WEP Warwick Evans Publishing

International Journal of Public Health and Medical Research
ISSN: 3006-7707 (Print), ISSN: 3006-3752 (Online) | Volume 5, Number 2, Year 2025
DOI: https://doi.org/10.62051/ijphmr.v5n2.01
Journal homepage: https://wepub.org/index.php/IJPHMR/index

Recent Advances in the Role of Edible Fungi in Sarcopenia: A Review

Xiaohui Yu, Pingping Yang, Linghan·Zhang, Wanting·Xu, Jiarong·Cai, Rui·Zhou, Yuxin·Wen, Mingguo·Zhang, Jiaoyang Li *

School of Health and Medical Technology, Chengdu Neusoft University, Sichuan, China

ABSTRACT

Sarcopenia, a degenerative skeletal muscle disease closely related to aging, has become a major threat to the health and quality of life of older adults. With the global trend of population aging, the social and economic problems caused by sarcopenia are becoming increasingly prominent. Currently, pharmacological treatments for sarcopenia are somewhat limited, whereas nutritional interventions have shown potential advantages in combating the condition. This review comprehensively discusses the bioactive components and functional properties of edible fungi and provides a thorough understanding of the severe health issues faced by sarcopenia patients, such as muscle degeneration and functional loss. Although animal experiments and early human studies support the positive effects of edible fungi, large-scale nutritional epidemiology studies in humans are still insufficient, which limits their application in the prevention and treatment of sarcopenia. Therefore, future research, such as randomized controlled trials, is needed to fully understand their effects on muscle health and to provide a solid scientific basis for the prevention and management of sarcopenia.

KEYWORDS

Edible fungi; Sarcopenia; Antioxidation; Anti-inflammation Polysaccharides

1. INTRODUCTION

Sarcopenia, also known as muscle loss, muscle atrophy syndrome, or muscle failure, is a progressive and systemic skeletal muscle disease involving the accelerated loss of muscle mass and function. It is associated with an increased risk of various adverse outcomes, including falls and fractures, disability and partial disability, loss of independence, decreased quality of life, hospitalization, and mortality [1-5]. Sarcopenia is generally considered a part of the natural aging process in older adults but can also be associated with various disease states in middle-aged individuals [6]. Concurrently, the importance of non-pharmacological approaches has been increasingly recognized by the medical community [7.

Although the pathophysiological mechanisms of sarcopenia are not yet fully understood, current research indicates that the condition can be treated or improved through reversible pathways [8]. However, due to a lack of high-quality evidence and potential drug-related side effects, there are currently no specific pharmacological treatment strategies approved for the prevention or treatment of sarcopenia [6]. Concurrently, the importance of non-pharmacological approaches has been increasingly recognized by the medical community [9, 10] Previous research has shown that diet is a potentially modifiable factor that can have a positive impact on delaying the progression of sarcopenia [11].

Edible fungi are a type of high-value macrofungi, rich in nutritional components such as high-quality protein, carbohydrates, various vitamins, and mineral elements [12]. They are characterized by being high in protein, low in sugar, low in fat, and low in cholesterol [12]. Furthermore, edible fungi contain a variety of bioactive substances, such as polysaccharides, dietary fiber, steroids, and polyphenols [12-15]. Studies have found that extracts from edible fungi have ben However, to date, the effects of edible fungi on sarcopenia remain unclear. This review synthesizes the literature on the bioactive components and functional properties of edible fungi and provides a deep understanding of the serious health problems faced by patients with sarcopenia, such as muscle degeneration and functional loss. The aim is to explore whether edible fungi could be a potential nutritional intervention strategy for sarcopenia.

2. SARCOPENIA OVERVIEW

Definition and Diagnosis

The term "sarcopenia" originates from the Greek phrase "poverty of flesh" and was first described in the 1980s as an age-related decline in lean body mass, which can affect an individual's mobility, nutritional status, and independence [17]. Subsequently, the definition has continued to evolve, marked by two significant milestones. First, since 2010, the concept of muscle function has been incorporated into six consensus definitions [1, 7, 18, 19]. Research indicates that muscle function is a more effective predictor of clinical-related outcomes than muscle mass alone [20, 21]. The second milestone occurred in 2016 when sarcopenia was coded as an independent disease in the International Classification of Diseases (ICD-10: M62 [22 23]). However, due to differences among various populations and disease states, the definition of sarcopenia continues to be a subject of ongoing evolution and discussion. Currently, the most widely cited definition was proposed by the European Working Group on Sarcopenia in Older People (EWGSOP) [7], supported by the Asian Working Group for Sarcopenia (AWGS) [1], and updated to EWGSOP2 in January 2019 [24]. Its specific diagnostic criteria are as follows: (1) Low muscle strength: handgrip strength <27 kg for men, <16 kg for women. (2) Low muscle mass: appendicular skeletal muscle mass (ASM) <20 kg for men, <15 kg for women; or appendicular skeletal muscle mass index (ASMI) (ASMI = ASM/height^2) <7.0 kg/m^2 for men, <5.5 kg/m^2 for women. (3) Low physical performance: gait speed ≤0.8 m/s. Possible sarcopenia is suspected in the presence of criterion (1); a diagnosis of sarcopenia is established upon the presentation of both criteria (1) and (2); and severe sarcopenia is diagnosed when criteria (1), (2), and (3) are all concurrently observed. In light of the cultural, background, and lifestyle differences between European and Asian populations, the AWGS modified its diagnostic algorithm and some criteria in 2019, while retaining the original definition of sarcopenia as "age-related loss of skeletal muscle mass, plus low muscle strength and/or low physical performance" [2]. The specific diagnostic criteria are: (1) Low muscle strength: handgrip strength <28 kg for men, <18 kg for women; (2) Low physical performance: 6-meter walk speed <1.0 m/s, or Short Physical Performance Battery (SPPB) score ≤9, or 5-time chair stand test ≥12 seconds. (3) Low muscle mass: using dual-energy X-ray absorptiometry (DXA), ASMI <7.0 kg/m^2 for men, <5.4 kg/m^2 for women; using bioelectrical impedance analysis (BIA), ASMI <7.0 kg/m^2 for men, <5.7 kg/m^2 for women. When criterion (1) or the 5-time chair stand test ≥12 seconds from criterion (2) is met, it indicates possible sarcopenia. Based on this, if criterion (3) and/or criterion (2) are also met, sarcopenia can be diagnosed; when all three criteria (1), (2), and (3) are met simultaneously, it is diagnosed as severe sarcopenia.

3. EPIDEMIOLOGY OF SARCOPENIA

Although the prevalence of sarcopenia varies depending on the research and definitions used, it is a common condition among older adults and patients with various medical conditions. In a systematic review by Nascimento PR et al [25], the global prevalence of sarcopenia in older adults ranged from 5% (95% confidence interval [CI]: 1%–10%) according to EWGSOP2 criteria to 17% (95% CI: 11%–23%) according to the International Working Group on Sarcopenia (IWGS)18. However, in a study by Petermann-Rocha F et al.26, the prevalence based on EWGSOP was as high as 22% (95% CI: 20%–25%), while the prevalence based on the Foundation for the National Institutes of Health (FNIH) criteria was the lowest at 11% (95% CI: 9%–14%). In the studies by Nascimento PR et al. [25] and Petermann-Rocha F et al. [26], the combined prevalence across all definitions was approximately 10% (95% CI: 7%–12%) and 16% (95% CI: 15%–17%), respectively. A recent meta-analysis indicated that the prevalence of sarcopenia in the global population aged 60 and over is between 10% and 27% [26]. In addition to being common in older adults, sarcopenia can also occur in middle age [6], and is prevalent in certain populations, such as patients with cancer [27], renal insufficiency [28], liver disease [29] and metabolic disorders [30]. Compared to the general population, the prevalence of sarcopenia is higher among these patients, ranging from 18% in diabetic patients [30] to 66% in patients with inoperable esophageal cancer [31]. Although evidence suggests that the incidence of sarcopenia increases with age, research on its incidence is relatively limited. One study reported an incidence of 1.6% in European men and women aged 40 to 79, according to the EWGSOP definition [32]. In a cohort of Chinese men and women with an average age of 72, the incidence of sarcopenia was 3.4% according to the AWGS definition [8].

Sarcopenia is one of the most common diseases among older adults today and is associated with multiple adverse health outcomes, including falls [33, 34], functional decline [35], frailty, reduced quality of life [36], increased healthcare costs, and mortality [37]. A systematic review and meta-analysis showed a consistent association between sarcopenia (defined by EWGSOP) and mortality, with a pooled odds ratio of 3.59 (95% CI: 2.96–4.27), and the effect was greater in men and women aged 79 and older [38]. Another systematic review confirmed that sarcopenia leads to a decline in overall quality of life, regardless of whether generic self-report tools or disease-specific questionnaires are used36. According to world population data, the number of people aged 65 and over is projected to double between 2019 and 2050, from 703 million to 1.5 billion, and the proportion of the older adult population will increase from 9% to 16%7. Sarcopenia is not only associated with a series of adverse health outcomes but also with increased medical expenditures [39]. Epidemiological surveys show that for hospitalized older adults, the direct and indirect costs for patients with sarcopenia are approximately five times higher than for those without the condition [40]. Furthermore, patients with sarcopenia have higher hospitalization rates and longer average hospital stays, with annual inpatient costs accounting for about 4% of the total national healthcare expenditure [41]. With the increasing proportion of the older adult population, the prevalence of sarcopenia will rise sharply in the coming years, leading to significant medical and economic burdens. Therefore, identifying modifiable risk factors for sarcopenia is of great public health importance.

4. PATHOPHYSIOLOGY

The homeostasis of skeletal muscle is determined by the balance between muscle hypertrophy, atrophy, and regeneration. With advancing age, this balance is disrupted, particularly manifesting as an imbalance between muscle protein synthesis and breakdown, which leads to a gradual loss of muscle mass and function, a state known as sarcopenia [6, 42]. Although the decline in muscle mass and function during aging is considered inevitable, the extent of this reduction varies significantly among individuals [43, 44]. The etiology of sarcopenia is multifactorial, involving genetic and environmental factors, but the specific mechanisms of these factors are not yet fully understood. Existing research has shown that factors such as oxidative stress [45, 46], chronic inflammation [47, 48], mitochondrial dysfunction [45], hormonal changes [49, 50], malnutrition [11, 51, 52] and reduced physical activity [53, 54] are closely related to the development of sarcopenia. In particular, oxidative stress and chronic inflammation play key roles in age-related muscle atrophy. They affect multiple intracellular signaling pathways, disrupt the balance between protein synthesis and breakdown, and promote apoptosis, thereby significantly reducing muscle mass [55]. Furthermore, previous studies have found that an increase in chronic low-grade inflammation induced by oxidative stress is detrimental to both human skeletal muscle and animal models [56].

Additionally, oxidative stress can directly damage macromolecules in skeletal muscle, such as lipids, nucleic acids, and proteins. Mitochondria are the primary source of reactive oxygen species (ROS), and excessive ROS production can lead to damage of mitochondrial DNA, affecting myocyte function and survival [57, 58]. Chronic low-grade inflammation can lead to a reduction in muscle protein synthesis and an increase in breakdown by activating the ubiquitin-proteasome system and altering mitochondrial dynamics, ultimately resulting in a loss of skeletal muscle mass and function [59]. Furthermore, chronic low-grade inflammation can also induce myocyte apoptosis and disrupt satellite cells, thereby limiting muscle repair and regeneration and promoting the onset of sarcopenia5 [9, 60]. Meanwhile, adequate nutritional status is crucial for maintaining skeletal muscle health, and a deficiency in essential amino acids and protein will reduce the rate of muscle synthesis, exacerbating the loss of muscle mass [61]. Conversely, nutritional interventions, such as supplementing with a mixture of leucine-rich essential amino acids and carbohydrates, have been shown to increase muscle protein synthesis, which is beneficial for preventing or treating sarcopenia [62, 63]. Moreover, research also indicates that combining resistance training with essential amino acid intake is an effective strategy for combating sarcopenia [64]. In summary, sarcopenia is a complex pathological condition driven by multiple factors.

5. OVERVIEW OF EDIBLE FUNGI

Fungi are a class of nutrient-rich and palatable macrofungi, including fleshy and gelatinous fruiting bodies or sclerotial tissues. Due to their nutritional composition and delicious taste, these fungi are widely used in food and traditional medicine around the world. According to the definition from the European International Life Sciences Institute, edible fungi are considered functional foods with potential therapeutic and disease-preventive properties due to their potential efficacy in improving, preventing, or treating certain diseases [65]. With the growing public awareness of healthy eating, the consumption of edible fungi has increased significantly, and it is projected to grow from approximately 12.74 million tons in 2018 to 20.84 million tons in 2026 [66].

Edible fungi are rich in protein, dietary fiber, essential amino acids, vitamins, and minerals, and are low in fat and calories, making them highly nutritious. Research indicates that bioactive components in edible fungi, such as polysaccharides [67], alkaloids [68], steroids [69], polyphenols [14] play important roles in natural antioxidation [70], anti-cancer [71], anti-aging [72], lipid-lowering [73], and immunomodulatory activities. In particular, polysaccharides from edible fungi have attracted considerable attention due to their excellent nutritional and therapeutic effects and are regarded as health compounds with broad application prospects. For instance, polysaccharides from Lentinula edodes (shiitake) exhibit significant antioxidant activity and can enhance the body's ability to kill tumor cells [74], while polysaccharides from Auricularia auricula-judae (black wood ear) can increase the activity of antioxidant enzymes in the heart and improve cardiac function [75]. Additionally, dietary fiber in edible fungi, as a key component, demonstrates multiple health benefits, such as enhancing immunity, anti-tumor activity, and lowering blood glucose, lipids, and cholesterol levels [76-80].

Recent studies have further revealed the relationship between edible fungi and chronic diseases, providing new insights for the field of public health. A prospective cohort study involving 19,830 Chinese adults showed a significant association between high consumption of edible fungi and a lower risk of hyperuricemia [81], suggesting that edible fungi may help reduce the incidence of hyperuricemia. Similar conclusions were reached in a large-scale collaborative cross-sectional study in the United States and Japan, which also investigated the link between edible fungi and hyperuricemia. This study found that the consumption of edible fungi was associated with a lower risk of developing hyperuricemia in middle-aged Japanese men [82], further supporting the connection between edible fungi and health benefits. A meta-analysis emphasized that increased intake of mushrooms is associated with a reduced risk of cancer [83]. Furthermore, a prospective cohort study of 13,156 Chinese older adults aged 65 and above found that high-frequency intake of mushrooms and algae was negatively correlated with all-cause mortality, suggesting long-term health benefits of edible fungi. In addition, a clinical trial confirmed that long-term supplementation with Hericium erinaceus (12 weeks) can prevent memory decline and improve cognitive function [84]. These studies not only reveal the potential health benefits of edible fungi but also provide a scientific basis for their inclusion as part of a daily diet. However, one study, a large cohort study with over 2 million person-years of follow-up, found no significant association between mushroom consumption and biomarkers or risk of cardiovascular disease and type 2 diabetes in American adults [85], suggesting that mushroom intake may have a limited effect on these diseases.

6. THE ASSOCIATION BETWEEN EDIBLE FUNGI AND SARCOPENIA

Although the link between edible fungi and various chronic diseases has been extensively studied, research on their association with sarcopenia is relatively scarce. Recent studies have begun to fill this gap. For example, a cross-sectional study covering 32,308 Chinese adults found a positive correlation between the consumption of edible fungi and enhanced handgrip strength, suggesting that edible fungi may have the potential to improve muscle function [86]. Further support comes from a randomized controlled trial, which showed that Brazilian mushrooms (Agaricus brasiliensis) may have the potential to alleviate muscle fatigue [87]. Concurrently, animal studies have also shown that edible fungi can effectively inhibit the production of blood lactate and promote energy metabolism, thereby enhancing muscle endurance [88]. The experiments by Yusuke Komiya et al. further demonstrated that feeding mice edible fungi for eight consecutive weeks significantly increased their muscle endurance [89]. In in vivo and in vitro models of muscle atrophy, it was found that extracts from Inonotus obliquus (chaga mushroom) could promote muscle growth and regeneration, helping to prevent muscle atrophy [90]. Additionally, immunologically active substances isolated from black wood ear can promote the release of nitric oxide (NO). As an effective vasodilator, NO can increase muscle blood flow and mitochondrial respiration [91, 92], thereby reducing muscle fatigue, improving muscle contraction strength, and enhancing repair capabilities [93, 94]. Furthermore, research has also shown that edible fungi can enhance muscle endurance by promoting the expression of key metabolic regulatory factors, such as AMP-activated protein kinase and peroxisome proliferator-activated receptor delta (PPAR-δ) [95]. This further reveals the potential molecular mechanisms of edible fungi in promoting muscle health.

Bioactive components in edible fungi, such as polysaccharides, polyphenols, and melanin [13-15], have received widespread attention for their significant antioxidant, anti-inflammatory, immunomodulatory, and anti-aging benefits [70, 72, 96]. Oxidative stress and molecular inflammation are key factors leading to muscle degeneration [97, 98], and the bioactive components in edible fungi seem to effectively intervene in this process. For example, studies have shown that black wood ear has significant in vitro antioxidant capacity, able to scavenge superoxide anions and hydroxyl radicals, with its efficacy being positively correlated with its molecular weight [99]. Crude polysaccharides from Russula lepida exhibit strong chelating and reducing abilities, as well as antioxidant activity, by scavenging hydroxyl and superoxide radicals [100]. Polysaccharides isolated from the mycelium of Agrocybe aegerita can enhance the activity of antioxidant enzymes, reduce the production of malondialdehyde (an indicator of oxidative stress), alleviate oxidative damage, and thus protect cells from ROS attack [101]. Further animal experiments have shown that polysaccharides from Lentinula edodes can achieve an antioxidant state by reducing inflammatory factors and eliminating lipid peroxides, while also inhibiting the expression of aging-related markers, demonstrating significant anti-aging effects [102]. In another animal study, it was found that polysaccharides from edible fungi can also increase the secretion of interleukin-6 and inhibit the expression of lipofuscin and advanced glycation end products (an age-related indicator), significantly mitigating aging induced by oxidative stress [103]. Additionally, the polyphenolic compounds (including catechins and chlorogenic acid) and melanin in black wood ear can exert antioxidant effects by scavenging 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radicals and superoxide anions [15].

In summary, while the evidence for a potential association between edible fungi and enhanced muscle function and endurance is primarily derived from animal experiments and molecular mechanism studies, this research provides a preliminary scientific basis for the potential positive effects of edible fungi on human sarcopenia. In particular, these studies reveal that edible fungi may improve muscle health through mechanisms such as promoting the release of nitric oxide and enhancing antioxidant and anti-inflammatory responses. However, although a few cross-sectional studies have shown a positive correlation between edible fungi consumption and increased muscle function in humans, direct epidemiological evidence linking edible fungi to the risk of sarcopenia remains relatively scarce.

7. SUMMARY AND PROSPECTS

Muscle health plays a crucial role in promoting healthy aging. As an important and modifiable lifestyle factor, diet and nutrition are essential for maintaining muscle mass, enhancing muscle strength, and improving overall physical function. According to the existing research summarized here, edible fungi, due to their rich nutritional value, have shown potential benefits for muscle health in animal models. However, large-scale nutritional epidemiological studies on the effects of edible fungi on human muscle health are still relatively scarce, which limits their application in the prevention and treatment of sarcopenia. Although current research on the association between edible fungi and sarcopenia is still in its early stages, existing evidence has highlighted the importance of further exploring the potential role of edible fungi in the prevention and treatment of sarcopenia. Future research needs to employ large-scale, multi-center prospective cohort studies and randomized controlled trials to further investigate the effects of edible fungi on human muscle health, particularly their potential role in preventing and treating sarcopenia. This will not only lay a solid scientific foundation for the prevention and treatment of sarcopenia but may also open up new avenues and strategies for understanding and addressing other age-related health issues.

REFERENCES

[1] CHEN LK, LIU LK, WOO J, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia [J]. J Am Med Dir Assoc, 2014, 15(2): 95-101.

[2] CHEN LK, WOO J, ASSANTACHAI P, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment [J]. J Am Med Dir Assoc, 2020, 21(3): 300-307.e302.

[3] LIU P, HAO Q, HAI S, et al. Sarcopenia as a predictor of all-cause mortality among community-dwelling older people: A systematic review and meta-analysis [J]. Maturitas, 2017, 103: 16-22.

[4] PéREZ-ZEPEDA MU, SGARAVATTI A, DENT E. Sarcopenia and post-hospital outcomes in older adults: A longitudinal study [J]. Arch Gerontol Geriatr, 2017, 69: 105-109.

[5] CRUZ-JENTOFT AJ, BAHAT G, BAUER J, et al. Sarcopenia: revised European consensus on definition and diagnosis [J]. Age Ageing, 2019, 48(4): 601.

[6] CRUZ-JENTOFT AJ, SAYER AA. Sarcopenia [J]. Lancet, 2019, 393(10191): 2636-2646.

[7] CRUZ-JENTOFT AJ, BAEYENS JP, BAUER JM, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People [J]. Age Ageing, 2010, 39(4): 412-423.

[8] YU R, WONG M, LEUNG J, et al. Incidence, reversibility, risk factors and the protective effect of high body mass index against sarcopenia in community-dwelling older Chinese adults [J]. Geriatr Gerontol Int, 2014, 14 Suppl 1: 15-28.

[9] DENISON HJ, COOPER C, SAYER AA, et al. Prevention and optimal management of sarcopenia: a review of combined exercise and nutrition interventions to improve muscle outcomes in older people [J]. Clin Interv Aging, 2015, 10: 859-869.

[10] MALAFARINA V, URIZ-OTANO F, INIESTA R, et al. Effectiveness of nutritional supplementation on muscle mass in treatment of sarcopenia in old age: a systematic review [J]. J Am Med Dir Assoc, 2013, 14(1): 10-17.

[11] MITHAL A, BONJOUR JP, BOONEN S, et al. Impact of nutrition on muscle mass, strength, and performance in older adults [J]. Osteoporos Int, 2013, 24(5): 1555-1566.

[12] ZHANG Y, WANG D, CHEN Y, et al. Healthy function and high valued utilization of edible fungi [J]. Food Science and Human Wellness, 2021, 10(4): 408-420.

[13] WEI Y, LI L, LIU Y, et al. Identification techniques and detection methods of edible fungi species [J]. Food Chem, 2022, 374: 131803.

[14] YAN Q-X, HUANG M-X, SUN P, et al. Steroids, fatty acids and ceramide from the mushroom Stropharia rugosoannulata Farlow apud Murrill [J]. Biochemical Systematics and Ecology, 2020, 88: 103963.

[15] LIU E, JI Y, ZHANG F, et al. Review on Auricularia auricula-judae as a Functional Food: Growth, Chemical Composition, and Biological Activities [J]. J Agric Food Chem, 2021, 69(6): 1739-1750.

[16] MUSZYŃSKA B, GRZYWACZ-KISIELEWSKA A, KAŁA K, et al. Anti-inflammatory properties of edible mushrooms: A review [J]. Food Chem, 2018, 243: 373-381.

[17] ROSENBERG IH. Sarcopenia: origins and clinical relevance [J]. J Nutr, 1997, 127(5 Suppl): 990s-991s.

[18] FIELDING RA, VELLAS B, EVANS WJ, et al. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International working group on sarcopenia [J]. J Am Med Dir Assoc, 2011, 12(4): 249-256.

[19] STUDENSKI SA, PETERS KW, ALLEY DE, et al. The FNIH sarcopenia project: rationale, study description, conference recommendations, and final estimates [J]. J Gerontol A Biol Sci Med Sci, 2014, 69(5): 547-558.

[20] DELMONICO MJ, HARRIS TB, VISSER M, et al. Longitudinal study of muscle strength, quality, and adipose tissue infiltration [J]. Am J Clin Nutr, 2009, 90(6): 1579-1585.

[21] VISSER M, SCHAAP LA. Consequences of sarcopenia [J]. Clin Geriatr Med, 2011, 27(3): 387-399.

[22] ANDONIAN MR, BARRETT AS, VINOGRADOV SN. Physical properties and subunits of Haemopis grandis erythrocruorin [J]. Biochim Biophys Acta, 1975, 412(2): 202-213.

[23] ANKER SD, MORLEY JE, VON HAEHLING S. Welcome to the ICD-10 code for sarcopenia [J]. J Cachexia Sarcopenia Muscle, 2016, 7(5): 512-514.

[24] CRUZ-JENTOFT AJ, BAHAT G, BAUER J, et al. Sarcopenia: revised European consensus on definition and diagnosis [J]. Age Ageing, 2019, 48(1): 16-31.

[25] CARVALHO DO NASCIMENTO PR, BILODEAU M, POITRAS S. How do we define and measure sarcopenia? A meta-analysis of observational studies [J]. Age Ageing, 2021, 50(6): 1906-1913.

[26] PETERMANN-ROCHA F, BALNTZI V, GRAY SR, et al. Global prevalence of sarcopenia and severe sarcopenia: a systematic review and meta-analysis [J]. J Cachexia Sarcopenia Muscle, 2022, 13(1): 86-99.

[27] SHACHAR SS, WILLIAMS GR, MUSS HB, et al. Prognostic value of sarcopenia in adults with solid tumours: A meta-analysis and systematic review [J]. Eur J Cancer, 2016, 57: 58-67.

[28] SHU X, LIN T, WANG H, et al. Diagnosis, prevalence, and mortality of sarcopenia in dialysis patients: a systematic review and meta-analysis [J]. J Cachexia Sarcopenia Muscle, 2022, 13(1): 145-158.

[29] TANTAI X, LIU Y, YEO YH, et al. Effect of sarcopenia on survival in patients with cirrhosis: A meta-analysis [J]. J Hepatol, 2022, 76(3): 588-599.

[30] FENG L, GAO Q, HU K, et al. Prevalence and Risk Factors of Sarcopenia in Patients With Diabetes: A Meta-analysis [J]. J Clin Endocrinol Metab, 2022, 107(5): 1470-1483.

[31] JOGIAT UM, BéDARD ELR, SASEWICH H, et al. Sarcopenia reduces overall survival in unresectable oesophageal cancer: a systematic review and meta-analysis [J]. J Cachexia Sarcopenia Muscle, 2022, 13(6): 2630-2636.

[32] GIELEN E, O'NEILL TW, PYE SR, et al. Endocrine determinants of incident sarcopenia in middle-aged and elderly European men [J]. J Cachexia Sarcopenia Muscle, 2015, 6(3): 242-252.

[33] HUANG P, LUO K, XU J, et al. Sarcopenia as a Risk Factor for Future Hip Fracture: A Meta-Analysis of Prospective Cohort Studies [J]. J Nutr Health Aging, 2021, 25(2): 183-188.

[34] CHEN H, MA J, LIU A, et al. The association between sarcopenia and fracture in middle-aged and elderly people: A systematic review and meta-analysis of cohort studies [J]. Injury, 2020, 51(4): 804-811.

[35] DOS SANTOS L, CYRINO ES, ANTUNES M, et al. Sarcopenia and physical independence in older adults: the independent and synergic role of muscle mass and muscle function [J]. J Cachexia Sarcopenia Muscle, 2017, 8(2): 245-250.

[36] TSEKOURA M, KASTRINIS A, KATSOULAKI M, et al. Sarcopenia and Its Impact on Quality of Life [J]. Adv Exp Med Biol, 2017, 987: 213-218.

[37] KELLEY GA, KELLEY KS. Is sarcopenia associated with an increased risk of all-cause mortality and functional disability? [J]. Exp Gerontol, 2017, 96: 100-103.

[38] BEAUDART C, ZAARIA M, PASLEAU F, et al. Health Outcomes of Sarcopenia: A Systematic Review and Meta-Analysis [J]. PLoS One, 2017, 12(1): e0169548.

[39] NORMAN K, OTTEN L. Financial impact of sarcopenia or low muscle mass-A short review [J]. Clin Nutr, 2019, 38(4): 1489-1495.

[40] ANTUNES AC, ARAúJO DA, VERíSSIMO MT, et al. Sarcopenia and hospitalisation costs in older adults: a cross-sectional study [J]. Nutr Diet, 2017, 74(1): 46-50.

[41] GOATES S, DU K, ARENSBERG MB, et al. Economic Impact of Hospitalizations in US Adults with Sarcopenia [J]. J Frailty Aging, 2019, 8(2): 93-99.

[42] BROWN DM, GOLJANEK-WHYSALL K. microRNAs: Modulators of the underlying pathophysiology of sarcopenia? [J]. Ageing Res Rev, 2015, 24(Pt B): 263-273.

[43] DODDS RM, SYDDALL HE, COOPER R, et al. Grip strength across the life course: normative data from twelve British studies [J]. PLoS One, 2014, 9(12): e113637.

[44] GOODPASTER BH, PARK SW, HARRIS TB, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study [J]. J Gerontol A Biol Sci Med Sci, 2006, 61(10): 1059-1064.

[45] JOSEPH AM, ADHIHETTY PJ, LEEUWENBURGH C. Beneficial effects of exercise on age-related mitochondrial dysfunction and oxidative stress in skeletal muscle [J]. J Physiol, 2016, 594(18): 5105-5123.

[46] GOMES MJ, MARTINEZ PF, PAGAN LU, et al. Skeletal muscle aging: influence of oxidative stress and physical exercise [J]. Oncotarget, 2017, 8(12): 20428-20440.

[47] BATSIS JA, MACKENZIE TA, JONES JD, et al. Sarcopenia, sarcopenic obesity and inflammation: Results from the 1999-2004 National Health and Nutrition Examination Survey [J]. Clin Nutr, 2016, 35(6): 1472-1483.

[48] BEYER I, METS T, BAUTMANS I. Chronic low-grade inflammation and age-related sarcopenia [J]. Curr Opin Clin Nutr Metab Care, 2012, 15(1): 12-22.

[49] ANDERSON LJ, LIU H, GARCIA JM. Sex Differences in Muscle Wasting [J]. Adv Exp Med Biol, 2017, 1043: 153-197.

[50] MESSIER V, RABASA-LHORET R, BARBAT-ARTIGAS S, et al. Menopause and sarcopenia: A potential role for sex hormones [J]. Maturitas, 2011, 68(4): 331-336.

[51] DEUTZ NE, BAUER JM, BARAZZONI R, et al. Protein intake and exercise for optimal muscle function with aging: recommendations from the ESPEN Expert Group [J]. Clin Nutr, 2014, 33(6): 929-936.

[52] VERLAAN S, ASPRAY TJ, BAUER JM, et al. Nutritional status, body composition, and quality of life in community-dwelling sarcopenic and non-sarcopenic older adults: A case-control study [J]. Clin Nutr, 2017, 36(1): 267-274.

[53] MONTERO-FERNáNDEZ N, SERRA-REXACH JA. Role of exercise on sarcopenia in the elderly [J]. Eur J Phys Rehabil Med, 2013, 49(1): 131-143.

[54] MARZETTI E, CALVANI R, TOSATO M, et al. Physical activity and exercise as countermeasures to physical frailty and sarcopenia [J]. Aging Clin Exp Res, 2017, 29(1): 35-42.

[55] CARTER CS, HOFER T, SEO AY, et al. Molecular mechanisms of life-and health-span extension: role of calorie restriction and exercise intervention [J]. Appl Physiol Nutr Metab, 2007, 32(5): 954-966.

[56] HOWARD C, FERRUCCI L, SUN K, et al. Oxidative protein damage is associated with poor grip strength among older women living in the community [J]. J Appl Physiol (1985), 2007, 103(1): 17-20.

[57] BUA E, JOHNSON J, HERBST A, et al. Mitochondrial DNA-deletion mutations accumulate intracellularly to detrimental levels in aged human skeletal muscle fibers [J]. Am J Hum Genet, 2006, 79(3): 469-480.

[58] FIGUEIREDO PA, MOTA MP, APPELL HJ, et al. The role of mitochondria in aging of skeletal muscle [J]. Biogerontology, 2008, 9(2): 67-84.

[59] LECKER SH. Ubiquitin-protein ligases in muscle wasting: multiple parallel pathways? [J]. Curr Opin Clin Nutr Metab Care, 2003, 6(3): 271-275.

[60] OGURA Y, MISHRA V, HINDI SM, et al. Proinflammatory cytokine tumor necrosis factor (TNF)-like weak inducer of apoptosis (TWEAK) suppresses satellite cell self-renewal through inversely modulating Notch and NF-κB signaling pathways [J]. J Biol Chem, 2013, 288(49): 35159-35169.

[61] CUTHBERTSON D, SMITH K, BABRAJ J, et al. Anabolic signaling deficits underlie amino acid resistance of wasting, aging muscle [J]. Faseb j, 2005, 19(3): 422-424.

[62] FUJITA S, DREYER HC, DRUMMOND MJ, et al. Nutrient signalling in the regulation of human muscle protein synthesis [J]. J Physiol, 2007, 582(Pt 2): 813-823.

[63] DREYER HC, VOLPI E. Role of protein and amino acids in the pathophysiology and treatment of sarcopenia [J]. J Am Coll Nutr, 2005, 24(2): 140s-145s.

[64] DRUMMOND MJ, DREYER HC, PENNINGS B, et al. Skeletal muscle protein anabolic response to resistance exercise and essential amino acids is delayed with aging [J]. J Appl Physiol (1985), 2008, 104(5): 1452-1461.

[65] Scientific concepts of functional foods in Europe. Consensus document [J]. Br J Nutr, 1999, 81 Suppl 1: S1-27.

[66] RENAUD B, BUDA M, LEWIS BD, et al. Effects of 5,6-dihydroxytryptamine on tyrosine-hydroxylase activity in central catecholaminergic neurons of the rat [J]. Biochem Pharmacol, 1975, 24(18): 1739-1742.

[67] MINGYI Y, BELWAL T, DEVKOTA HP, et al. Trends of utilizing mushroom polysaccharides (MPs) as potent nutraceutical components in food and medicine: A comprehensive review [J]. Trends in Food Science & Technology, 2019, 92: 94-110.

[68] LOHMANN JS, VON NUSSBAUM M, BRANDT W, et al. Rosellin A and B, two red diketopiperazine alkaloids from the mushroom Mycena rosella [J]. Tetrahedron, 2018, 74(38): 5113-5118.

[69] BAOSONG C, SIXIAN W, GAOQIANG L, et al. Anti-inflammatory diterpenes and steroids from peels of the cultivated edible mushroom Wolfiporia cocos [J]. Phytochemistry Letters, 2020, 36: 11-16.

[70] DUBOST N, OU B, BEELMAN R. Quantification of polyphenols and ergothioneine in cultivated mushrooms and correlation to total antioxidant capacity [J]. Food Chemistry, 2007, 105(2): 727-735.

[71] REVERBERI M, FABBRI AA, ZJALIC S, et al. Antioxidant enzymes stimulation in Aspergillus parasiticus by Lentinula edodes inhibits aflatoxin production [J]. Appl Microbiol Biotechnol, 2005, 69(2): 207-215.

[72] WANG W, CHEN K, LIU Q, et al. Suppression of tumor growth by Pleurotus ferulae ethanol extract through induction of cell apoptosis, and inhibition of cell proliferation and migration [J]. PLoS One, 2014, 9(7): e102673.

[73] VALVERDE ME, HERNáNDEZ-PéREZ T, PAREDES-LóPEZ O. Edible mushrooms: improving human health and promoting quality life [J]. Int J Microbiol, 2015, 2015: 376387.

[74] ZHANG Y, LI S, WANG X, et al. Advances in lentinan: Isolation, structure, chain conformation and bioactivities [J]. Food Hydrocolloids, 2011, 25(2): 196-206.

[75] WU Q, TAN Z, LIU H, et al. Chemical characterization of Auricularia auricula polysaccharides and its pharmacological effect on heart antioxidant enzyme activities and left ventricular function in aged mice [J]. Int J Biol Macromol, 2010, 46(3): 284-288.

[76] WAN H, HORVATH C. Behavior of soluble and immobilized acid phosphatase in hydro-organic media [J]. Biochim Biophys Acta, 1975, 410(1): 135-144.

[77] TOMINAGA Y, TSUJISAKA Y. Purification and some enzymatic properties of the chitosanase from Bacillus R-4 which lyses Rhizopus cell walls [J]. Biochim Biophys Acta, 1975, 410(1): 145-155.

[78] HULTBERG B, LUNDBLAD A, MASSON PK, et al. Specificity studies on alpha-mannosidases using oligosaccharides from mannosidosis urine as substrates [J]. Biochim Biophys Acta, 1975, 410(1): 156-163.

[79] YOSHIMURA F, SUZUKI T. Calcium-stimulated adenosine triphosphatase in the microsomal fraction of tooth germ from porcine fetus [J]. Biochim Biophys Acta, 1975, 410(1): 167-177.

[80] ELGART ES, GUSOVSKY T, ROSENBERG MD. Preparation and characterization of an enzymatically active immobilized derivative of myosin [J]. Biochim Biophys Acta, 1975, 410(1): 178-192.

[81] ZHANG T, RAYAMAJHI S, MENG G, et al. Edible mushroom consumption and incident hyperuricemia: results from the TCLSIH cohort study [J]. Food Funct, 2021, 12(19): 9178-9187.

[82] BA DM, ZHANG S, NISHITA Y, et al. Mushroom consumption and hyperuricemia: results from the National Institute for Longevity Sciences-Longitudinal Study of Aging and the National Health and Nutrition Examination Survey (2007-2018) [J]. Nutr J, 2023, 22(1): 62.

[83] BA DM, SSENTONGO P, BEELMAN RB, et al. Higher Mushroom Consumption Is Associated with Lower Risk of Cancer: A Systematic Review and Meta-Analysis of Observational Studies [J]. Adv Nutr, 2021, 12(5): 1691-1704.

[84] SHEN J, HE M, LV R, et al. Association of Mushrooms and Algae Consumption with Mortality among Chinese Older Adults: A Prospective Cohort Study [J]. Nutrients, 2022, 14(19): 3891.

[85] LEE DH, YANG M, GIOVANNUCCI EL, et al. Mushroom consumption, biomarkers, and risk of cardiovascular disease and type 2 diabetes: a prospective cohort study of US women and men [J]. Am J Clin Nutr, 2019, 110(3): 666-674.

[86] ZHANG J, GU Y, DONG X, et al. Association between edible mushrooms consumption and handgrip strength: A large-scale population based on the TCLSIH cohort study [J]. Clin Nutr, 2022, 41(6): 1197-1207.

[87] SILVA FF, DE OLIVEIRA GAC, COSTA HCM, et al. Royal Sun Culinary-Medicinal Mushroom, Agaricus brasiliensis (Agaricomycetes), Supplement in Training Capacity Improvement Parameters [J]. Int J Med Mushrooms, 2017, 19(9): 759-766.

[88] AKAMATSU N, NAKAJIMA H, ONO M, et al. Increase in acetyl CoA synthetase activity after phenobarbital treatment [J]. Biochem Pharmacol, 1975, 24(18): 1725-1727.

[89] KOMIYA Y, NAKAMURA T, ISHII M, et al. Increase in muscle endurance in mice by dietary Yamabushitake mushroom (Hericium erinaceus) possibly via activation of PPARδ [J]. Anim Sci J, 2019, 90(6): 781-789.

[90] YOU CL, LEE SJ, LEE J, et al. Inonotus obliquus upregulates muscle regeneration and augments function through muscle oxidative metabolism [J]. Int J Biol Sci, 2023, 19(15): 4898-4914.

[91] BESCóS R, SUREDA A, TUR JA, et al. The effect of nitric-oxide-related supplements on human performance [J]. Sports Med, 2012, 42(2): 99-117.

[92] SUZUKI T, MORITA M, KOBAYASHI Y, et al. Oral L-citrulline supplementation enhances cycling time trial performance in healthy trained men: Double-blind randomized placebo-controlled 2-way crossover study [J]. J Int Soc Sports Nutr, 2016, 13: 6.

[93] GLENN JM, GRAY M, WETHINGTON LN, et al. Acute citrulline malate supplementation improves upper- and lower-body submaximal weightlifting exercise performance in resistance-trained females [J]. Eur J Nutr, 2017, 56(2): 775-784.

[94] PETROVIC V, BUZADZIC B, KORAC A, et al. Antioxidative defence alterations in skeletal muscle during prolonged acclimation to cold: role of L-arginine/NO-producing pathway [J]. J Exp Biol, 2008, 211(Pt 1): 114-120.

[95] KUMAR R, NEGI PS, SINGH B, et al. Cordyceps sinensis promotes exercise endurance capacity of rats by activating skeletal muscle metabolic regulators [J]. J Ethnopharmacol, 2011, 136(1): 260-266.

[96] WASSER SP. Current findings, future trends, and unsolved problems in studies of medicinal mushrooms [J]. Appl Microbiol Biotechnol, 2011, 89(5): 1323-1332.

[97] MENG SJ, YU LJ. Oxidative stress, molecular inflammation and sarcopenia [J]. Int J Mol Sci, 2010, 11(4): 1509-1526.

[98] LIGUORI I, RUSSO G, CURCIO F, et al. Oxidative stress, aging, and diseases [J]. Clin Interv Aging, 2018, 13: 757-772.

[99] SU Y, LI L. Structural characterization and antioxidant activity of polysaccharide from four auriculariales [J]. Carbohydr Polym, 2020, 229: 115407.

[100] KHATUA S, ACHARYA K. Alkaline extractive crude polysaccharide from Russula senecis possesses antioxidant potential and stimulates innate immunity response [J]. J Pharm Pharmacol, 2017, 69(12): 1817-1828.

[101] JING H, LI J, ZHANG J, et al. The antioxidative and anti-aging effects of acidic- and alkalic-extractable mycelium polysaccharides by Agrocybe aegerita (Brig.) Sing [J]. Int J Biol Macromol, 2018, 106: 1270-1278.

[102] REN Z, LI J, SONG X, et al. The regulation of inflammation and oxidative status against lung injury of residue polysaccharides by Lentinula edodes [J]. Int J Biol Macromol, 2018, 106: 185-192.

[103] PAN W-J, DING Q-Y, WANG Y, et al. A bioactive polysaccharide TLH-3 isolated from Tricholoma lobayense protects against oxidative stress-induced premature senescence in cells and mice [J]. Journal of Functional Foods, 2018, 42: 159-170.