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The Health Revolution of *Atractylodes macrocephala*: Transition from Traditional Herb to Modern Health Products

Weiwei Huang
Physicov Med. Tech. Ltd., Zhejiang, Zhuji, 311800, Zhejiang, China
Corresponding email: weiwei.huang@pmtcl.org
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Abstract *Atractylodes macrocephala* (Bai Zhu) is a key herb in traditional Chinese medicine (TCM), long revered for its wide-ranging health benefits. This study provides a detailed overview of Bai Zhu's botanical characteristics and phytochemical constituents, analyzing its applications in TCM. It extensively discusses the herb's pharmacological activities, including anti-inflammatory, immunomodulatory, antioxidant, and gastrointestinal benefits, emphasizing the scientific evidence supporting these effects. The study also delves into innovative product formulations that promote the integration of Bai Zhu into contemporary health practices, such as supplements, teas, and extracts. Additionally, it addresses the challenges of regulatory barriers and the need for standardization and quality control. Recognizing the significant market potential and consumer acceptance of Bai Zhu-based products, the study proposes future directions for research and product development, highlighting the potential for new therapeutic applications and the importance of collaboration between traditional and modern medicine. The findings of this study will provide scientific support for the prevention and treatment of related diseases, fostering the application and development of Bai Zhu in the modern health industry.
Keywords *Atractylodes macrocephala*; Traditional medicine; Pharmacology; Health products; Polysaccharides; Anti-inflammatory; Anticancer

1 Introduction

Atractylodes macrocephala, a prominent herb in traditional Chinese medicine (TCM), has been revered for centuries for its extensive health benefits. Known for its potent medicinal properties, this herb has recently garnered significant attention in modern health sciences, transitioning from traditional remedies to contemporary health products.

Atractylodes macrocephala, commonly referred to as Baizhu, is a perennial herb native to China. It belongs to the Asteraceae family and is primarily cultivated in the Zhejiang, Anhui, and Hunan provinces. The rhizome of *Atractylodes macrocephala* is the most utilized part, known for its rich composition of bioactive compounds such as sesquiterpenoids, polysaccharides, and essential oils. These constituents are credited with various pharmacological activities, including anti-inflammatory, immunomodulatory, and gastrointestinal protective effects (Zhu et al., 2018; Gu et al., 2019; Qian et al., 2022).

In traditional Chinese medicine (TCM), *Atractylodes macrocephala* holds a significant place due to its diverse therapeutic properties. It is traditionally used to invigorate the spleen, replenish qi, and eliminate dampness. The herb is prescribed for conditions such as gastrointestinal dysfunction, cancer, osteoporosis, obesity, and fetal irritability (Zhu et al., 2018; Yang et al., 2021). Its efficacy in treating these ailments is supported by various pharmacological studies that highlight its anti-inflammatory, antioxidant, and immunomodulatory effects (Zhu et al., 2018; Bailly, 2020; Zhou et al., 2021). The herb's significance in TCM is deeply rooted in its ability to balance the body's internal environment, promoting overall wellness and preventing diseases. Its efficacy and safety, backed by centuries of empirical evidence, have made it an indispensable component of numerous traditional formulations (Zhu et al., 2018; Cheng et al., 2023).The herb's importance is further underscored by its inclusion in

numerous TCM formulations and its high market value, particularly those sourced from Zhejiang province, which are considered superior (Hu et al., 2019).

This study aims to comprehensively evaluate the medicinal value of *Atractylodes macrocephala* (Bai Zhu), bridging the knowledge gap between its traditional use and modern scientific validation. The research will delve into the pharmacological properties of Bai Zhu, revealing its bioactive components and their potential mechanisms of action. Emphasizing Bai Zhu as a key ingredient transitioning from traditional herbal medicine to modern health products, the study highlights its significant application potential in contemporary medical fields. The findings of this study will provide scientific evidence for the prevention and treatment of related diseases, promoting the application and development of Bai Zhu in the modern health industry.

2 Botanical Characteristics

2.1 Plant description

Atractylodes macrocephala Koidz., commonly known as Baizhu in China, is a perennial herbaceous plant belonging to the Asteraceae family. The plant is characterized by its thick, cylindrical rhizomes, which are the primary part used in traditional medicine. The leaves are alternate, simple, and have a serrated margin. The flowers are small, white to pale yellow, and are arranged in dense, terminal clusters. The plant typically grows to a height of 30-60 cm and has a robust root system that supports its medicinal properties (Zhu et al., 2018; Liu et al., 2022). The flowering season generally occurs from August to October (Cai et al., 2020; Wang et al., 2020).

2.2 Geographic distribution

Atractylodes macrocephala is native to East Asia, predominantly found in China, Korea, and Japan. In China, it is primarily cultivated in the Zhejiang, Anhui, Hunan, and Sichuan provinces. The plant thrives in well-drained, fertile soils and prefers mountainous or hilly terrains with sufficient sunlight and moderate climatic conditions. The natural distribution and cultivation practices have been influenced by the plant's adaptation to different ecological zones within these regions (Zhu et al., 2018; Li and Yang, 2020).

2.3 Cultivation and harvesting practices

The cultivation of *Atractylodes macrocephala* involves selecting fertile, well-drained soil with a neutral to slightly acidic pH. The soil must be rich in organic matter and well-drained to prevent waterlogging, which can damage the rhizomes. The plant is typically propagated through rhizome cuttings, which are planted in the spring. Optimal growth conditions include a temperate climate with moderate rainfall and temperatures ranging from 15 °C to 25 °C. The plants are spaced about 30 cm apart to allow for adequate growth and development of the rhizomes. The fields require regular weeding, and the plants are often grown in a rotation system to maintain soil fertility and prevent disease buildup.

Harvesting usually occurs in the autumn when the rhizomes have reached full maturity. The rhizomes are carefully dug out, cleaned, and dried in the sun or using low-temperature drying methods to preserve their medicinal properties. Proper post-harvest handling is crucial to maintain the quality and efficacy of the rhizomes, which are then processed into various forms such as powders, decoctions, and extracts for use in traditional and modern health products (Zhu et al., 2018; Liu et al., 2022; Qian et al., 2022).

3 Phytochemical Constituents

3.1 Major active compounds

Atractylodes macrocephala, commonly known as Baizhu, contains a variety of bioactive compounds that contribute to its medicinal properties. The major active compounds isolated from *A. macrocephala* include sesquiterpenoids, triterpenoids, polyacetylenes, coumarins, phenylpropanoids, flavonoids, flavonoid glycosides, steroids, benzoquinones, and polysaccharides (Zhu et al., 2018). Among these, sesquiterpenoids such as atractylone, atractylenolide I, II, and III are the most notable, known for their anti-inflammatory and anti-tumor activities (Gu et al., 2019; Jin et al., 2021). Polysaccharides from the rhizomes have shown significant immunomodulatory, gastroprotective, and anti-tumor effects (Liu et al., 2022). These compounds have been

shown to inhibit cell proliferation, induce cancer cell death, and modulate immune responses, making them significant in the treatment of various diseases (Bailly, 2020).

Liu et al. (2022) analyzed the chemical composition, biological activities, and applications of polysaccharides from *Atractylodes macrocephala* (Bai Zhu). Polysaccharides in Bai Zhu are key medicinal components, exhibiting various bioactivities such as immunomodulation, antitumor effects, gastrointestinal protection, liver protection, and blood glucose reduction. The study revealed that Bai Zhu polysaccharides are primarily composed of glucose, galactose, rhamnose, arabinose, mannose, galacturonic acid, and xylose. The research provided a detailed analysis of the structural characteristics of these polysaccharides, the impact of extraction and purification methods on their bioactivity, and validated their pharmacological effects through various experimental models, including both in vitro and in vivo models.

3.2 Extraction methods

The extraction of phytochemicals from *Atractylodes macrocephala* involves various methods to ensure the efficient isolation of its active compounds. Steam distillation is a commonly used technique for extracting essential oils. In this method, steam is passed through the plant material, causing the volatile compounds to vaporize. These vapors are then condensed and collected (Zhu et al., 2018). Another prevalent technique is solvent extraction, which uses solvents such as ethanol, methanol, or acetone to dissolve and extract non-volatile compounds like polysaccharides and flavonoids.

The process involves soaking the plant material in the solvent, followed by filtration and concentration of the extract (Zheng et al., 2018). This method is favored for its simplicity and effectiveness in extracting a broad range of phytochemicals. Supercritical fluid extraction (SFE) employs supercritical CO_2 as a solvent to extract essential oils and other lipophilic compounds. This technique is preferred for its ability to produce high-purity extracts without residual solvents (Si et al., 2021). Lastly, ultrasonic-assisted extraction enhances extraction efficiency by using ultrasonic waves to disrupt cell walls and facilitate the release of phytochemicals. This method is particularly effective for extracting high-molecular-weight compounds such as polysaccharides (Luo et al., 2022).

3.3 Chemical analysis techniques

To identify and quantify the phytochemical constituents of *Atractylodes macrocephala*, several advanced chemical analysis techniques are employed. High-Performance Liquid Chromatography (HPLC) is commonly used for the separation and quantification of non-volatile compounds such as polysaccharides, flavonoids, and phenolic acids. When coupled with UV or MS detectors, HPLC allows for precise analysis of these compounds (Lv et al., 2021). Gas Chromatography-Mass Spectrometry (GC-MS) is another technique used to analyze volatile compounds and essential oils. GC-MS provides detailed information on the chemical composition and molecular structure of these compounds (Gu et al., 2019). Nuclear Magnetic Resonance (NMR) Spectroscopy is employed to determine the structure of organic compounds by observing the behavior of nuclei in a magnetic field. This method is highly effective for elucidating the structures of complex molecules.

Additionally, Fourier Transform Infrared (FTIR) Spectroscopy is utilized to identify functional groups in compounds and to characterize polysaccharides and proteins. FTIR provides insights into the chemical bonds and molecular interactions within the extract (Feng et al., 2019). Collectively, these methods enable a comprehensive analysis of the phytochemical profile of *Atractylodes macrocephala*, facilitating a deeper understanding of its medicinal properties and potential therapeutic applications.

4 Traditional Uses in TCM

4.1 Historical context

Atractylodes macrocephala, known as Baizhu in China, has been a cornerstone of traditional Chinese medicine (TCM) for centuries. It has been employed for centuries in East Asia, particularly in China, Japan, and Korea, for its health benefits and medicinal properties. Historically, Baizhu has been used as a tonic agent to treat various ailments, including gastrointestinal dysfunction, cancer, osteoporosis, obesity, and fetal irritability (Zhu et al., 2018; Wang et al., 2019; Liu et al., 2022). The herb's use in TCM is deeply rooted in its ability to strengthen the

spleen and supplement Qi, which are fundamental concepts in TCM for maintaining health and treating diseases (Wang et al., 2019). The herb's longstanding application in TCM is a testament to its perceived efficacy and safety, rooted deeply in Chinese cultural practices and medical knowledge.

4.2 Common formulations and prescriptions

In TCM, *Atractylodes macrocephala* is often used in combination with other herbs to enhance its therapeutic effects. Common formulations include Si Jun Zi Tang (Four Gentlemen Decoction), which combines *Atractylodes macrocephala* with *Panax ginseng*, *Poria cocos*, and *Glycyrrhiza uralensis*. This classical prescription is widely used to strengthen the spleen and improve digestion. Another well-known formula is Shen Ling Bai Zhu San, which includes *Atractylodes macrocephala* along with *Poria cocos*, *Coix lacryma-jobi*, and *Dioscorea opposita* to treat chronic diarrhea and boost the spleen's function. Baizhu Shaoyao San, which combines *Atractylodes macrocephala* with *Paeonia lactiflora* and *Glycyrrhiza uralensis*, is used to relieve abdominal pain and muscle spasms (Zhu et al., 2018; Bailly, 2020). Another notable prescription is the use of Baizhu in various traditional herbal medicines that contain atractylenolides, which are sesquiterpenoids with antioxidant, anti-inflammatory, and anticancer properties (Bailly, 2020). These formulations are designed to boost Qi and improve gastrointestinal health, reflecting the herb's traditional use in TCM (Chen et al., 2018).

4.3 Therapeutic indications

Atractylodes macrocephala is traditionally indicated for several conditions in TCM. The herb is widely used to treat digestive disorders such as poor appetite, bloating, and diarrhea by strengthening the spleen and stomach. Cheng et al. (2023) explored the potential mechanisms by which *Atractylodes macrocephala* volatile oil (AVO) alleviates acute ulcerative colitis (UC) by modulating gut microbiota and their metabolism. The study used a dextran sulfate sodium (DSS)-induced C57BL/6 mouse model to simulate acute UC and treated the mice with AVO (Figure 1). The results showed that AVO effectively reduced symptoms of blood in the stool, colon damage, and inflammation in UC mice. Using 16S rRNA sequencing and metabolomics analysis, the study revealed that AVO significantly altered the composition of the gut microbiota. Specifically, AVO reduced the abundance of potentially harmful bacteria such as *Turicibacter*, *Parasutterella*, and *Erysipelatoclostridium*, while increasing the abundance of potentially beneficial bacteria such as *Enterorhabdus*, *Parvibacter*, and *Akkermansia*. Additionally, AVO regulated 56 metabolites related to gut microbiota metabolism, impacting 102 KEGG metabolic pathways. Several of these pathways are crucial for maintaining intestinal homeostasis, including amino acid metabolism, bile acid metabolism, and retinoic acid metabolism. These findings support the potential pharmacological mechanism of AVO in modulating gut microbiota composition and metabolism, providing scientific evidence for its use as a novel prebiotic for treating UC.

According to the study by Cheng et al. (2023), the mice treated with *Atractylodes macrocephala* volatile oil (AVO) showed reduced body weight loss, significantly lower rectal bleeding, and fecal consistency scores compared to the model group. Additionally, the colon length of the AVO-treated mice was restored. These results indicate that AVO effectively alleviates UC symptoms and improves the pathological state of the colon, demonstrating its potential efficacy as a treatment for UC. This provides experimental support for AVO as a novel therapeutic agent.

Atractylodes macrocephala is also effective in managing edema and water retention by helping to eliminate dampness from the body. Respiratory issues, including phlegm and related problems, are often treated with *Atractylodes macrocephala*, which helps clear the lungs and improve breathing. Furthermore, the herb is prescribed to combat general weakness and fatigue by replenishing qi (vital energy) and strengthening the spleen (Zhu et al., 2018; Qian et al., 2022). Additionally, Baizhu has been shown to have anti-hyperuricemic and anti-inflammatory effects in hyperuricemia and gouty arthritis models, further supporting its traditional use in treating chronic diseases (Qian et al., 2022).

Atractylodes macrocephala has a rich history in TCM, with its traditional uses and formulations being validated by modern pharmacological research. Its therapeutic indications are diverse, making it a valuable herb in both historical and contemporary medical practices.

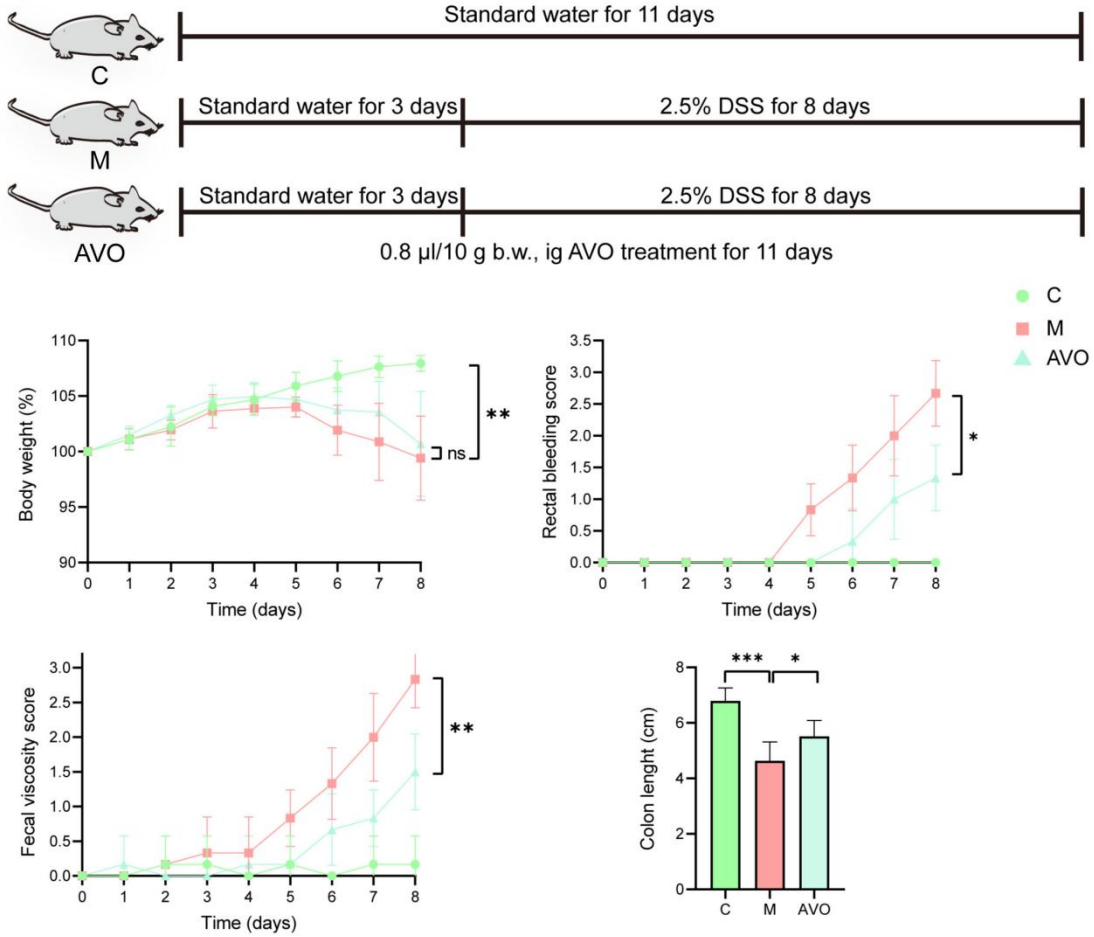

Figure 1 The curative effect of AVO on UC mice (Adopted from Cheng et al., 2023)

Image caption: (A) The method of animal grouping and treatment; (B) The change of body weight of each group after DSS challenge and AVO treatment; (C) The rectal bleeding score of each group after DSS challenge and AVO treatment; (D) The fecal viscosity score of each group after DSS challenge and AVO treatment. (E) The colon length of each group after DSS challenge and AVO treatment; $^{*}P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$, and ns means $P > 0.05$ (Adopted from Cheng et al., 2023)

5 Pharmacological Activities

5.1 Anti-inflammatory effects

Atractylodes macrocephala exhibits significant anti-inflammatory properties, which have been demonstrated through various studies. The essential oils and specific compounds such as atractylenolides from *A. macrocephala* have shown to inhibit the production of inflammatory mediators like nitric oxide (NO) and prostaglandin E2 (PGE2) in lipopolysaccharide (LPS)-stimulated macrophages (Jeong et al., 2019; Bailly, 2020; Wu et al., 2020).

Jeong et al. (2019) extracted and identified three compounds from *Atractylodes macrocephala*: 2-[(2E)-3,7-dimethyl-2,6-octadienyl]-6-methyl-2,5-cyclohexadiene-1,4-dione (compound 1), 1-acetoxy-tetradec-6E,12E-dien-8,10-diyne-3-ol (compound 2), and 1,3-diacetoxy-tetradec-6E,12E-dien-8,10-diyne (compound 3). These compounds exhibited concentration-dependent inhibition of nitric oxide (NO) and prostaglandin E2 (PGE2) production in lipopolysaccharide (LPS)-activated RAW 264.7 macrophages. Using Western blot and RT-PCR analyses, compounds 1-3 were shown to inhibit the protein and mRNA levels of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) (Figure 2). Additionally, these compounds suppressed the transcriptional activity of nuclear factor-κB (NF-κB) and its nuclear translocation in LPS-activated cells. The study results indicate that these compounds have potential anti-inflammatory effects and may be promising candidates for treating inflammatory diseases.

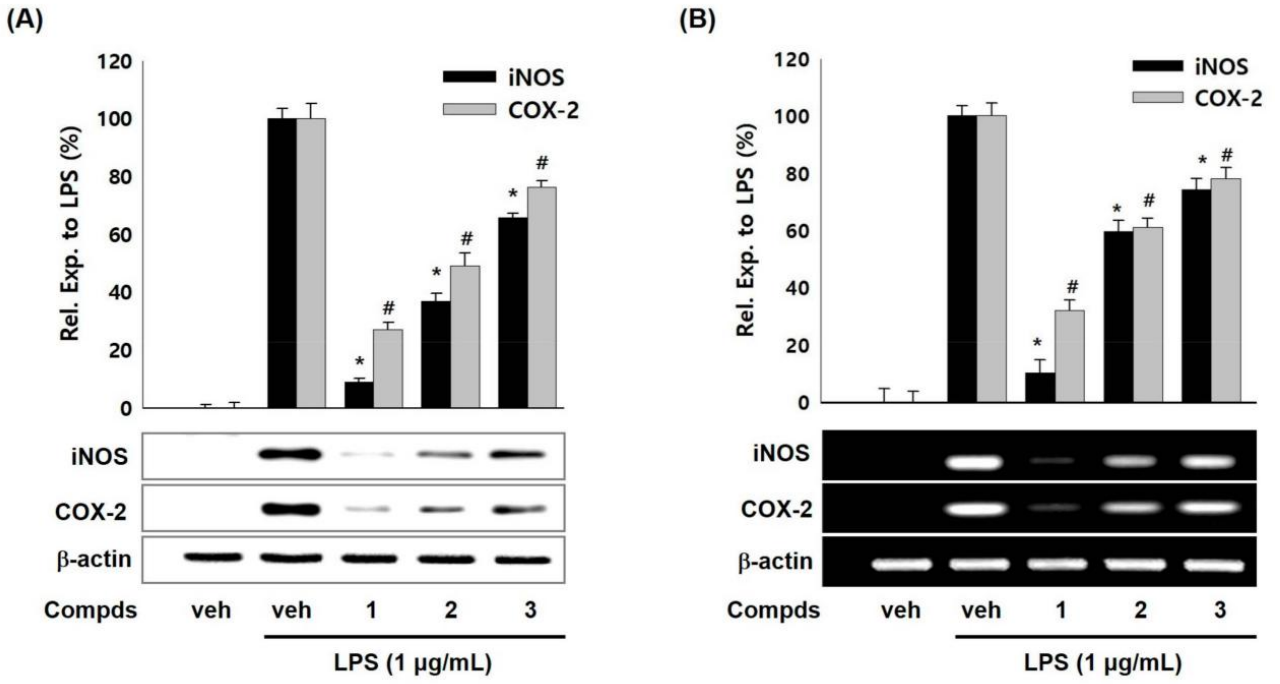

Figure 2 Effects of compounds 1–3 on the expression of LPS-induced iNOS/COX-2 protein and mRNA in RAW 264.7 macrophages (Adopted from Jeong et al., 2019)

Image caption: (A) Cells were activated with LPS (1 μg/mL) in presence or absence of compounds 1–3 (10 μM) for 20 h. Cell lysates were prepared and the iNOS, COX-2, and β-actin protein levels were determined by Western blotting; (B) Cells were treated with compounds 1–3 (10 μM) and/or LPS (1 μg/mL) for 6 h. The mRNA levels for iNOS, COX-2, and β-actin were determined by RT-PCR. The relative intensity of iNOS/COX-2 to β-actin bands was measured by densitometry. Veh means vehicle. The values represented mean ± S.D. of three individual experiments. $^{*}p < 0.01$ indicate significant difference (* iNOS, COX-2) from LPS alone (Adopted from Jeong et al., 2019)

Jeong et al. (2019) analyzed protein samples using Western blotting, showing that LPS significantly increased the protein expression of iNOS and COX-2. However, treatment with compounds 1-3 resulted in a decrease in iNOS and COX-2 protein levels (Figure 2A). This indicates that these compounds can effectively inhibit the expression of key inflammatory mediators induced by LPS during inflammatory responses. Additionally, RT-PCR was used to measure the levels of iNOS and COX-2 mRNA in cells treated with LPS and compounds 1-3. Compared to LPS treatment alone, cells treated with compounds 1-3 showed a significant decrease in iNOS and COX-2 mRNA levels (Figure 2B). These results further confirm that these compounds inhibit the expression of iNOS and COX-2 at the transcriptional level, potentially reducing inflammation mediated by these enzymes. By validating both protein and gene expression, the study clearly demonstrates the effectiveness of compounds 1-3 in inhibiting key inflammatory pathways in macrophages. This reinforces the potential of these compounds as candidates for anti-inflammatory therapy.

Additionally, these compounds suppress the expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2) at both protein and mRNA levels, and inhibit the nuclear translocation of nuclear factor-kappa B (NF-κB), a key regulator of inflammation (Jeong et al., 2019; Yang et al., 2020). The anti-inflammatory effects are also linked to the modulation of cytokine production, including the reduction of tumor necrosis factor-alpha (TNF-α) and interleukins (IL-1β, IL-6) (Yang et al., 2020; Qian et al., 2022).

5.2 Immunomodulatory properties

A. macrocephala has been shown to possess immunomodulatory properties, which are beneficial in enhancing the immune response. Polysaccharides from *A. macrocephala* can activate T lymphocytes and alleviate immunosuppression induced by cyclophosphamide through the novel_mir2/CD28/AP-1 signaling pathway (Li et

al., 2021). Additionally, atractylenolides have been reported to modulate immune responses by affecting the production of inflammatory cytokines and influencing macrophage polarization (Bailly, 2020; Qian et al., 2022). These immunomodulatory effects suggest potential applications in managing immune-related disorders and enhancing overall immune function.

5.3 Antioxidant activities

The antioxidant properties of *Atractylodes macrocephala* are largely due to its rich content of flavonoids and other polyphenolic compounds. These compounds exhibit strong free radical scavenging activities, thereby protecting cells from oxidative stress and related damage. Studies have shown that the essential oils and extracts from *Atractylodes macrocephala* significantly reduce reactive oxygen species (ROS) levels and enhance the activities of antioxidant enzymes, contributing to its protective effects against oxidative damage (Hwang et al., 2022; Li et al., 2023).

5.4 Gastrointestinal benefits

A. macrocephala has been traditionally used to treat gastrointestinal disorders, and modern research supports its efficacy in this area. The herb has been shown to improve gastrointestinal function by enhancing motility and reducing inflammation in the gut (Zhu et al., 2018; Wang et al., 2019). The polysaccharides from *Atractylodes macrocephala* play a critical role in these effects by modulating gut microbiota and enhancing intestinal health (Yang et al., 2022; Cheng et al., 2023). Studies have demonstrated that *A. macrocephala* can ameliorate chemotherapy-induced diarrhea by modulating gut microbiota and reducing intestinal inflammation (Wang et al., 2019). These gastrointestinal benefits are likely due to the combined effects of its anti-inflammatory, antioxidant, and immunomodulatory properties.

Choi et al. (2024) focused on the therapeutic effects of *Atractylodes macrocephala* Koidz (AMK) on human gastric cancer. Using AGS human gastric adenocarcinoma cells, the researchers investigated the impact of AMK extracts on cell apoptosis and xenograft tumors. The study found that AMK extracts reduced the viability of AGS cells, increased the proportion of sub-G1 phase cells and mitochondrial membrane potential, promoted the generation of reactive oxygen species (ROS), activated caspase activity, and regulated mitogen-activated protein kinase (MAPK). Additionally, AMK extracts significantly inhibited AGS cell migration and the growth of three-dimensional tumor spheres (Figure 3). In vivo experiments demonstrated that AMK extracts effectively suppressed the growth of AGS xenograft tumors in NSG mice. The results suggest that AMK exhibits anti-gastric cancer potential by promoting cell cycle arrest and inducing apoptosis, providing a new approach for gastric cancer treatment.

Choi et al. (2024) used a wound healing assay to evaluate the effect of AMK extracts on the migration ability of AGS cells. The results showed that after 24 hours of treatment with AMK extracts, the migration ability of AGS cells was significantly reduced. This indicates that AMK extracts can effectively inhibit the migration of tumor cells, which is a crucial factor in tumor metastasis. Additionally, the study further validated the anticancer potential of AMK extracts using a three-dimensional multicellular tumor spheroid (MTS) model. After six days of AMK extract treatment, optical microscopy revealed a marked reduction in the growth of the tumor spheroids. The decrease in tumor spheroid volume further confirmed the ability of AMK extracts to inhibit AGS cell proliferation in vitro. Through these experiments, the study demonstrated that AMK extracts exhibit antitumor activity by affecting cell migration and interfering with the growth of tumor spheroids. These findings support the potential of AMK extracts as an anticancer treatment, particularly in inhibiting tumor spread and metastasis. This provides experimental evidence for the use of AMK extracts as a therapeutic agent for gastric cancer, especially in preventing tumor dissemination and metastasis.

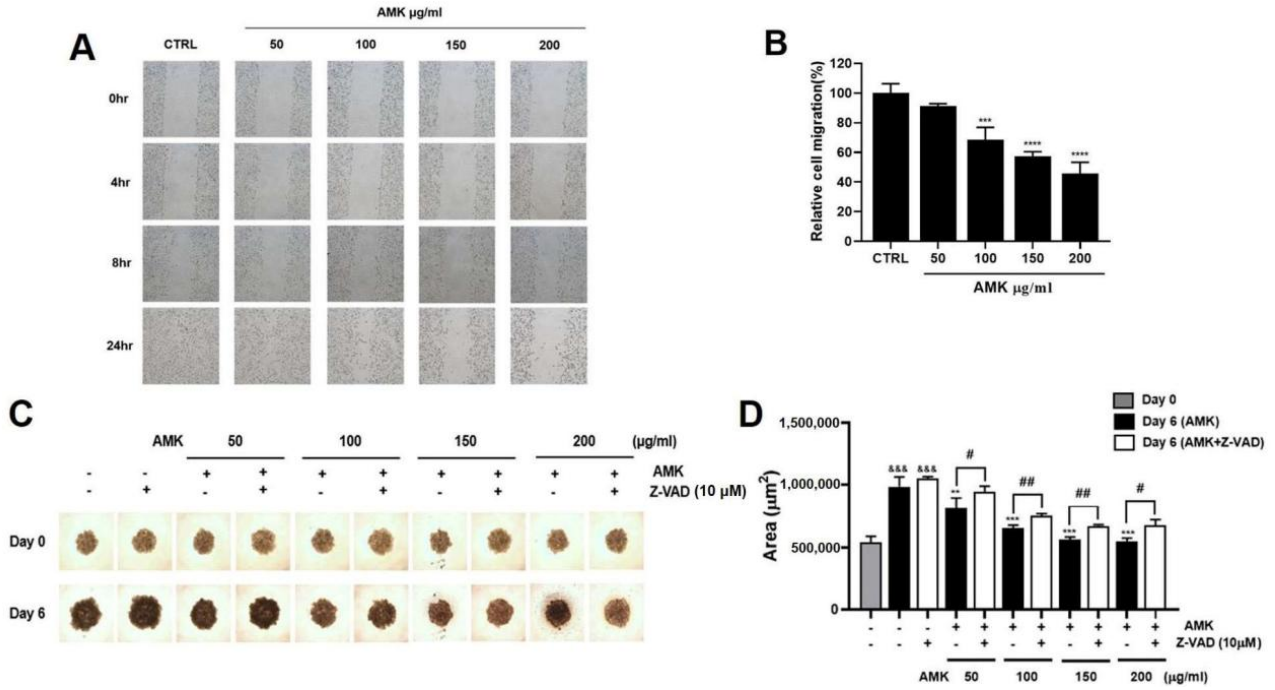

Figure 3 Effects of AMK extract on the migratory capacity and the growth within a 3D spheroid model in AGS cells (Adapted from Choi et al., 2024)

Image caption: (A) Cells were imaged at 0, 4, 8, and 24 h after treatment with various AMK extract concentrations; (B) After 24 h treatment with AMK extract (50, 100, 150, and 200 μg/mL), the results showed a significant decrease in mobility. Spheroids were allowed to form over three days and then treated with AMK extract for six days using pre-treatment options including or excluding 10 μM z-VAD for 1 h before AMK extract treatment; (C) It shows a representative spheroid captured by phase contrast microscopy nine days after initial cell seeding (6 days after drug treatment); (D) The spheroid size was quantified using NIS-Elements BR software (Version 4.3). Results are presented as the means ± standard error. ** $p < 0.01$, *** $p < 0.001$ and **** $p < 0.0001$ compared to untreated controls. There is a significant size difference between spheroids on day 0 and day 6 of drug treatment ($^{\&\&\&}$ $p < 0.001$) and spheroids without AMK extract treatment and spheroids treated with AMK extract have a significant difference. Differences between the Z-VAD treated group and the non-Z-VAD treated group are indicated as $^{\#}$ $p < 0.05$, $^{\#\#}$ $p < 0.01$. AMK: *Atractylodes macrocephala* Koidz. CTRL: Control (Adapted from Choi et al., 2024)

5.5 Other notable pharmacological effects

Beyond its anti-inflammatory, immunomodulatory, and antioxidant activities, *Atractylodes macrocephala* exhibits various other pharmacological effects. These include anti-tumor properties, as demonstrated by the induction of apoptosis in cancer cells via mitochondrial pathways and the modulation of key signaling pathways (Chan et al., 2020). The herb also shows potential in treating metabolic disorders, such as hyperuricemia, by inhibiting enzymes involved in uric acid production and improving renal function (Qian et al., 2022). Additionally, A. macrocephala has been reported to have neuroprotective, anti-osteoporotic, and anti-aging activities, further highlighting its potential as a versatile therapeutic agent (Zhu et al., 2018).

Atractylodes macrocephala is a multifaceted medicinal herb with a wide range of pharmacological activities, including anti-inflammatory, immunomodulatory, antioxidant, gastrointestinal, and other notable effects. These properties support its traditional uses and suggest potential applications in modern health products. Further research is warranted to fully elucidate the molecular mechanisms and optimize its therapeutic potential.

6 Modern Health Product Development

6.1 Transition from traditional herb to modern applications

Baizhu has been utilized for centuries in East Asian medicine to treat a variety of ailments, including gastrointestinal dysfunction, cancer, osteoporosis, and obesity (Zhu et al., 2018). The transition from traditional herb to modern health products has been driven by extensive research into its phytochemistry and pharmacology.

Over 79 chemical compounds have been identified in *A. macrocephala*, including sesquiterpenoids, triterpenoids, and polysaccharides, which contribute to its diverse pharmacological effects such as anti-tumor, anti-inflammatory, and neuroprotective activities (Zhu et al., 2018). This scientific validation has paved the way for the development of modern applications, ensuring that the therapeutic benefits of *A. macrocephala* are accessible in more convenient and standardized forms.

6.2 Innovation in product formulations

The versatility of *Atractylodes macrocephala* has spurred innovation in its product formulations. Today, it is available in various forms, such as dietary supplements, teas, and herbal extracts. Supplements typically include capsules or tablets standardized to contain specific concentrations of active compounds. Polysaccharide extracts from *A. macrocephala* have shown significant potential in promoting intestinal health by stimulating the migration of intestinal epithelial cells, which is crucial for healing intestinal injuries (Zeng et al., 2018).

Herbal teas incorporating *Atractylodes macrocephala* are marketed for their digestive and calming properties, leveraging the herb's traditional uses. Extracts, available as tinctures or powders, offer concentrated doses of the active ingredients and are often included in formulations for their convenience and efficacy. These innovative products ensure that the beneficial properties of *Atractylodes macrocephala* are accessible to a broader audience in forms that fit modern lifestyles (Gu et al., 2019; Lv et al., 2021).

Additionally, the essential oils of *A. macrocephala*, when combined with other traditional herbs like *Panax ginseng*, have demonstrated efficacy in ameliorating chemotherapy-induced diarrhea by modulating gut microbiota (Wang et al., 2019). These findings have encouraged the development of new formulations that maximize the synergistic effects of *A. macrocephala*'s bioactive compounds.

6.3 Integration into functional foods and beverages

In addition to supplements and extracts, *Atractylodes macrocephala* has been integrated into functional foods and beverages, enhancing their nutritional and therapeutic value. Functional foods, such as fortified cereals and snack bars, incorporate *Atractylodes macrocephala* to leverage its immune-boosting and anti-inflammatory properties. These products are designed to offer health benefits beyond basic nutrition, making them an attractive option for health-conscious consumers (Feng et al., 2020; Jin et al., 2021).

Beverages, including herbal teas and health drinks, utilize *Atractylodes macrocephala* for its calming and digestive benefits. These products are often marketed as wellness beverages, aimed at reducing stress, improving digestion, and enhancing overall well-being. The inclusion of *Atractylodes macrocephala* in these functional foods and beverages not only diversifies its applications but also ensures its continued relevance in modern health practices (Chan et al., 2020; Yang et al., 2022).

The successful transition of *Atractylodes macrocephala* from a traditional herb to a modern health product highlights the synergy between ancient wisdom and contemporary science, ensuring its place in the future of health and wellness.

7 Clinical Applications and Research

7.1 Summary of clinical studies

Atractylodes macrocephala, a traditional Chinese medicinal herb, has been extensively studied for its therapeutic potential in various clinical settings. Numerous clinical studies have demonstrated its benefits in treating gastrointestinal disorders, inflammatory conditions, and metabolic diseases. For instance, a meta-analysis evaluated the effectiveness of *Atractylodes macrocephala* in treating chronic constipation and found it significantly superior to other treatments, highlighting its safety and efficacy (Chen et al., 2018). Studies have shown that *Atractylodes macrocephala* possesses anti-hyperuricemia and anti-inflammatory properties, effectively reducing serum uric acid levels and inflammation in rat models of gouty arthritis (Qian et al., 2022). Additionally, bioinformatics and network pharmacology studies have identified key active substances and target genes, further elucidating its role in treating digestive tract diseases and various tumors (Cheng et al., 2023).

7.2 Efficacy and safety profiles

The efficacy of *Atractylodes macrocephala* has been supported by multiple pharmacological investigations. The herb's anti-inflammatory and immunomodulatory properties have been well-documented, with studies showing significant reductions in inflammatory markers such as TNF-α, IL-1β, and IL-6 (Gu et al., 2019; Yang et al., 2022). Specifically, in hyperuricemia and gouty arthritis models, it effectively reduced serum uric acid levels and improved renal injury and fibrosis by inhibiting adenosine deaminase (ADA) and xanthine oxidase (XOD) levels (Qian et al., 2022). Safety profiles indicate that while *Atractylodes macrocephala* is generally well-tolerated, further research is needed to fully understand its long-term toxicity and clinical efficacy (Zhu et al., 2018).

7.3 Potential health benefits supported by clinical evidence

Atractylodes macrocephala has shown potential in various clinical applications, supported by robust clinical evidence. One of its primary benefits is in gastrointestinal health. The herb has been traditionally used to treat digestive issues, and clinical evidence supports its use in improving conditions such as chronic constipation and ulcerative colitis. Studies have shown that polysaccharides from *Atractylodes macrocephala* ameliorate DSS-induced colitis by regulating the Th17/Treg cell balance, indicating its potential in managing inflammatory bowel diseases (Yang et al., 2022). In addition to its gastrointestinal benefits, *Atractylodes macrocephala* is well-known for its anti-inflammatory and immunomodulatory effects. The herb has been shown to inhibit NF-κB activation and reduce pro-inflammatory cytokines, making it effective in treating inflammatory conditions and modulating the immune response (Gu et al., 2019).

Furthermore, clinical studies have highlighted the potential of *Atractylodes macrocephala* in managing metabolic disorders such as hyperuricemia and gout. The herb reduces serum uric acid levels and improves renal function, which is beneficial for patients with gouty arthritis.

8 Challenges and Opportunities

8.1 Regulatory hurdles

The transition of *Atractylodes macrocephala* from a traditional herb to a modern health product faces significant regulatory challenges. Traditional Chinese medicines (TCMs) like *A. macrocephala* are often subject to stringent regulatory scrutiny when introduced into new markets. Regulatory bodies require comprehensive data on safety, efficacy, and quality, which can be difficult to compile given the historical and ethnopharmacological nature of these products. For instance, the diverse pharmacological activities of *A. macrocephala*, such as its anti-inflammatory and anti-hyperuricemic effects, need to be validated through rigorous clinical trials to meet regulatory standards (Zhu et al., 2018; Qian et al., 2022). Additionally, the complexity of its chemical composition, including polysaccharides and other bioactive compounds, poses challenges in standardizing and ensuring consistent quality across different batches (Liu et al., 2022).

8.2 Standardization and quality control

Standardization and quality control are critical for the successful commercialization of *A. macrocephala*. The herb contains a wide array of chemical compounds, including sesquiterpenoids, polysaccharides, and polyacetylenes, which contribute to its therapeutic effects (Zhu et al., 2018). Ensuring the consistency of these compounds in commercial products is challenging due to variations in cultivation, harvesting, and processing methods. Advanced analytical techniques and robust quality control protocols are necessary to monitor the levels of active constituents and to detect any contaminants or adulterants. Moreover, the development of standardized extracts with defined chemical profiles can help in achieving uniformity and reliability in therapeutic outcomes (Liu et al., 2022).

8.3 Market potential and consumer acceptance

Despite the challenges, the market potential for *A. macrocephala* as a modern health product is substantial. The growing interest in natural and plant-based remedies, coupled with the herb's diverse pharmacological activities, positions it well in the health and wellness market. *A. macrocephala* has demonstrated significant therapeutic benefits, including immunomodulatory, antitumor, gastroprotective, and hepatoprotective effects, which can

appeal to a broad consumer base (Zhu et al., 2018; Liu et al., 2022). However, consumer acceptance will depend on effective marketing strategies that highlight its traditional use and scientific validation. Educating consumers about the benefits and safety of *A. macrocephala*, supported by clinical evidence, can enhance its acceptance and integration into modern health regimens (Qian et al., 2022).

In conclusion, while there are notable challenges in the regulatory, standardization, and quality control aspects of transitioning *A. macrocephala* from a traditional herb to a modern health product, the opportunities in terms of market potential and consumer acceptance are promising. Addressing these challenges through rigorous scientific research and strategic marketing can pave the way for the successful commercialization of *A. macrocephala*.

9 Future Directions

9.1 Emerging research areas

The future research on *A. macrocephala* (AM) should focus on several emerging areas to fully harness its therapeutic potential. One promising area is the detailed investigation of the molecular mechanisms underlying the pharmacological effects of AM. While current studies have identified various bioactive compounds such as sesquiterpenoids, polysaccharides, and polyacetylenes, the precise molecular pathways through which these compounds exert their effects remain largely unexplored (Zhu et al., 2018). Additionally, the role of AM in modulating gut microbiota and its implications for gastrointestinal health and systemic diseases is another burgeoning field that warrants further exploration (Liu et al., 2022).

9.2 Potential new applications

The pharmacological versatility of AM suggests numerous potential new applications. For instance, its anti-hyperuricemic and anti-inflammatory properties could be leveraged to develop novel treatments for gout and other inflammatory conditions (Qian et al., 2022). Moreover, the immunomodulatory and antitumor activities of AM polysaccharides indicate their potential as adjunct therapies in cancer treatment. The unique chemical structure of AM polysaccharides also opens up possibilities for their use as natural plant supplements and vaccine adjuvants, which could significantly enhance immune responses.

9.3 Collaboration between traditional and modern medicine

To maximize the therapeutic benefits of AM, a collaborative approach between traditional and modern medicine is essential. Integrating traditional knowledge with contemporary scientific research can lead to the development of standardized AM-based health products with proven efficacy and safety profiles. This collaboration can also facilitate the comprehensive evaluation of AM's medicinal quality and its long-term clinical efficacy. Furthermore, interdisciplinary research involving pharmacologists, botanists, and clinicians can help bridge the gap between traditional uses and modern applications, ensuring that AM's full therapeutic potential is realized.

10 Concluding Remarks

A. macrocephala, a traditional Chinese medicinal herb, has demonstrated a wide range of pharmacological activities, including anti-inflammatory, antioxidant, anticancer, and immunomodulatory effects. The primary bioactive compounds identified in *A. macrocephala* include sesquiterpenoids, polysaccharides, and polyacetylenes, which contribute to its therapeutic potential. Studies have shown that *A. macrocephala* can effectively treat gastrointestinal dysfunction, cancer, osteoporosis, obesity, and other chronic diseases. Additionally, the herb has been found to modulate gut microbiota, which may play a role in its efficacy against conditions like ulcerative colitis. The processing methods of *A. macrocephala* also influence its pharmacological properties, with different methods yielding varying levels of bioactive compounds.

Future research should focus on elucidating the molecular mechanisms and structure-function relationships of the bioactive compounds in *A. macrocephala*. Understanding these mechanisms will help in optimizing the therapeutic use of the herb and developing new health products. Additionally, more studies are needed to explore the synergistic and antagonistic effects of these compounds. Investigating the long-term toxicity and clinical efficacy of *A. macrocephala* will be crucial for its safe application in modern medicine. The potential of *A. macrocephala* in modulating gut microbiota also opens new avenues for research in treating gastrointestinal

diseases and other related conditions. Furthermore, the impact of different processing methods on the efficacy of *A. macrocephala* should be studied to standardize its use in health products.

The transition of *A. macrocephala* from a traditional herb to a modern health product marks a significant milestone in the integration of traditional and modern medicine. The extensive pharmacological activities and therapeutic potential of *A. macrocephala* validate its traditional uses and highlight its importance in contemporary health care. As research continues to uncover the complex interactions and benefits of its bioactive compounds, *A. macrocephala* is poised to become a cornerstone in the development of new, effective health products. The ongoing health revolution of *A. macrocephala* underscores the value of traditional medicinal knowledge and its potential to contribute to modern medical advancements.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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