

Research Progress on the Mechanisms and Applications of Active Ingredients in Traditional Chinese Medicine for the Intervention of Exercise-Induced Fatigue

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Abstract: High-intensity or prolonged exercise training easily leads to exercise-induced fatigue, thereby affecting sports performance and increasing the risk of skeletal muscle injury and immunosuppression. In recent years, with the cross-integration of sports pharmacology and natural product chemistry, Traditional Chinese Medicine (TCM) has demonstrated unique clinical advantages in promoting recovery from exercise fatigue due to its "holistic regulation" characteristics, which involve multiple components, multiple targets, and multiple pathways. This article systematically reviews the core mechanisms by which the active ingredients of TCM intervene in exercise-induced fatigue, exploring their molecular pathways in targeting oxidative stress, regulating the immune microenvironment, accelerating the clearance of metabolic waste, and modulating central neurotransmitters. Furthermore, this review evaluates the current application status of single Chinese herbs and classic compound formulas in sports medicine, and prospectively discusses the scientific barriers and methodological limitations in current research. This aims to provide rigorous evidence-based medical support for the development of novel, natural anti-fatigue sports supplements.

Keywords: Traditional Chinese Medicine (TCM); Exercise-induced Fatigue; Multi-target Mechanism; Lactate Shuttle; Oxidative Stress; Application Progress.

1. Introduction

1.1. The Core Position of Fatigue Elimination in Modern Sports Medicine

With the profound development of competitive sports and national fitness initiatives, high-intensity exercise training has become the norm. However, physical overload exceeding the body's tolerance threshold easily induces exercise-induced fatigue (EIF). EIF is a non-pathological state of fatigue, primarily manifesting as a decline in muscle performance caused by excessive physical activity, which severely affects the daily life and work capacity of athletes, military personnel, and manual laborers[1]. This phenomenon not only results in a significant decrease in the work capacity of skeletal muscles but, in severe cases, can also trigger systemic immune dysfunction, endocrine disorders, and substantially increase the incidence of sports injuries[2]. Therefore, how to efficiently and safely eliminate EIF and promote functional remodeling has become a core issue urgently needing resolution in the fields of modern sports medicine and sports science.

1.2. Limitations of Existing Intervention Methods

Currently, conventional intervention methods for EIF mainly include physical recovery (e.g., rest, ice baths) and single-nutrient supplementation. Although these conventional means can alleviate local muscle stiffness to some extent, simple rest often fails to rapidly and thoroughly resolve the deep-level metabolic disorders triggered by high-intensity loads. For persistent microcirculatory dysfunction, acute oxidative stress injury, accumulation of harmful metabolites, and long-term inflammatory responses induced by strenuous

exercise, conventional single-intervention methods struggle to exert systemic, long-term regulatory effects [3]. Consequently, finding natural anti-fatigue interventions with definitive efficacy, minimal side effects, and favorable long-term outcomes has become a current research hotspot in modern sports science.

1.3. Introduction of the "Holistic Regulation" Theory of TCM and Its Clinical Translation Significance

Faced with the bottlenecks of conventional modern sports recovery methods, TCM exhibits unique theoretical advantages and immense potential for clinical translation in sports medicine. In traditional Chinese medical theory, exercise fatigue is often regarded as a state of "deficiency" (Xu Sun) or "overexertion" (Lao Juan) and has been diagnosed and treated as a deficiency syndrome for decades[2]. Unlike the single-target intervention model of modern medicine, TCM possesses the characteristic of "holistic regulation" via multiple components, targets, and pathways. Modern research has confirmed that active components of TCM, such as naturally derived medicinal polysaccharides, can alleviate fatigue in peripheral tissues by improving energy metabolism, eliminating excessive metabolites, and inhibiting oxidative stress and inflammatory responses [3]. They can also achieve systemic anti-fatigue effects by regulating the intestinal microecology (e.g., remodeling the gut microbiota)[4]. Deeply mining and reviewing the molecular mechanisms and clinical applications of TCM—such as spleen-invigorating therapies or specific compound formulas—in intervening with exercise fatigue[5] not only enriches the theoretical framework of recovery in sports medicine but also provides a solid evidence-based foundation for developing safe and efficient

novel natural sports supplements.

2. Current Research Status of the Main Pathogenic Mechanisms of Exercise-Induced Fatigue

The occurrence of EIF is a complex physiological and biochemical process involving multiple organs and systems. The sports medicine community generally believes that its core mechanism is not dominated by a single factor, but is the result of the combined effects of alterations in the local skeletal muscle microenvironment and systemic metabolic homeostasis imbalance. Among various hypotheses, energy metabolism imbalance and oxidative stress are the two core mechanisms explaining peripheral EIF. In recent years, with the development of molecular biology techniques, the academic understanding of these two mechanisms has gradually shifted from a traditional unidirectional damage model to a dynamic adaptation model [6].

2.1. Energy Metabolism Imbalance and the Lactate Shuttle Mechanism

Traditional sports physiology research posits that high-intensity exercise limits the energy supply from the skeletal muscle aerobic oxidation system, accelerating anaerobic glycolysis, which leads to a massive accumulation of lactate in skeletal muscle cells and microcirculatory blood. The decrease in intracellular pH caused by lactate dissociation directly inhibits the activity of key rate-limiting enzymes and interferes with cross-bridge cycling, ultimately leading to peripheral fatigue[6]. However, defining lactate purely as a pathogenic factor of fatigue can no longer fully explain modern metabolic kinetic phenomena. The currently widely accepted "Lactate Shuttle Theory" confirms that lactate is essentially a crucial energy substrate and metabolic signaling molecule for the myocardium, brain tissue, and slow-twitch muscle fibers during strenuous exercise[7]. Therefore, the evaluation criteria for modern anti-fatigue intervention strategies have shifted: ideal interventions should not be limited to accelerating the simple clearance of lactate, but should focus on optimizing the Cori cycle and intercellular transport efficiency, promoting the transport of locally accumulated lactate to target organs for secondary utilization. The evolution of this theoretical framework provides a new entry point for evaluating the precise pharmacological value of blood-activating and stasis-resolving Chinese herbs in improving microcirculation and promoting energy recovery.

2.2. Oxidative Stress Injury and Adaptive Regulation

During strenuous exercise, a surge in the body's oxygen consumption causes electron leakage in the mitochondrial electron transport chain, resulting in the massive generation of reactive oxygen species (ROS). When the ROS concentration exceeds the compensatory limits of the body's endogenous antioxidant defense system, lipid peroxidation reactions are triggered. This reaction not only destroys the structural integrity of the skeletal muscle cell membrane but also induces the release of pro-inflammatory cytokines, constituting the biochemical basis for delayed-onset muscle soreness (DOMS) and skeletal muscle micro-damage after exercise[8]. Although oxidative stress is widely considered a significant inducer of exercise fatigue, cutting-edge sports molecular biology research has confirmed that ROS exhibit a

typical "Hormesis" effect in skeletal muscles. A moderate concentration of ROS is a key signaling molecule that induces skeletal muscle mitochondrial biogenesis, improves insulin sensitivity, and promotes moderate muscle hypertrophy [9]. Clinical evidence-based data show that long-term high-dose supplementation with single strong antioxidants (such as high-dose Vitamin C or E) actually blunts the body's cellular adaptive responses, thereby weakening the effects of exercise training [10]. These mechanisms indicate that scientific anti-fatigue interventions need the dual regulatory ability to maintain the body's redox homeostasis, rather than simply scavenging free radicals. This provides an important theoretical basis for exploring the multi-target, multi-pathway mechanisms of TCM in intervening with EIF.

3. Multi-Target Mechanisms of TCM in Intervening Exercise-Induced Fatigue

The core advantage of TCM in intervening with EIF lies in its network pharmacology characteristics featuring multiple components and pathways. For TCM to deeply integrate with modern sports science, unlike single-target modern medical interventions, it must isolate its true intervention logic within the molecular microenvironment and objectively evaluate the uniqueness and potential limitations of its pharmacological mechanisms.

3.1. Targeting Oxidative Stress Pathways and Homeostatic Regulation of Endogenous Antioxidants

The activation of the body's endogenous antioxidant defense system is key to alleviating exercise-induced oxidative stress. Recent studies have confirmed that core active ingredients of TCM, such as *Lycium barbarum* polysaccharides (LBP), can specifically activate the Nuclear factor erythroid 2-related factor 2 (Nrf2) and its downstream Heme oxygenase-1 (HO-1) signaling pathway, significantly enhancing the antioxidant compensatory capacity of skeletal muscle cells at the genetic level [11]. Furthermore, polysaccharides from *Bupleurum chinense* have been shown to significantly reduce the levels of lactate dehydrogenase (LDH) and creatine kinase (CK) in the serum of exhausted animal models by regulating the AMPK/Nrf2 signaling pathway, substantially mitigating mitochondrial membrane permeability alterations and muscle fiber micro-damage[12]. In recent years, cordycepin and acidic polysaccharides from *Cordyceps militaris* have also been verified to activate the Keap1/Nrf2/HO-1 signaling axis. This not only significantly enhances the skeletal muscle antioxidant capacity of over-exercised rats but also effectively ameliorates central memory and cognitive impairments induced by oxidative stress[13][14].

However, when evaluating the clinical value of antioxidant interventions, one must beware that excessive free radical scavenging may obliterate the physiological adaptations brought by exercise. The simple use of high-dose single strong antioxidants has been proven to weaken training effects. In this context, TCM polysaccharides exhibit potential pharmacological advantages: their mechanism of action is not to act directly as a brute-force free radical "scavenger," but to elevate the body's "endogenous" defense reserves by activating upstream transcription factors like Nrf2. This dual regulatory ability to maintain redox homeostasis

provides a novel theoretical solution to avoid the "blunting of training adaptations" caused by antioxidant abuse.

3.2. Regulation of Immune Microenvironment Homeostasis and Anti-Inflammatory Mechanisms

Continuous high-intensity exercise easily leads to an imbalance in the body's immune microenvironment. Experimental data show that classic formulas like Shuyu decoction (SYD) can significantly reduce the overexpression of pro-inflammatory cytokines such as Interleukin-1 β (IL-1 β), Interleukin-6 (IL-6), and Tumor Necrosis Factor- α (TNF- α) in the serum of exhausted rats. Simultaneously, they upregulate the level of the anti-inflammatory cytokine IL-10 and increase the proportion of CD4+/CD8+ T cells in the blood and spleen, thereby effectively improving exercise-induced immune dysfunction[15]. Moreover, Astragalus polysaccharides (APS) have been found to modulate the gut microbiota structure via the "gut-brain axis," increasing the production of short-chain fatty acids (SCFAs), which in turn inhibits the central and peripheral NF- κ B inflammatory signaling pathways[16]. Notably, Schisandra chinensis extracts have been proven in exhaustive swimming models to significantly downregulate the secretion of pro-inflammatory cytokines like IL-1 and effectively protect the ultrastructure of adrenocortical cells from severe immune stress damage[17].

In the field of anti-inflammatory recovery, the academic value of TCM differs significantly from traditional Western medicine. Traditional sports medicine often relies on Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) for rapid analgesia, but substantial evidence-based data indicate that while NSAIDs non-specifically inhibit cyclooxygenase, they also hinder the activation of skeletal muscle satellite cells and hypertrophic adaptation. In contrast, the immune-modulating effects of TCM polysaccharides and compound formulas do not entirely suppress the acute physiological inflammation beneficial for tissue repair, but rather focus on preventing micro-damage from deteriorating into chronic systemic inflammation. This immune homeostasis remodeling mechanism holds great clinical translation prospects in fatigue monitoring during long-term, high-load training cycles.

3.3. Improvement of Microcirculatory Hemodynamics and Remodeling of Energy Metabolism

The rapid clearance of metabolic waste and the resynthesis of energy substrates depend heavily on the improvement of skeletal muscle microcirculation and mitochondrial function. Recent studies have shown that the aqueous extract of *Atractylodes macrocephala* (AMWE) not only significantly reduces the accumulation of anaerobic metabolites such as blood lactate (LA) and blood urea nitrogen (BUN) but also promotes skeletal muscle mitochondrial biogenesis by activating the PGC-1 α /NRF1/TFAM signaling axis, significantly enhancing the flux of the tricarboxylic acid (TCA) cycle and ATP generation efficiency[18]. Additionally, Shenqi Funeng Xingnao prescription (SQFNXNP) has been proven to delay excessive muscle glycogen consumption and inhibit lipid peroxidation by targeting the HIF-1/FoxO signaling pathway[19]. Meanwhile, *Cordyceps militaris* extract (CMEE) was found to directly target the cellular ATP

generation pathway, enhancing cellular energy production efficiency without significantly altering muscle morphology[20]; and a mixed extract containing *Schisandra* (HX108-CS) has been verified in multiple experiments to significantly reduce blood lactate accumulation following high-intensity exercise[21].

Combined with the cutting-edge "Lactate Shuttle Theory," the deep clinical significance of TCM in metabolic interventions becomes evident. For Chinese herbs with blood-activating, stasis-resolving, and spleen-invigorating effects, their pharmacological value is not limited to dilating microvessels or promoting simple lactate excretion, but lies in optimizing the systemic energy metabolism network. By improving the transport efficiency of the Cori cycle, certain active TCM ingredients can facilitate the efficient transport of locally accumulated lactate to the liver for gluconeogenesis or into the mitochondria for aerobic oxidation. This mechanism of converting metabolic waste into energy substrates vastly expands the application potential of TCM in intermittent, high-intensity physical sports.

3.4. Regulation of Central Neurotransmitters and Protection of the Brain Microenvironment

The essence of central fatigue is a protective inhibition generated by the cerebral cortex to avoid excessive bodily depletion. In recent years, the molecular mechanisms of TCM and traditional therapies in central intervention have been continuously revealed. Research has found that long-term physical overload induces neuroinflammatory responses in the hippocampus. Interventions such as moxibustion can significantly downregulate the levels of pro-inflammatory cytokines like IL-6 in the hippocampus of exhausted rat models, thereby alleviating exercise-induced central neuroinflammatory injury[22]. Similarly, Mongolian warm acupuncture therapy was confirmed to significantly improve learning and memory dysfunction induced by chronic fatigue by downregulating the iNOS/NO signaling pathway and the expression of pro-inflammatory cytokines in the hippocampal region[23]. Regarding oral TCM, ginseng aqueous extract was found to remodel the gut microbial community, utilizing secondary metabolites (such as butyrate and other SCFAs) produced by specific flora as signaling molecules to cross the blood-brain barrier and inversely regulate the metabolic homeostasis of the central nervous system, thereby alleviating central fatigue[24]. In terms of composite interventions, the combination of *Schisandra* and *Rhodiola* has been proven to significantly balance the excitability of the hypothalamic-pituitary-adrenal (HPA) axis and substantially reduce the overexpression of the c-Fos gene in the hypothalamus of rats under stress, thereby inhibiting the spread of central fatigue at both the neurotransmitter and early gene expression levels[25].

Although the mechanisms of TCM in intervening with central fatigue have achieved breakthroughs in animal models, its actual pharmacokinetic processes in human subjects remain controversial. The actual permeability of certain macromolecular natural products across the human blood-brain barrier is extremely low. Therefore, the indirect regulatory mechanism mediated by the "gut-brain axis," rather than the direct entry of the original TCM compounds into the brain, may be the mainstream paradigm by which TCM exerts its central anti-fatigue effects. Future research urgently needs to introduce non-invasive functional

neuroimaging techniques to further verify the actual activation trajectories of TCM on the brain's fatigue network at the human level.

4. Application and Prospects of TCM in Sports Medicine

Based on the multi-target and multi-pathway pharmacological mechanisms described above, TCM has gradually been translated into practical intervention strategies in modern sports medicine clinical practice. From the precise extraction and supplementation of active ingredients from single herbs to the holistic syndrome differentiation and regulation of classic compound formulas, TCM provides abundant natural interventions to counteract peripheral tissue micro-damage and central nervous protective inhibition induced by high-intensity training. However, to achieve deep integration of traditional Chinese medical theory with modern competitive sports science, it is necessary not only to explore underlying mechanisms but also to verify actual efficacy in human Randomized Controlled Trials (RCTs).

4.1. Clinical Intervention Effects and Evaluation of Single Chinese Herbs

In the clinical application of single Chinese herbs, Panax ginseng and *Rhodiola rosea* are currently the two most extensively researched natural sports supplements based on evidence-based medicine. Ginseng shows immense application potential in enhancing aerobic endurance and delaying fatigue. A systematic review and meta-analysis spanning nearly a decade demonstrated that ginseng extract supplementation can significantly prolong the exhaustive exercise time of human subjects and effectively increase maximal oxygen uptake (VO_{2max})[26]. Randomized double-blind trials targeting male recreational athletes also confirmed that short-term supplementation with ginseng extract significantly reduces blood lipid levels and oxygen consumption rates during sub-maximal aerobic exercise, optimizing energy utilization economy[27]. *Rhodiola*, as a typical high-altitude adaptogen, has been shown in recent systematic reviews to significantly improve endurance-related markers, increase SOD activity, and substantially decrease serum CK and blood lactate levels[28]. In an RCT involving professional basketball players, continuous 28-day supplementation with *Rhodiola* significantly shortened the completion time of simulated games and drastically reduced the athletes' Rating of Perceived Exertion (RPE) scores[29].

In addition to these two widely used single herbs, high-quality human clinical data on *Cordyceps sinensis* and *Schisandra* are continuously emerging. A cutting-edge randomized, double-blind, crossover trial (RCT) confirmed that pre-supplementation with *Cordyceps sinensis* before high-intensity interval exercise (HIIE) significantly accelerates the recruitment and expansion of stem cells (CD34⁺/Pax7⁺) in human skeletal muscle after exercise, confirming its definitive efficacy in accelerating micro-damage repair at the human cellular level[30]. Furthermore, an RCT targeting middle-aged and older adults showed that continuous 12-week supplementation with *Schisandra* extract combined with low-intensity exercise significantly increased the lower limb skeletal muscle strength of the subjects[31].

However, when evaluating the efficacy of single Chinese herbs, it must be objectively noted that the results of current clinical trials still present heterogeneity. Some studies did not

observe an absolute improvement in sports performance following TCM extract supplementation. This is closely related to individual metabolic differences among subjects, the geographical purity of the medicinal plants, and variations in the absolute content of active ingredients[32].

4.2. Synergistic Application of TCM Compound Formulas

Compared to single Chinese herbs, TCM compound formulas—relying on the compatibility principle of "Emperor, Minister, Assistant, and Courier"—exhibit more comprehensive intervention effects when dealing with multi-dimensional, systemic exercise fatigue. Modern experiments confirm that classic formulas like *Ren-Shen-Bu-Qi* decoction can significantly increase hepatic glycogen reserves and blood glucose levels while reducing peripheral serum CK and lactate concentrations by activating relevant upstream signaling pathways[33], thus ensuring energy substrate supply during prolonged exercise.

The advantages of compound interventions are even more pronounced in sports support in special environments. A study on subjects undergoing high-altitude (2200 meters) training showed that a composite supplement of *Rhodiola* and *Cordyceps sinensis* significantly maintained autonomic nervous system activity, achieving more outstanding aerobic endurance improvements than the placebo group [34]. Moreover, *Saengmaeksan*, a classic ancient formula rich in ginseng and *Schisandra*, was proven to significantly lower blood ammonia and aspartate aminotransferase (AST) levels, and increase Immunoglobulin A (IgA) concentrations during the high-intensity training cycles of collegiate tennis players, demonstrating excellent synergistic efficacy in anti-fatigue and hepatoprotection [35].

From the perspective of modern network pharmacology, the synergistic effect of compound formulas is by no means a simple physical addition of multiple single-drug components. The core academic value of compound interventions lies in breaking the phenomena of "metabolic compensation" or "receptor desensitization" easily triggered by single-target chemical drugs. How to utilize modern separation technologies to precisely isolate the "core compound groups" that truly exert anti-fatigue effects is an essential path for the future modernization of compound formulas.

4.3. Existing Research Limitations and Future Prospects

Although TCM exhibits broad clinical translation prospects in the field of exercise fatigue recovery, the construction of its modern scientific system still faces challenges. Currently, a vast amount of mechanistic research remains at the animal model level; high-quality, large-sample, multi-center RCTs are relatively scarce, severely limiting its evidence-based recommendation grading in the international sports medicine community[36]. Secondly, quality fluctuations between batches make exploring optimal dosages extremely difficult.

Future in-depth research in this field should focus on: first, introducing rigorous multi-omics joint technologies (e.g., metabolomics, proteomics) to achieve precise targeted mapping of mechanisms; second, establishing fingerprint chromatograms strictly benchmarked against World Anti-Doping Agency (WADA) standards to ensure absolute safety; third, developing highly time-sensitive "targeted" TCM compound nutritional products deeply integrated with the specific metabolic characteristics of various sports disciplines.

5. Conclusion

The elimination of exercise-induced fatigue and functional remodeling remain major topics of continuous focus in modern competitive sports and public health. This article systematically reviewed the multi-target mechanisms and clinical application status of TCM in intervening with EIF. Comprehensive literature and evidence-based data demonstrate that TCM can effectively break through the limitations of conventional single nutritional supplements; its core pharmacological advantage against fatigue lies in "holistic regulation" and "homeostatic remodeling." TCM enhances endogenous antioxidant reserves by activating pathways like Nrf2; achieves a microenvironmental balance of pro-inflammatory and anti-inflammatory factors by regulating the gut-brain axis and systemic immune cytokines; optimizes the lactate shuttle and systemic energy recovery efficiency by improving microcirculatory networks; and effectively maintains neurotransmitter dynamic balance at the central level. This three-dimensional anti-fatigue network fully highlights the scientific value of traditional Chinese medical theory.

However, in the process of transforming TCM into modern standardized sports supplements, severe challenges remain, including difficulties in analyzing active component groups and a relative scarcity of high-quality RCTs. Precisely isolating core active substances through multi-omics joint technologies and establishing a strict anti-doping standardization system are indispensable paths for achieving breakthroughs in this field. With the innovation of modern extraction processes, TCM is bound to provide safe and efficient natural intervention solutions for enhancing elite sports performance and maintaining public sports health with a more rigorous posture.

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References

- [1] LIU Y, LI C, SHEN X. The use of traditional Chinese medicines in relieving exercise-induced fatigue [J]. *Frontiers in Pharmacology*, 2022, 13: 969827.
- [2] CHEN S, et al. Shuyu decoction exhibits anti-fatigue properties via alleviating exercise-induced immune dysfunction [J]. *Journal of Ethnopharmacology*, 2024, 319(Pt 1): 117109.
- [3] LIU Y, FENG Z, HU Y. Polysaccharides derived from natural edible and medicinal sources as agents targeting exercise-induced fatigue: A review [J]. *International Journal of Biological Macromolecules*, 2023, 254(Pt 3): 127986.
- [4] ZHOU S, et al. Ginseng ameliorates exercise-induced fatigue potentially by regulating the gut microbiota [J]. *Food & Function*, 2021, 12(9): 3954-3964.
- [5] WU X, ZHANG Y, LIU Y, et al. Traditional Chinese medicine Jianpi therapy in exercise-induced fatigue: A protocol for systematic review and meta-analysis [J]. *Medicine (Baltimore)*, 2022, 101(2): e28594.
- [6] ALLEN D G, LAMB G D, WESTERBLAD H. Skeletal muscle fatigue: cellular mechanisms [J]. *Physiological Reviews*, 2008, 88(1): 287-332.
- [7] BROOKS G A. The science and translation of lactate shuttle theory [J]. *Cell Metabolism*, 2018, 27(4): 757-785.
- [8] POWERS S K, JACKSON M J. Exercise-induced oxidative stress: cellular mechanisms and impact on muscle force production [J]. *Physiological Reviews*, 2008, 88(4): 1243-1276.
- [9] GOMEZ-CABRERA M C, DOMENECH E, VIÑA J. Moderate exercise is an antioxidant: upregulation of antioxidant genes by training [J]. *Free Radical Biology and Medicine*, 2008, 44(2): 126-131.
- [10] RADAK Z, CHUNG D T, GOTO S. Systemic adaptation to oxidative challenge induced by regular exercise [J]. *Free Radical Biology and Medicine*, 2008, 44(2): 153-159.
- [11] ZHANG M, ZHAO X, LIU Q, et al. Anti-Fatigue Effects of Lycium barbarum Polysaccharide and Effervescent Tablets by Regulating Oxidative Stress and Energy Metabolism in Rats [J]. *Foods*, 2022, 11(18): 2854.
- [12] WANG Y, WANG J, ZHENG X, et al. Structure and potential anti-fatigue mechanism of polysaccharides from *Bupleurum chinense* DC [J]. *International Journal of Biological Macromolecules*, 2023, 233: 123533.
- [13] TANG X, et al. Cordycepin combined with antioxidant effects improves fatigue caused by excessive exercise [J]. *Scientific Reports*, 2025, 15(1): 8141.
- [14] CAO J, et al. Cordyceps *militaris* acidic polysaccharides improve learning and memory impairment in mice with exercise fatigue through the PI3K/NRF2/HO-1 signalling pathway [J]. *Journal of Ethnopharmacology*, 2022, 303: 116035.
- [15] CHEN S, TANG X, SHEN J, et al. Shuyu decoction exhibits anti-fatigue properties via alleviating exercise-induced immune dysfunction [J]. *Journal of Ethnopharmacology*, 2024, 319(Pt 1): 117109.
- [16] CAO J, WEI M, KANG Y, et al. Astragalus polysaccharide ameliorated complex factor-induced chronic fatigue syndrome by modulating the gut microbiota and metabolites in mice [J]. *Biomedicine & Pharmacotherapy*, 2023, 163: 114787.
- [17] WANG X, et al. Effect of *Schisandra chinensis* on interleukins, glucose metabolism, and pituitary-adrenal and gonadal axis in rats under strenuous swimming exercise [J]. *Chinese Journal of Integrative Medicine*, 2014.
- [18] ZHANG Y, DONG J, WANG Z, et al. *Atractylodes macrocephala* Koidz. water extract alleviates exercise-induced fatigue by activating mitochondrial biogenesis via the PGC-1 α /NRF1/TFAM axis [J]. *Journal of Ethnopharmacology*, 2025, 348: 119881.
- [19] LI S, WANG Y, ZHANG Y, et al. Shenqi Funeng Xingnao prescription alleviates exercise-induced fatigue by regulating the HIF-1/FoxO signaling pathway [J]. *Journal of Ethnopharmacology*, 2025, 348: 119881.
- [20] CHOI E, OH J, SUNG G H. Beneficial Effect of *Cordyceps militaris* on Exercise Performance via Promoting Cellular Energy Production [J]. *Mycobiology*, 2020, 48(6): 512-517.
- [21] KIM H, et al. Effect of HX108-CS Supplementation on Exercise Capacity and Lactate Accumulation After High-Intensity Exercise [J]. *Journal of the International Society of Sports Nutrition*, 2013, 10(1): 21.

- [22] LU J, MA Y, WANG X, et al. Moxibustion Reduces Inflammatory Response in the Hippocampus of a Chronic Exercise-Induced Fatigue Rat [J]. *Frontiers in Integrative Neuroscience*, 2019, 13: 48.
- [23] CHEN Y, BA Y, TU Y, et al. Effects of Mongolian Warm Acupuncture on iNOS/NO and Inflammatory Cytokines in the Hippocampus of Chronic Fatigue Rats [J]. *Frontiers in Integrative Neuroscience*, 2020, 13: 78.
- [24] ZHOU S, YUAN X, QI Z, et al. Ginseng ameliorates exercise-induced fatigue potentially by regulating the gut microbiota [J]. *Food & Function*, 2021, 12(9): 3954-3964.
- [25] ZHANG Y, et al. Schisandra chinensis and Rhodiola rosea exert an anti-stress effect on the HPA axis and reduce hypothalamic c-Fos expression in rats subjected to repeated stress [J]. *Experimental and Therapeutic Medicine*, 2016, 11(1): 353-359.
- [26] WIECZOREK M, CHRZANOWSKA O, WITEK K, et al. Effect of Ginseng Supplementation on Exercise Endurance as a Support for Cardiovascular Disease Management: A Systematic Review and Meta-Analysis [J]. *Nutrients*, 2024, 17(1): 161.
- [27] LEE Y, KANG H M, LEE Y H, et al. Short-Term Panax Ginseng Extract Supplementation Reduces Fasting Blood Triacylglycerides and Oxygen Consumption during Sub-Maximal Aerobic Exercise in Male Recreational Athletes [J]. *Nutrients*, 2024, 16(11): 1561.
- [28] LU Y, WEI Y, ZHAO J, et al. The effect of Rhodiola rosea supplementation on endurance performance and related biomarkers: a systematic review and meta-analysis [J]. *Frontiers in Nutrition*, 2024, 11: 1475510.
- [29] ZHANG X, YU S, LIU C, et al. The Effect of Short-Term Rhodiola rosea Supplementation on Simulated Game Time, Perceived Fatigue, and Performance in Basketball Players [J]. *Nutrients*, 2024, 16(22): 3918.
- [30] VALDEZ J, et al. Cordyceps sinensis accelerates stem cell recruitment to human skeletal muscle after exercise [J]. *Food & Function*, 2024, 15(8): 4010-4020.
- [31] PARK S, et al. Effect of Schisandra chinensis Baillon extracts and regular low-intensity exercise on muscle strength and mass in older adults: a randomized, double-blind, placebo-controlled trial [J]. *The American Journal of Clinical Nutrition*, 2021, 113(6): 1440-1446.
- [32] CALDWELL K L, HARRISON M R, BAUMER T G, et al. The Effects of a Korean Ginseng, GINST15, on Perceptual Effort, Psychomotor Performance, and Physical Performance in Men and Women [J]. *Journal of Sports Science & Medicine*, 2018, 17(1): 92-100.
- [33] WANG H, TENG M, FAN Z, et al. Ren-Shen-Bu-Qi decoction alleviates exercise fatigue through activating PI3K/AKT/Nrf2 pathway in mice [J]. *Chinese Medicine*, 2024, 19: 147.
- [34] CHEN C, et al. Rhodiola crenulata- and Cordyceps sinensis-based supplement boosts aerobic exercise performance after short-term high altitude training [J]. *High Altitude Medicine & Biology*, 2014, 15(3): 371-379.
- [35] SHI J, et al. Effect of Saengmaeksan on Fatigue, Liver Function, and Immunity Combined with High-Intensity Training [J]. *Journal of Immunology Research*, 2023, 2023: 3269293.
- [36] CHENG S, LIU M Z, ZHAO Y Z, et al. Clinical massage therapy for patients with exercise-induced fatigue: A protocol for systematic review and meta analysis [J]. *Medicine (Baltimore)*, 2020, 99(26): e20827.