

The Health Benefits of Alpine Plant Resources: An Integrated Study of Ecological Adaptation and Public Health Promotion

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Abstract: the extreme environment of plateau regions has shaped unique ecological adaptations in plants, which respond to environmental stress through morphological adjustments, physiological and metabolic remodeling, and the synthesis of specific bioactive compounds. These characteristics hold significant value for human health; however, integrated research on ecological adaptation and health benefits remains insufficient. This study integrates multidisciplinary approaches from plant ecology, pharmacology and public health to elucidate the mechanisms linking the ecological adaptation of plateau plants to their health benefits, thereby providing support for resource utilization and the promotion of public health. To adapt to environments characterized by low oxygen and low atmospheric pressure, high-altitude plants enhance glycolysis, accumulate polyols, and induce the synthesis of bioactive compounds such as flavonoids, polysaccharides and alkaloids. These plants can effectively combat hypoxia and fatigue, regulate three highs (high blood pressure, high blood sugar and high cholesterol), and contribute to improving public health by boosting immunity and providing anti-inflammatory and antioxidant effects. They demonstrate significant potential, particularly in the prevention of high-altitude diseases and chronic conditions. This study aims to elucidate the intrinsic relationship between ecological adaptability, bioactive compounds and health benefits, providing a theoretical basis for the targeted development of functional foods and natural medicines from high-altitude plants. It also offers new strategies for promoting public health (particularly for populations in special environments and those in sub-optimal health), serving the national 'Healthy China 2030' strategy whilst emphasizing the key role of ecological adaptability research in

uncovering the health benefits of plants, thereby contributing new insights to international high-altitude health research.

Keywords: Plateau; Plants; Adaptation; Health promotion

1. Introduction

According to the World Health Organisation's definition, " Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. " the sociological concept of public health is a dynamic expression of the overall health status of the entire population. " Public health" is what we refer to as "national health"[1] . Since the 21st century, population health issues in high-altitude regions worldwide have become increasingly prominent, with high-altitude residents facing challenges such as metabolic disorders caused by chronic hypoxia and an increased risk of cardiovascular disease. In traditional medical practice, high-altitude plants have been widely used to enhance physical strength and prevent disease; however, a lack of scientific validation has limited the efficient development of these resources.

Building upon a systematic review of high-altitude plant resources, this study provides an in-depth analysis of the unique value and application prospects of these plants in promoting public health. High-altitude plants primarily refer to endemic species growing at elevations above 2, 500 metres, widely distributed across global high-altitude regions such as the Qinghai-Tibet Plateau and the Andes Mountains. These regions are characterised by extreme environmental conditions, including low oxygen levels, intense ultraviolet radiation, low temperatures and aridity. To adapt to these environments, high-altitude plants have evolved unique physiological structures and metabolic mechanisms, such as enhanced glycolytic capacity and the accumulation of osmotic regulators like polyols, whilst significantly

inducing the synthesis of secondary metabolites including flavonoids, polysaccharides and alkaloids. These compounds exert antioxidant, anti-fatigue, immunomodulatory and cardioprotective effects through mechanisms such as free radical scavenging, regulation of the HIF pathway and inhibition of inflammation. They are particularly effective in aiding high-altitude populations to adapt to chronic hypoxia, enhancing athletic performance and preventing metabolic diseases.

The aim of this study is to elucidate the intrinsic link between the ecological adaptability of high-altitude plants and their health benefits. Through a multidisciplinary integrated approach, we seek to reveal the regulatory mechanisms by which environmental factors influence the synthesis of bioactive compounds, and to evaluate their practical application potential in the prevention and treatment of high-altitude-related diseases, as well as in enhancing athletic performance and modulating the immune system. Within the framework of national health promotion, high-altitude plant resources provide natural and safe intervention strategies for populations in special environments (such as high-altitude residents) and those in a sub-healthy state. The prospects for developing functional foods, natural medicines and other products are vast, and these resources are expected to become a new growth point for the health industry.

2. Ecological Adaptation of High-Altitude Plants

2.1 Comprehensive Stressors in the Plateau Environment: Synergistic Pressure from Climate and Soil

In examining the ecological adaptability of high-altitude plants, extreme cold, low oxygen levels, intense ultraviolet radiation and soil conditions are key environmental factors that cannot be overlooked. High-altitude regions are typically characterised by a significant decrease in oxygen concentration; at altitudes above 4,000 metres, oxygen levels may be as low as approximately 60% of those at sea level. Temperature on the plateau shows a significant linear negative correlation with altitude, with an overall vertical temperature lapse rate of approximately 0.41–0.6°C per 100 metres, slightly lower than the global average (0.6°C per 100 metres)[2]; overall precipitation decreases continuously with increasing altitude. Due to the region's exposure

to the Asian monsoon, humidity is high, and the maximum precipitation altitude is extremely low. This hypoxic and cold environment has compelled plants to develop efficient oxygen utilisation mechanisms, enhanced cellular respiration efficiency, and the expression of genes adapted to hypoxic conditions.

The physicochemical properties of plateau soils further shape plant survival strategies. Soil electrical conductivity, as the primary driver of variation in plateau plant diversity, shows a significant negative correlation with plant richness; high electrical conductivity directly reflects soil salinity, and excessive salinity inhibits plant growth by altering root zone osmotic pressure and disrupting metabolism, thereby selecting a small number of highly salt-tolerant species and reducing overall diversity[3]; On the other hand, it alters the quantity of litterfall and the composition of root exudates, thereby affecting soil nutrient input. Furthermore, soil pH in high-altitude regions tends to be elevated (typically between 7.5 and 9.0); excessive salinity prevents the establishment of other species, and under the influence of saline-alkali habitats, plant diversity is low, which also leads to the specialisation and adaptive evolution of plant species[4]. Within the suitable range (pH 7.5–8.5), it can exert a positive effect on plant growth by regulating the form and availability of nutrients in the soil: an alkaline environment reduces the leaching of metal ions such as aluminium and manganese from the soil, thereby reducing toxic damage to the root system, whilst simultaneously promoting root cell elongation and meristematic activity, and enhancing the root system's ability to seek out soil water and nutrients[5]; Secondly, moderately alkaline conditions can increase the solubility of elements such as phosphorus, calcium and magnesium in the soil, improving the efficiency of plant uptake of essential mineral nutrients and, consequently, influencing the accumulation of their medicinal compounds. However, during the long-term adaptation process, highly saline-alkaline habitats also restrict plant species diversity, driving specialisation and adaptive evolution.

In summary, climatic, temperature, UV and soil factors in high-altitude plateau environments do not act in isolation, but rather jointly influence plant survival strategies through a cumulative stress effect. Low temperatures and low atmospheric pressure jointly exacerbate

photosynthetic limitations in plants, whilst ultraviolet radiation and soil nutrient depletion act synergistically to inhibit plant growth and development. the long-term pressure exerted by these environmental factors has driven the development of unique adaptive mechanisms in plateau plants at morphological, physiological and molecular levels. A thorough analysis of the mechanisms by which environmental factors influence plants can provide a scientific basis for predicting the stability of plateau ecosystems under climate change and for the conservation of rare plateau plant resources.

2.2 Adaptive and Genetic Evolutionary Mechanisms of Plateau Plants

Through long-term adaptation to extreme environments such as low temperatures, intense radiation, low oxygen levels and drought, high-altitude plants have developed multidimensional, synergistic physiological and biochemical adaptation mechanisms. Existing research has revealed their molecular and physiological foundations across multiple levels, including metabolic regulation, photosynthetic adaptation and antioxidant defence. In terms of metabolic adaptation, flavonoid and phenylpropanoid metabolic pathways (such as the synthesis of quercetin, apigenin and ferulic acid glycosides) have been subject to directed selection and significantly activated. the expression of related genes has been up-regulated and even tends towards population-level fixation, constructing a robust chemical antioxidant barrier that effectively counters UV radiation and oxidative damage. In terms of resource utilisation, plants ensure a balance between photosynthetic capacity and nutrient uptake by dynamically adjusting the stoichiometric characteristics of elements such as carbon, nitrogen and phosphorus, as well as their above-ground and below-ground allocation strategies[6] . Concurrently, the stoichiometric characteristics of elements within the plant body undergo regular changes in response to environmental gradients, dynamically adjusting resource allocation strategies; under drought conditions, metabolic activity is maintained by increasing nitrogen content. These physiological and biochemical processes do not operate in isolation but synergise with strategies such as the reinforcement of antioxidant enzyme systems (e. g., peroxidases) and the mitigation of photostimulation through enhanced light

utilisation. Together, they form a multi-level network that safeguards physiological homeostasis under extreme conditions. This not only ensures the physiological stability of high-altitude plants in harsh environments but also provides a crucial theoretical basis for the screening of stress-resistant genetic resources and ecological restoration breeding.

These phenotypic adaptations are rooted in genetic-level variation and adaptive evolution. At the genomic level, in high-altitude plants such as *Arabidopsis sumeru*, gene families associated with DNA damage repair, ubiquitin-mediated protein degradation (in response to radiation damage) and stress responses have expanded and undergone strong positive selection, whilst disease-resistance-related genes may have contracted, reflecting genetic adaptation to specific environments. Concurrently, the adaptation of high-altitude plants involves the coordinated regulation of multiple molecular pathways. Studies indicate that pathways associated with cold response (the CBF cold response pathway), UV protection (the flavonoid synthesis pathway), and hypoxia response (the ethylene signalling pathway) exhibit specific regulatory patterns in high-altitude plants. From the perspective of population genetics and adaptive evolution, population genetic studies have revealed that Tibetan *Arabidopsis* exhibits a very small effective population size and distinctive relict characteristics, whilst traits such as silique density are subject to significant natural selection pressure, collectively highlighting the central role of natural selection in shaping the adaptations of high-altitude plants.

In the context of public health promotion, these mechanisms in high-altitude plants are equally valuable. the antioxidants found in high-altitude plants can serve as natural antioxidants, helping the human body resist oxidative stress caused by factors such as environmental pollution and unhealthy lifestyles, thereby preventing various chronic diseases. By studying the UV-protective and antioxidant mechanisms of these plants, scientists can develop more effective sunscreens and antioxidants, providing new protective measures for human health.

3. Bioactive Compounds Unique to Alpine Plants and Their Potential Applications in Sports Science

3.1 Polysaccharides: The Cornerstone of Energy Metabolism and Immune Regulation

High-altitude plant polysaccharides are among the most extensively studied bioactive compounds, such as Rhodiola polysaccharides and snow lotus polysaccharides. In sports science, the core value of polysaccharides lies in two aspects: support for energy metabolism and immune modulation.

Polysaccharides are an important source of energy. To adapt to hypoxic environments, high-altitude plants often maintain energy supply by enhancing the glycolytic pathway. the polysaccharides they are rich in, once digested and absorbed by the human body, can serve as substrates for the synthesis of muscle and liver glycogen, thereby prolonging endurance exercise duration and delaying the onset of fatigue[7]. Research indicates that supplementation with plant polysaccharides from specific sources can significantly increase the time mice can swim to exhaustion; this mechanism is closely linked to increased skeletal muscle glycogen stores and the maintenance of stable blood glucose levels during exercise. This is of great significance for athletes in endurance sports such as long-distance running and cycling. Secondly, the "open window" phenomenon (i. e. temporary suppression of immune function) that occurs following high-intensity exercise is a key factor in athletes' susceptibility to illness. Polysaccharides from high-altitude plants have been shown to possess potent immunomodulatory properties[8]; they can activate macrophages and natural killer (NK) cells, promote the secretion of cytokines (such as IL-2 and IFN- γ), and thereby enhance both non-specific and specific immune functions. In sporting practice, supplementation with components such as Rhodiola polysaccharides helps to alleviate immune suppression following high-intensity training, reduce the incidence of upper respiratory tract infections, and ensure the continuity and systematic nature of training programmes.

3.2 Flavonoids and Phenolic Compounds: Potent Antioxidant and Anti-inflammatory Effects

Intense ultraviolet radiation at high altitudes induces plants to synthesise high levels of flavonoids (such as quercetin and apigenin) and phenolic compounds to protect themselves from oxidative damage. These compounds are natural

antioxidants, and their role is particularly prominent in counteracting exercise-induced oxidative stress.

Prolonged high-intensity exercise leads to the massive production of reactive oxygen species (ROS) in the body, exceeding the body's capacity to eliminate them. This triggers oxidative stress, resulting in lipid peroxidation of cell membranes, protein oxidation and DNA damage. This not only accelerates fatigue but is also closely associated with delayed onset muscle soreness (DOMS) and micro-injuries to muscle tissue. Flavonoids found in high-altitude plants can either directly scavenge free radicals or enhance the body's overall antioxidant capacity by upregulating the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px)[9]. For example, quercetin extracted from *Artemisia argyi* has been shown to significantly reduce the levels of malondialdehyde (MDA, a product of lipid peroxidation) in the serum of rats following exercise to exhaustion, whilst simultaneously increasing SOD activity, thereby effectively alleviating oxidative damage to skeletal and cardiac muscle.

Furthermore, these compounds possess significant anti-inflammatory effects. Exercise-induced micro-injuries in muscles trigger inflammatory responses, leading to the release of pro-inflammatory factors such as tumour necrosis factor- α (TNF- α) and interleukin-6 (IL-6). Flavonoids can alleviate DOMS and promote post-exercise recovery by inhibiting the activation of inflammatory signalling pathways, such as nuclear factor κ B (NF- κ B), thereby reducing the production of pro-inflammatory factors[10]. For athletes who require frequent high-intensity training, this is key to accelerating recovery and enhancing training efficiency.

3.3 Alkaloids and Glycosides: Adaptogenic Effects and Cardiovascular Protection

Rhodiola glycosides and matrine are glycosides and alkaloids unique to high-altitude plants, the most notable of which is their adaptogenic effect. Adaptogens are substances that enhance the body's non-specific resistance to various stressors, including physical, chemical and biological factors.

During exercise-induced stress, Rhodiola glycosides have been shown to regulate the function of the hypothalamic-pituitary-adrenal

(HPA) axis and balance the secretion of stress hormones (such as cortisol)[11]. Over-training often leads to persistently elevated cortisol levels, triggering excessive catabolism, which is detrimental to the body's recovery. Supplementation with Rhodiola extract helps maintain cortisol at appropriate levels, thereby promoting post-exercise anabolic processes. Furthermore, rhodiolic acid improves microcirculation in the myocardium and brain, enhancing tissue oxygen utilisation, which is beneficial for enhancing aerobic capacity and adaptability during high-altitude training.

In summary, the unique bioactive components of high-altitude plants demonstrate significant potential in energy supply, antioxidant activity, anti-inflammation, immune regulation and stress adaptation through multi-target, multi-pathway mechanisms, aligning closely with the requirements of exercise science.

4. The Role of High-Altitude Plants in the Prevention and Management of Chronic Diseases: An Interpretation from the Perspective of Exercise Science

Regular physical exercise is the cornerstone of the prevention and control of chronic diseases (such as cardiovascular disease, type 2 diabetes and obesity). The bioactive compounds in high-altitude plants not only act directly on the pathological mechanisms of these diseases but also indirectly amplify the health benefits of exercise by enhancing athletic performance and improving exercise-induced physiological adaptations. This section will explore the synergistic role of high-altitude plants in the prevention and control of chronic diseases from the perspective of exercise science.

4.1 Prevention of Cardiovascular Disease: Improving Cardiac Function and Vascular Health During Exercise

Regular exercise lowers blood pressure, improves lipid profiles and enhances cardiac function, serving as a primary means of preventing cardiovascular disease. The bioactive components of high-altitude plants can produce synergistic effects with exercise. For example, rhodiolic acid and various flavonoids possess vasodilatory properties and improve endothelial function. Endothelial dysfunction is an early event in atherosclerosis. Exercise itself stimulates the release of nitric oxide (NO), thereby improving endothelial function. Studies

indicate that extracts from high-altitude plants can further activate endothelial nitric oxide synthase (eNOS), increasing the bioavailability of NO. Consequently, they enhance the reduction in peripheral vascular resistance achieved through exercise, thereby aiding in blood pressure reduction.

For individuals with concomitant hypertension, exercise tolerance is often limited. By enhancing myocardial hypoxia tolerance and providing antioxidant protection to myocardial cells[12], high-altitude plant components may help improve exercise safety and tolerance in this population, enabling them to derive greater benefits from exercise. Furthermore, their lipid-lowering and anti-atherosclerotic properties can fundamentally reduce the cardiovascular risks associated with exercise training, creating a virtuous cycle of "prevention-improvement-support".

4.2 Regulation of Type 2 Diabetes and Metabolic Syndrome: Enhancing Exercise-Mediated Glucose Homeostasis

Exercise is one of the most effective ways to improve insulin sensitivity. Polysaccharides from high-altitude plants and certain flavonoid components play a significant role in regulating glucose metabolism. They can mimic the action of insulin or enhance the sensitivity of insulin signalling pathways (such as the PI3K/Akt pathway), thereby promoting the uptake and utilisation of glucose by peripheral tissues such as skeletal muscle.

In exercise practice, the combined supplementation of high-altitude plant extracts may produce a synergistic effect where the whole is greater than the sum of its parts. On the one hand, exercise itself depletes muscle glycogen, increasing skeletal muscle uptake of blood glucose; on the other hand, the active compounds can further enhance insulin sensitivity. This synergistic effect helps to control fasting and postprandial blood glucose levels more effectively, reducing blood glucose fluctuations. For individuals with prediabetes or early-stage diabetes, this combined strategy can effectively delay disease progression prior to pharmacological intervention. At the same time, improved blood glucose control provides patients with better energy levels, helping to enhance their willingness and persistence in participating in physical activity.

4.3 Obesity Management: Promoting Lipid Metabolism and Increasing Energy Expenditure

Exercise combined with dietary control is central to weight loss. Certain alkaloids and glycosides found in high-altitude plants have been shown to promote fat breakdown and inhibit fat synthesis. The mechanism may involve the activation of the AMP-activated protein kinase (AMPK) pathway, which acts as a sensor for cellular energy; exercise is also a potent activator of this pathway. When obese individuals engage in exercise for weight loss, supplementation with active compounds from high-altitude plants may help: mobilise and oxidise fat more effectively during exercise, thereby improving fat loss efficiency; moderately increase the basal metabolic rate at rest, thereby increasing total energy expenditure; and, through their anti-inflammatory effects, alleviate the chronic low-grade inflammatory state associated with obesity, thereby improving obesity-related metabolic disorders. This provides a beneficial adjunct to exercise-based weight loss.

4.4 Prevention and Treatment of Sarcopenia: Anti-inflammatory and Antioxidant Effects to Protect Muscle Mass

Sarcopenia is a syndrome characterised by age-related declines in skeletal muscle mass, strength and function, with regular resistance exercise being key to its prevention and management. However, older adults experience more pronounced inflammatory and oxidative stress responses following exercise, and their recovery is slower. The potent antioxidant and anti-inflammatory components of high-altitude plants demonstrate unique value in this context. By mitigating exercise-induced muscle damage and oxidative stress, they create an internal environment more conducive to muscle protein synthesis and muscle regeneration. This means that older adults can better tolerate training loads during resistance training, experience reduced muscle soreness, and achieve more favourable gains in muscle mass and strength—factors that are crucial for maintaining functional ability and preventing falls in older adults.

By acting directly on the pathophysiological mechanisms of chronic diseases and producing synergistic effects with exercise interventions, the active components of high-altitude plants demonstrate multi-dimensional advantages in the prevention and management of chronic diseases.

Future research should focus on: conducting long-term intervention studies combining exercise with high-altitude plant supplementation for specific chronic disease populations; thoroughly exploring the cross-talk between their molecular mechanisms and exercise adaptation signalling pathways; and developing personalised application protocols tailored to different chronic diseases and exercise regimens. Integrating high-altitude plant resources into holistic strategies for exercise-promoted health holds broad clinical application prospects and public health significance.

5. The Health-Promoting Value of High-Altitude Plant Resources: Building a New Model of Sports and Health Integration

The 'Healthy China 2030' Outline Plan emphasises the promotion of the integration of sports and medicine, as well as non-medical health interventions. With their unique ecological adaptability and extensive biological activity, high-altitude plant resources provide valuable assets for achieving the transition from treating existing diseases to preventing diseases before they occur. This section will focus on exploring how to integrate high-altitude plant resources with industries such as sports, tourism and agriculture to construct a multi-sectoral integrated development model for the promotion of public health.

5.1 Development of Plateau Plants and Sports Nutrition Products

Sports nutrition products serve as the most direct link between high-altitude plant resources and public health. A range of products can be developed to address the health needs of different demographic groups:

For the general fitness population: Develop general food products or nutritional supplements with anti-fatigue and immune-boosting properties. For example, instant drinks and energy bars containing barley β -glucan and *Rhodiola rosea* extract as key ingredients can serve as nutritional support before and after daily exercise.

For professional athletes: Research and develop high-performance sports supplements. For example, compound formulations rich in high-altitude plant flavonoids and polysaccharides to accelerate physical recovery after high-intensity training and reduce oxidative damage and muscle inflammation. This requires stricter

purity and dosage control, as well as doping testing, to ensure safety and efficacy[13].

For specific demographics: Develop protein supplements rich in antioxidants and beneficial for maintaining muscle health for middle-aged and elderly individuals, to be combined with resistance training to prevent and treat sarcopenia.

5.2 Deep Integration of Plateau Wellness Tourism and the Sports Industry

The unique natural scenery and plant resources of plateau regions provide unrivalled conditions for the development of the new sports+wellness+tourism sector.

5.2.1 Highland Hiking and Adaptive Wellness

For individuals in a state of sub-health or recovering from chronic illnesses, design scientifically sound high-altitude hiking routes that combine "ecological experiences with health promotion". During the itinerary, incorporate the consumption of functional foods made from local high-altitude plants (such as *Rhodiola rosea* tea), guided by experts in exercise physiology, to help participants gradually acclimatise to the high-altitude environment, thereby improving cardiopulmonary function and regulating mood through physical activity.

5.2.2 Tibetan Medicinal Baths and Sports Recovery

Combining traditional Tibetan medicinal baths (typically containing various high-altitude medicinal plants) with modern sports recovery principles[14]. At high-end wellness centres or athlete training bases, medicinal bath services are provided for participants who have undergone high-intensity training or competitions. Utilising the warming and anti-inflammatory properties of the herbs, these baths promote blood circulation, accelerate lactic acid clearance and aid muscle recovery.

5.2.3 Dietary Support at High-Altitude Training Centres

At high-altitude training centres, athletes are provided with nutritious meals based on distinctive high-altitude edible plants (such as barley, fern, and matsutake mushrooms). This not only supplies high-quality nutrition for training, but the natural active compounds also help athletes adapt better to the hypoxic environment, thereby enhancing training outcomes.

5.2.4 High-Altitude Plants+Community Health Promotion

Scientifically validated health products and application schemes derived from high-altitude plants are promoted through channels such as community health centres and fitness centres. For example, comprehensive intervention programmes are developed for community residents with metabolic syndrome, incorporating dietary advice (including specific high-altitude plant ingredients) and exercise prescriptions, with long-term monitoring of health indicators and evaluation of outcomes.

5.3 Non-medical health interventions under the sports-medicine integration model

Promote sports-medicine integration intervention programmes based on high-altitude plant resources within communities and health management institutions.

Nutritional Supplements in Exercise Prescriptions for Chronic Diseases: Whilst developing personalised exercise prescriptions for patients with conditions such as hypertension and diabetes, recommend the concurrent use of scientifically validated health foods derived from high-altitude plants. For example, advise diabetic patients to consume plant-based beverages containing ingredients that aid glucose metabolism before taking a post-meal walk, to enhance the blood sugar-controlling effects of exercise.

"Exercise-Nutrition-Psychological" Comprehensive Health Management Package: Develop a comprehensive package integrating mild exercise programmes (such as Tai Chi and brisk walking), high-altitude plant-based nutritional products and mental health guidance, targeting sub-healthy groups such as white-collar workers under high work pressure to provide one-stop health promotion services[15].

5.4 Challenges and Development Pathways

Despite the promising outlook, the development of this field still faces challenges such as a weak theoretical foundation, homogenisation in product R&D, a shortage of multidisciplinary talent, and a lack of standards. Future efforts should focus on:

5.4.1 Strengthening Scientific Research Support
Strengthen interdisciplinary collaboration across fields such as exercise science, botany, pharmacy, nutrition and ecology. Conduct systematic research into the pharmacokinetics of active compounds from high-altitude plants in athletes to determine their effective dosages,

targets of action and physiological mechanisms. Particular attention should be paid to their functional effects in combating fatigue, boosting immunity and promoting recovery, thereby providing a scientific basis for product development and health guidance.

5.4.2 Establishing Industry Standards

Under the guidance of relevant government departments, collaborate with industry associations, research institutions and leading enterprises to jointly formulate standards for functional foods and health and wellness products derived from high-altitude plants, covering aspects such as raw material collection, processing techniques, quality testing and efficacy evaluation. Enhance industry transparency and credibility through standardisation, thereby fostering healthy market competition.

5.4.3 Cultivating Multidisciplinary Talent

Universities and research institutions are encouraged to establish interdisciplinary programmes such as "Sports Nutrition and High-Altitude Plant Resources" and "Health Management and Ecological Resource Utilisation", to cultivate professionals who possess expertise in both sports and health sciences as well as a mindset for resource development and industrialisation. A multi-tiered talent development system will be established through various approaches, including curriculum integration, university-industry collaboration and practical training bases.

5.4.4 Promoting Industrial Integration

We will guide collaborative efforts across the sports, tourism, agriculture and health management sectors to establish an integrated industrial chain encompassing the ecological cultivation of high-altitude plants, ingredient extraction, product R&D, health experiences and wellness tourism. Through innovative models such as 'plant resources+exercise promotion+health tourism', we will extend the value of the industry and achieve the multiple objectives of ecological conservation, economic development and health promotion.

High-altitude plant resources serve as a natural link between the ecological environment and human health. By closely integrating their bioactive components with sports science, and incorporating them into healthy diets, wellness tourism and the integration of sports and medicine, a multi-tiered, personalised system for

promoting public health can be established. This is not only an effective means of unlocking the economic value of high-altitude plants and protecting biodiversity, but also a valuable exploration in implementing the "Healthy China" strategy and promoting the safeguarding of public health through non-medical means.

6. Conclusions and Outlook

In summary, high-altitude plant resources serve as a vital bridge linking unique ecological environments with human health. The bioactive compounds derived from their ecological adaptation demonstrate significant potential in enhancing athletic performance, accelerating physical recovery and preventing chronic diseases. Through an integrated, multidisciplinary research approach that systematically elucidates their mechanisms of action, and builds upon this foundation to conduct precision product development and business model innovation, high-altitude plant resources will undoubtedly provide new and powerful natural solutions for the promotion of public health under the 'Healthy China 2030' strategic objectives, particularly in enhancing the physical health of the nation. Future research should place greater emphasis on translating laboratory evidence into practical applications, ensuring that this precious gift of nature benefits a wider population.

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