; Duchnik, E. Exercise-induced oxidative stress and melatonin supplementation: current evidence. J Physiol Sci. 2021, 71, (1):27. https://doi.org/10.1186/s12576-021-00812-2
17. Maarman, G.J.; Reiter, R.J. Melatonin therapy for blunt trauma and strenuous exercise: A mechanism involving cytokines, NFκB, Akt, MAFBX and MURF-1. J Sports Sci. 2018, 36, (16):1897-1901. https://doi.org/10.1080/02640414.2018.1424491.
18. Maldonado, M.D.; Manfredi, M.; Ribas-Serna, J.; Garcia-Moreno, H.; Calvo, J.R. Melatonin administrated immediately before an intense exercise reverses oxidative stress, improves immunological defenses and lipid metabolism in football players. Physiol Behav. 2012, 105, (5):1099-103. https://doi.org/10.1016/j.physbeh.2011.12.015
19. Rigamonti, A.E.; Rubino, F.M.; Caroli, D.; Bondesan, A.; Mai, S.; Cella, S.G.; Centofanti, L.; Paroni, R.; Sartorio, A. Effects of Melatonin on Exercise-Induced Oxidative Stress in Adults with Obesity Undergoing a Multidisciplinary Body Weight Reduction Program. J Clin Med. 2024, 13, (17):5216. https://doi.org/10.3390/jcm13175216.
20. Samanta, S. Arch. Physiological and pharmacological perspectives of melatonin. Physiol Biochem. 2022, 128, (5):1346-1367. https://doi.org/10.1080/13813455.2020.1770799
21. Ferlazzo, N.; Andolina, G.; Cannata, A.; Costanzo, M.G.; Rizzo, V.; Currò, M.; Ientile, R.; Caccamo, D. Is Melatonin the Cornucopia of the 21st Century? Antioxidants 2020, 9, 1088. https://doi.org/10.3390/antiox9111088
22. Migliorini, F.; Schäfer, L.; Simeone, F.; Memminger, M.K.; Eschweiler, J.; Vaishya, R. Therapeutic potential of melatonin in musculoskeletal medicine. J Orthop. 2025, 72, 117-123. https://doi.org/10.1016/j.jor.2025.11.011
23. Jia, M.; Luo, A.; Wei, M.; Zhang, Y.; Wu, T.; Chen, N. Melatonin: beyond circadian regulation - exploring its diverse physiological roles and therapeutic potential. Sleep Med Rev. 2025, 82. https://doi.org/10.1016/j.smrv.2025.102123

24. Farjallah, M.A.; Hammouda, O.; Zouch, M.; Ghattassi, K.; Graja, A.; Driss, T.; Chamari, K.; Souissi, N. Effect of melatonin ingestion on physical performance, metabolic responses, and recovery after an intermittent training session. Physiol Int. 2018, 105, (4):358-370. https://doi.org/10.1556/2060.105.2018.4.24
25. Mahdi, N.; Delleli, S.; Jebabli, A.; Ben Maaoui, K.; Del Coso, J.; Chtourou, H.; Ardigò, L.P.; Ouergui, I. Melatonin Supplementation Enhances Next-Day High-Intensity Exercise Performance and Recovery in Trained Males: A Placebo-Controlled Crossover Study. Sports (Basel). 2025, 13, (6):190. https://doi.org/10.3390/sports13060190
26. Farjallah, M.A., Ghattassi, K.; Kamoun, A.; Graja, A.; Ben Mahmoud, L.; Driss, T.; Jamoussi, K.; Sahnoun, Z.; Souissi, N.; Zmijewski, P.; Hammouda, O. Melatonin supplementation alleviates cellular damage and physical performance decline induced by an intensive training period in professional soccer players. PLoS One. 2022, 17 (9):e0273719. https://doi.org/10.1371/journal.pone.0273719
27. Almendros-Ruiz, A.; Lopez-Moro, A.; Conde-Pipò, J.; Santalla, A.; Requena, B.; Mariscal-Arcas, M. The Effects of Melatonin Supplementation on Professional Football Player Performance: A Systematic Review. Nutrients. 2023, 15, (20):4467. https://doi.org/10.3390/nu15204467
28. Celorrio San Miguel, A.M.; Roche, E.; Herranz-López, M.; Celorrio San Miguel, M.; Mielgo-Ayuso, J.; Fernández-Lázaro, D. Impact of Melatonin Supplementation on Sports Performance and Circulating Biomarkers in Highly Trained Athletes: A Systematic Review of Randomized Controlled Trials. Nutrients. 2024, 16, (7):1011. https://doi.org/10.3390/nu16071011.
29. Pradhan, S.; Parganiha, A.; Agashe, C.D.; Pati, A.K. Circadian rhythm in sportspersons and athletic performance: A mini review. Chronobiol Int. 2024, 41, (2):137-181. https://doi.org/10.1080/07420528.2024.2305663
30. Przewłócka, K.; Korewo-Labelle, D.; Berezka, P.; Karnia, M.J.; Kaczor, J.J. Current Aspects of Selected Factors to Modulate Brain Health and Sports Performance in Athletes. Nutrients. 2024, 16, (12):1842. https://doi.org/10.3390/nu16121842
31. Fusi, J.; Scarfò, G.; Di Silvestro, R.; Franzoni, F. Improving Sleep Quality to Enhance Athletic Activity-The Role of Nutrition and Supplementation: A Mini-Short Review. Nutrients. 2025, 17(11):1779. https://doi.org/10.3390/nu17111779.