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Anti-pathogenic effects of *Artemisia argyi* and its applications: the past, present, and future

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Review

Anti-pathogenic effects of *Artemisia argyi* and its applications: the past, present, and future

Le Chen[a,b,Δ], Xinran Deng[a,b,c,Δ], Xiang Xiao[a,b,Δ], Jinglin Yang[a,b], Xiaoying Hou[d,a,*], Dahui Liu[a,b,*], Hongzhi Du[a,b,e,f,*]

[a] *School of Pharmacy, Hubei University of Chinese Medicine, Wuhan 430065, China*
[b] *Hubei Shizhen Laboratory, Hubei University of Chinese Medicine, Wuhan 430065, China*
[c] *State Key Laboratory of Natural Medicines, China Pharmaceutical University, Nanjing 211198, China*
[d] *School of Medicine, Jianghan University, Wuhan 430056, China*
[e] *Center of Traditional Chinese Medicine Modernization for Liver Diseases, Hubei University of Chinese Medicine, Wuhan 430065, China*
[f] *Hubei Health Industry Development Research Center, Hubei University of Chinese Medicine, Wuhan 430065, China*

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ABSTRACT

As a globally known medicinal and aromatic herb, *Artemisia argyi* (*A. argyi*) has excellent health benefit and economic value, especially in the field of anti-pathogenic microorganisms. At present, pathogens such as parasites, fungi, bacteria, and viruses, pose a serious threat to human health and environmentally friendly, becoming a substantial global medical burden. Researchers worldwide are focusing on developing natural antibacterial drugs. Thereinto, we collected data on the pharmacological effects of *A. argyi* on pathogenic microorganisms from ancient Chinese herbal texts and medical books, and the publications referring to the effects of *A. argyi* on bacteria, fungi, viruses, and other pathogenic microorganisms from 2005 to 2025. Simultaneously, patent searches were conducted to explore the development and utilization of the anti-pathogenic activity of *A. argyi* in various fields over the past 20 years. We found that *A. argyi* has excellent efficacy and extensive practical applications against pathogenic microorganisms. Modern studies have confirmed its inhibitory effects on common bacteria such as *Escherichia coli* and *Staphylococcus aureus*; human and crop pathogenic fungi such as *Candida albicans* and *Aspergillus niger*; and viruses such as herpes zoster virus, respiratory syncytial virus, and hepatitis B virus. Moreover, the development and application of anti-pathogenic activity of *A. argyi* are broad. In brief, this study provides perspectives for fully utilizing the advantages of *A. argyi* in anti-pathogenic effect, and supporting its potential for functional product development and applications in the fields of daily health products, agriculture and the pharmaceutical industry.

1. Introduction

Asteraceae is the largest family of plants, whereas *Artemisia* is the largest plant genus. At present, approximately 300 kinds of *Artemisia* plants are in the Asteraceae family, which mainly exist in the temperate, cold temperate, and subtropical regions of Asia, Europe and North America. *Artemisia* plants are commonly used as medicinal plants because of their rich active components, such as terpenoids, flavonoids, and phenolic acids. Several medicinal plants belonging to *Artemisia* genus are used worldwide. In 2015, the Chinese scientist Youyou Tu won the Nobel Prize in Physiology or Medicine for the discovery of artemisinin from *Artemisia annua* [1], which attracted global attention to other species of the *Artemisia* genus, including the globally renowned medicinal plant *Artemisia argyi*.

A. argyi is widely distributed in the northern temperate regions, especially in Asia, Europe, and North America. It has been used in China for over 3000 years, firstly recorded in *Shi Jing* (a famous Chinese classical literature) near 1100 B.C. and recognized as medicine in *Ming Yi Bie Lu* during the Han and Wei dynasties. It has since been recorded in various medical and prescription books across different dynasties. Meanwhile, *A. argyi*, as the medicine and food homology materials, was first recorded in *Materia Medica for Dietotherapy* in Tang Dynasty. In Asian countries such as China, North Korea, South Korea and Japan, it is often used in the production of noodles and pastries. Furthermore, *A. argyi* is widely used for moxibustion, which is popular in Asian. At present, acupuncture and moxibustion is practiced in 183 countries, and was listed as World Intangible Cultural Heritage in 2010. Subsequently, traditional Chinese medicine therapy including moxibustion, was recommended by the World Health Organization in 2019. *A. argyi* contains hundreds of active substances such as flavonoids, phenolic acids and essential oils, which have long been used in traditional Chinese medicine prescriptions, Chinese patent medicines, and health medicine products. Mod-

* Corresponding author.
E-mail addresses: jhhxy2021@jhun.edu.cn (X. Hou); liudahui@hbucm.edu.cn (D. Liu); dhz3163@hbucm.edu.cn (H. Du)
Δ These authors contributed equally to this work.

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ern pharmacological research has confirmed that *A. argyi* has antibacterial, anti-inflammatory, antitumor, and multiple organ-protective effects. Our group has been conducting systematic research on the resources, chemical compositions, and pharmacological effects of *A. argyi* for years, and has published dozens of papers [2-4]. Based on the medicinal research, we found that *A. argyi* has excellent efficacy and extensive practical applications in resisting pathogenic microorganisms.

Pathogens such as parasites, fungi, bacteria, and viruses, pose a serious threat to human health and have become a substantial global medical burden. Currently, drug resistance occurs extensively in traditional chemotherapy drugs because of the singleness of the action target [5,6]. This has led to the emergence of numerous superbugs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), multidrug-resistant *Streptococcus pneumoniae* (MDRSP), and multidrug-resistant *Mycobacterium tuberculosis* (MDR-TB), posing a major challenge in clinical anti-infection treatment [5, 7, 8]. Researchers worldwide have long attempted to identify effective antimicrobial drugs. Natural source products are now widely recognized as important sources of drugs, such as artemisinin, penicillin, griseofulvin, and other natural antimicrobial drugs. Therefore, based on long-term research and exploration, integrated with herbal textual research and modern literature research, our team has summarized the latest progress in the development and application of *A. argyi*' s anti-pathogenic effects (Fig. 1). This provides scientific support for its practical application and offers insights for the development of natural pharmaceutical products, daily health products, and the products used in agriculture.

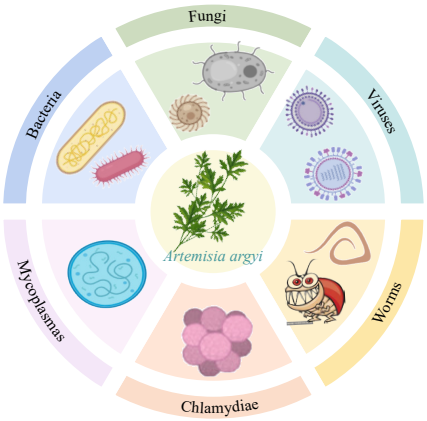


Fig. 1 *A. argyi*, a globally known medicinal and aromatic herb, can inhibit many kinds of pathogens (bacteria, viruses, fungi, worms, chlamydiae, etc.).

2. Herbal textual research on anti-pathogenic activity of *A. argyi*

A. argyi, also known as ice table, moxibustion grass, and medicine grass, has been recorded in various herbal works throughout Chinese history. It was first formally recorded as a medicine in the *Ming Yi Bie Lu* by Hongjing Tao during the Liang Dynasty. *Ming Yi Bie Lu* records "Crushing the *A. argyi* into juice could stop injury bleeding and kill roundworms". This may be the earliest konwn record of *A. argyi* having an anti-pathogenic effect. Later, in the Eastern Jin Dynasty, *Zhou Hou Bei Ji Fang* documented the anti-roundworm and antiviral properties of *A. argyi*. During the Tang Dynasty, several works, including *Xin Xiu Ben Cao*, *Wai Tai Mi Yao*, *Qian Jing Yi Fang*, and *Zhou Hou Bei Ji Fang* recorded its anti-pathogenic effects, indicating that *A. argyi* is recommended by doctors. Subsequent classic herb works of the Song Dynasty , such as *Tai Ping Sheng Hui Fang* and *Sheng Ji Zong Lu* also recorded the anti-pathogenic effects of *A. argyi*. *Ben Cao Gang Mu* in the Ming Dynasty is a work of natural history with worldwide influence, and is praised as "the great book of oriental medicine" by foreign scholars. It contains the most detailed records of the antiviral, antibacterial, antifungal and anti-parasitic pathogens effect of *A. argyi* (Fig. 2). The anti-pathogenic effects of *A. argyi* is extensively recognized in ancient Chinese herbs, and it is widely used in clinical practice.

In fact, *A. argyi* has been used since ancient times to combat pathogenic microorganisms and treat various diseases. *Zhou Hou Bei Ji Fang*, recorded that "Four moxibustions are used at the four angles of the patient' s bed to treat malaria, epidemics, and warm toxins". "*A. argyi* to exorcise evil spirits" was once regarded as a superstition. However, modern medicine has revealed that "evil spirits" include viruses, bacteria and other microorganisms. At the same time, as a folk food, *A. argyi* is still used for dietary health care. Classical literature on *Materia Medica for Dietotherapy* recorded that "Tender *A. argyi* picked in the spring for food, or mixed with flour for wonton and eaten with rice could cure all pathogenic factors and alleviate dysentery". This study also provides theoretical support for the use of *A. argyi* in therapeutic diets. According to ancient Chinese herbal works, *A. argyi* has been used to treat infectious diseases for hundreds of years. However, since the specific pathogenic microorganisms for diseases were not discovered until the past 100 years, the antimicrobial spectrum of *A. argyi* for infectious diseases in ancient China cannot be accurately determined. Based on modern pathological studies, it is speculated that *A. argyi* may inhibit microorganisms such as *Vibrio cholerae*, *Escherichia coli*, *Bacillus dysenteriae*, *Shigella dysenteriae* and other bacteria, as well as many different types of pathogens such as dermatophytes, influenza viruses and roundworms, etc. (Table 1). In short, *A. argyi* has

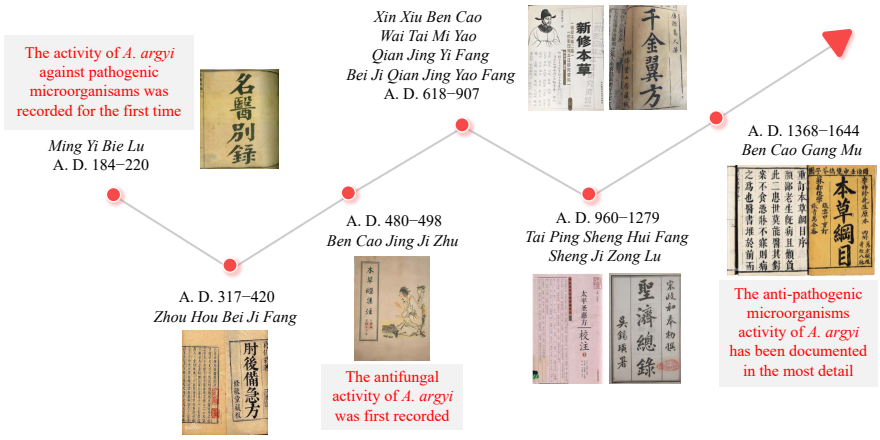


Fig. 2 Herbal textual research on the anti-pathogenic effects of *A. argyi*.

Table 1 Records in ancient medical books regarding the anti-infective diseases of *A. argyi*.

Pathogen classification	Pathogens that could exist	Herbal works	Recorded content
Parasite	Roundworm	A.D. 184–220 *Ming Yi Bie Lu*	"Crushing *A. argyi* juice to swallow, can stop bleeding, kill roundworm".
		A.D. 317–420 *Zhou Hou Bei Ji Fang*	"Roundworm heart ache like thorns, mouth spit water. A liter of *A. argyi* leaves boiled in water and taking it can eliminate roundworms".
Bacterium	*Vibrio cholera*	A.D. 618–907 *Wai Tai Mi Yao*	"Cholera causes vomiting and can be cured by boiling a liter of *A. argyi* in water and taking it".
		A.D. 1368–1644 *Ben Cao Gang Mu*	"Treatment of gynecological diseases, and vomiting caused by *V. cholerae*, cold and heat after dysentery".
	Escherichia coli; *Shigella dysenteriae*	A.D. 618–907 *Xin Xiu Ben Cao*	"*A. argyi*, bitter taste, mild, can treat all diseases, decocting and taking can treat diarrhea, vomiting, blood collapse".
	Shigella dysenteriae	A.D. 960–1279 *Sheng Ji Zong Lu*	"Medicinal ingredients such as *A. argyi* and orange peel can be boiled and taken to treat recurrent dysentery".
Fungus	*Dermatophytes*	A.D. 480–498 *Ben Cao Jing Ji Zhu*	"Taking *A. argyi* decocted with bitter wine can cure skin ringworm".
Virus	-	A.D. 317–420 *Zhou Hou Bei Ji Fang*	"Moxibustion is used to each corner of four corners of the patient' s bed to treat malaria, epidemics, and warm toxins".

been reported to resist pathogenic microorganisms for thousands of years , and is widely used in practice.

3. Modern studies on the anti-pathogenic effect of *A. argyi*

Pathogenic microorganisms can be divided into three major categories according to their size, structure, and composition: non-cellular (viruses), prokaryotic cellular (bacteria, mycoplasma, chlamydia, and rickettsia), and eukaryotic cellular (fungi). Recent research has reported on the anti-pathogenic activity of *A. argyi*. We used keywords such as "*Artemisia argyi*", "antimicrobial", "antibacteria", "antifungus", and "antivirus" to retrieve relevant literatures published from January 2005 to July 2025 in PubMed, Web of Science, CNKI, and other databases. A total of 291 articles related to the anti-pathogenic activity of *A. argyi* were found (Fig. 3A). In general, the report of *A. argyi*' s antimicrobial activity increased annually, reaching to a peak in 2020 (43 articles), which may be related to the widespread concern regarding the COVID-19 outbreak in 2019, further illustrating the importance of *A. argyi*' s anti-pathogenic effect.

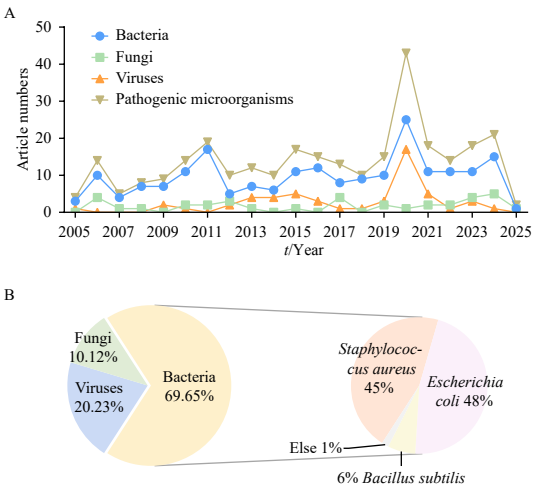


Fig. 3 Statistical analysis of the articles on the anti-pathogenic effects of *A. argyi* from January 2005 to July 2025. (A) The time distribution curve of the article numbers. (B) Distribution proportion of article numbers studying bacteria, fungi, and viruses.

Currently, it is believed that both volatile and nonvolatile components of *A. argyi* have anti-pathogenic activity, with the nonvolatile components having the highest content. Many studies have shown that the nonvolatile components with antimicrobial activity are mainly flavonoids, organic acids, polysaccharides, coumarins, and larger terpenoids in extracts (e.g., water, alcohol, acid, and ethyl acetate extracts) [9]. The volatile components are mainly essential oil including abundant terpenoids, alcohols, ethers, ketones, and a comparatively minor amounts of aldehydes, esters, organic acids, and aromatic compounds, which are also the main active substances of *A. argyi* [9, 10]. Methods for extracting essential oil from *A. argyi* include steam distillation, supercritical CO_2 extraction, petroleum ether extraction, and solid-phase microextraction [9]. The contents and types of compounds extracted using different extraction methods differ, and their effectiveness in resisting pathogenic microorganisms also varies. Over the past 20 years, literature has shown that nearly 70% of *A. argyi* related research has focused on its antibacterial effects, with antiviral and antifungal comprising approxiamtely 20% and 10%, respectively (Fig. 3B).

Moreover, we further conducted a bibliometric analysis of 45 articles collected by Web of Science from 2005 to 2025 using CiteSpace 6.3 software, to clarify the research status of the anti-pathogenic effect of *A. argyi* (Fig. 4). Notably, these articles were all distributed between 2014 and 2025. As shown in Fig. 4A, Chinese scientists participated in the publication of 42 articles, accounting for 93.33%, followed by the United States. And the two have established a close cooperative relationship. Notably, a research team has gradually formed with Prof. Bingui Wang, Linghong Meng and Xiaoming Li from the Institute of Oceanology of the Chinese Academy of Sciences, as well as the team with Prof. Dahui Liu (One of the corresponding authors), Yuhuan Miao and Bisheng Huang from Hubei University of Chinese Medicine (Figs. 4B and 4C). The former focuses on discovering antibacterial compounds from endophytic fungi of *A. argyi* [11-13], while the latter pays more attention to the antifungal activity of active ingredients from *A. argyi*, including crops and clinical fungi [3, 14, 15]. In addition, co-occurrence analysis of keywords found that "*Artemisia argyi*", "antimicrobial activity", "antibacterial activity", "essential oil", "antioxidant", and "antifungal activity" were high-frequency keywords (Fig. 4D). This was almost consistent with the analysis results in Fig. 3B, and these findings indicate that the chemical composition and antibacterial activity of the essential oil were the research hotspot for the anti-pathogenic effect of *A. argyi*. Next, we analyzed and reviewed the research progress on the anti-pathogenic effects of *A. argyi*.

3.1. Antibacterial activity

Bacteria are the most frequently reported pathogens of *A. argyi* (Figs. 3B and 4D). And bacteria are prokaryotic cell-type organisms, with no nuclei, nuclear membranes, nucleoli, or other organelles. They exhibit diverse shapes including cocci, bacilli, and spirilla, and are futher classified into gram-positive and gram-negative types based their different cell wall structures. *A. argyi* extracts have broad-spectrum antibacterial activity against gram-positive and gram-negative bacteria, such as *S. aureus* and *E. coli*. Many studies have confirmed that *A. argyi* has strong antibacterial activity.

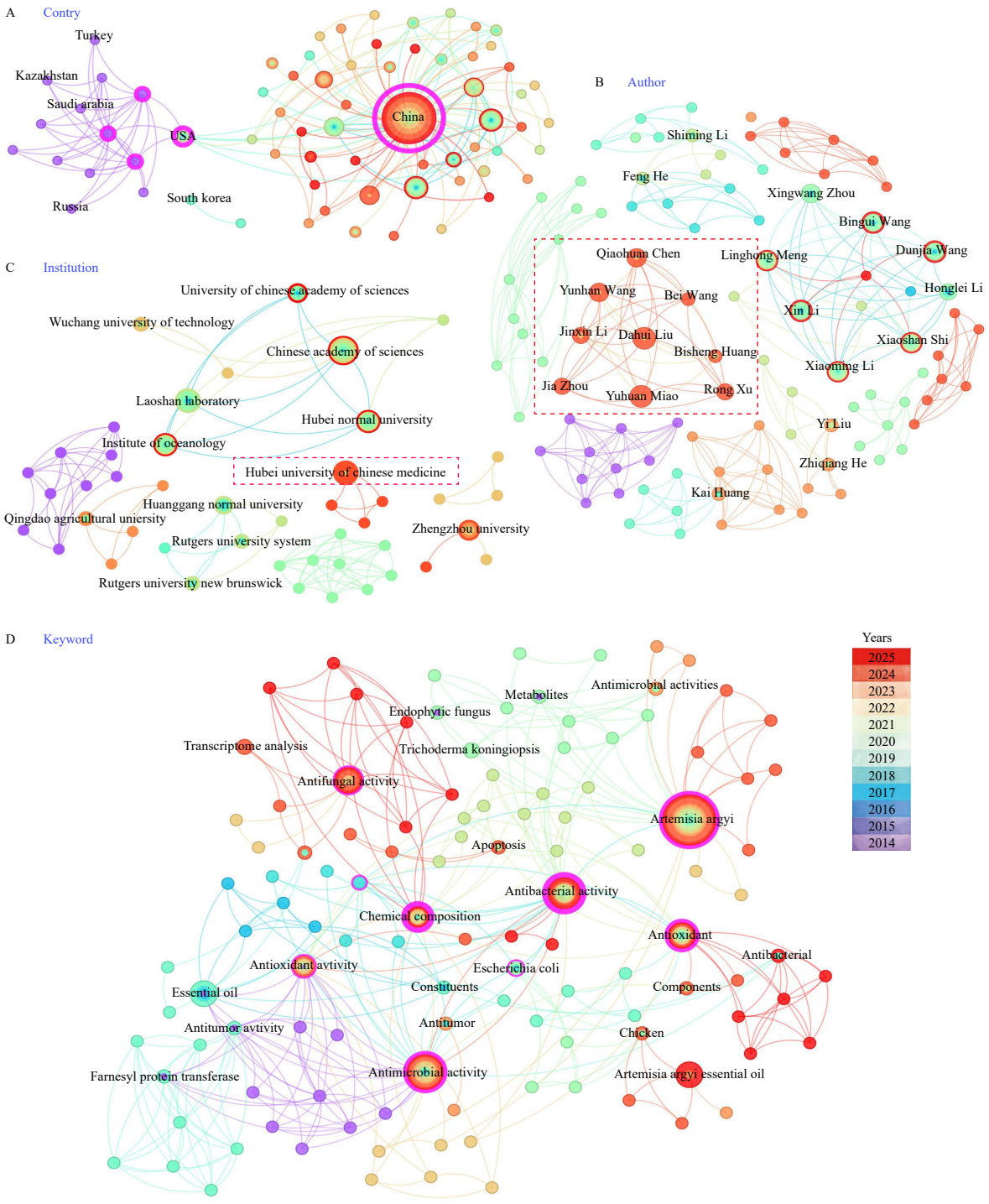


Fig. 4 Bibliometric analysis of the countries (A), authors (B), institutions (C) and keywords (D) of the articles included in the Web of Science from January 2005 to July 2025.

3.1.1. Antibacterial effects of different components of A. argyi

(1) Crude extracts of *A. argyi*

Several studies have explored the antibacterial effects of *A. argyi* extracts (Table 2). Essential oil is the main active substance isolated from *A. argyi* (Fig. 5). Antibacterial effects can vary according to the different varieties, storage time, and extraction methods of essential oil. First, the antibacterial spectrum of the essential oil from "Bei ai" was broader than that from "Qi ai" in terms of varieties [27]. Second, different storage durations mainly affected the proportion of terpenoids and esters in *A. argyi* essential oil (AAEO), with fresh AAEO exhibiting a wider antibacterial spectrum [27]. Moreover, researcher extracted AAEO using steam distillation, subcritical extraction and simultaneous distillation extraction (SDE), respectively [18]. They found that AAEO extracted using SDE had a higher yield and shorter extraction time. Although the types of compounds were fewer than other two methods, the contents of borneol, caryophyllene oxide, neointermedeol, α-thujone and β-caryophyllene reached to 82.93%, all of which exhibited significant inhibitory activity against tested bacteria [18]. Additionally, AAEO extracted with *n*-hexane demonstrated better antibacterial effects than that extracted with dichloromethane using the same SDE extraction method [28]. Owing to bacteria resistance, people are more cautious towards antibiotics use, driving the need for natural alternatives. *A. argyi*, as a

Table 2 Overview of antibacterial effects of *A. argyi* extracts.

Extract	Bacterial species	Bacteriostatic parameter	References
Essential oil	*Staphylococcus aureus*	MIC: 16.0 μg·mL^{-1}–8.0 mg·mL^{-1}	16, 17
		MIC: 6.25–12.5 μL·mL^{-1}	18
	Escherichia coli	MIC: 1.0–12.5 μL·mL^{-1}; MBC: 1.0 μL·mL^{-1}	18, 19
		MIC: 32.0 μg·mL^{-1}–3.91 mg·mL^{-1}; MBC: 64.0 μg·mL^{-1}–7.81 mg·mL^{-1}	16, 20, 21
	Bacillus subtilis	MIC: 3.13–12.5 μL·mL^{-1}	18
		MIC: 32.0 μg·mL^{-1}–1.95 mg·mL^{-1}; MBC: 64.0 μg·mL^{-1}–7.81 mg·mL^{-1}	16, 21
	Pseudomonas aeruginosa	MIC: 64.0 μg·mL^{-1}	16
Water extract	*Staphylococcus aureus*	MIC: 3.0 mg·mL^{-1}; MBC: 6.0 mg·mL^{-1}	22
	Escherichia coli	MIC: 5.0 mg·mL^{-1}–0.67 g·mL^{-1}	20, 23
	Staphylococcus epidermidis	MIC: 0.22 g·mL^{-1}	23
	Bacillus subtilis	MIC: 15.62 g·L^{-1}; MBC: 62.5 g·L^{-1}	24
Alcohol extract	*Escherichia coli*	MIC: 3.91–12.5 mg·mL^{-1}	20, 21
	Bacillus subtilis	MIC: 3.91 mg·mL^{-1}	21
	Pasteurella multocida	MIC: 7.8 mg·mL^{-1}; MBC: 15.6 mg·mL^{-1}	25
Acid extract	*Staphylococcus aureus*	MIC: 0.1 g·mL^{-1}	26
	Salmonella enteritidis	MIC: 0.2 g·mL^{-1}	26

natural antibacterial drug, deserves in-depth exploration. Some studies have found that AAEO exhibits comparable inhibition against *S. aureus* to erythromycin, and also demonstrates excellent efficacy against *E. coli* and *Pseudomonas aeruginosa* [29] (Fig. 5A). Its inhibitory effect on *E. coli* is stronger than that of a 10-fold dilution of 1.6 million units of penicillin [30]. This provides a direction for the development of *A. argyi* into a natural antibiotics candidate.

In addition, studies have suggested that the nonvolatile components of *A. argyi*, such as water, alcohol and acid extracts, also have antibacterial activity. Researchers have compared the antibacterial effects of the volatile and nonvolatile components of *A. argyi*. AAEO demonstrates broad-spectrum antibacterial activity, surpassing that of the water and alcohol extracts of *A. argyi* [21, 31]. Furthermore, the alcohol extract of *A. argyi* exhibits stronger inhibitory effects on *E. coli* than the water extract [20]. In addition, the acid extract of *A. argyi* has significant antibacterial activity against *S. aureus* and *Salmonella enteritidis*, whereas the water extract has no discernible antibacterial effect [26]. These studies highlight that various extracts of *A. argyi* have antibacterial effects, indicating that *A. argyi* is a valuable antibacterial drug and guiding the development and utilization of *A. argyi*.

(2) Effective subfraction of *A. argyi*

It is generally accepted that concentrated effective fractions may exhibit superior effects compared to crude extracts. Previous study found that the total alkaloids extracted from *A. argyi* using ultrasound combined with enzyme extraction had antibacterial activity against *S. aureus* and *E. coli*, with minimum inhibitory concentration (MIC) values of 3.2 and 1.6 mg·mL^{-1}, respectively [29]. Similarly, total triterpenoids extracted from *A. argyi* us-

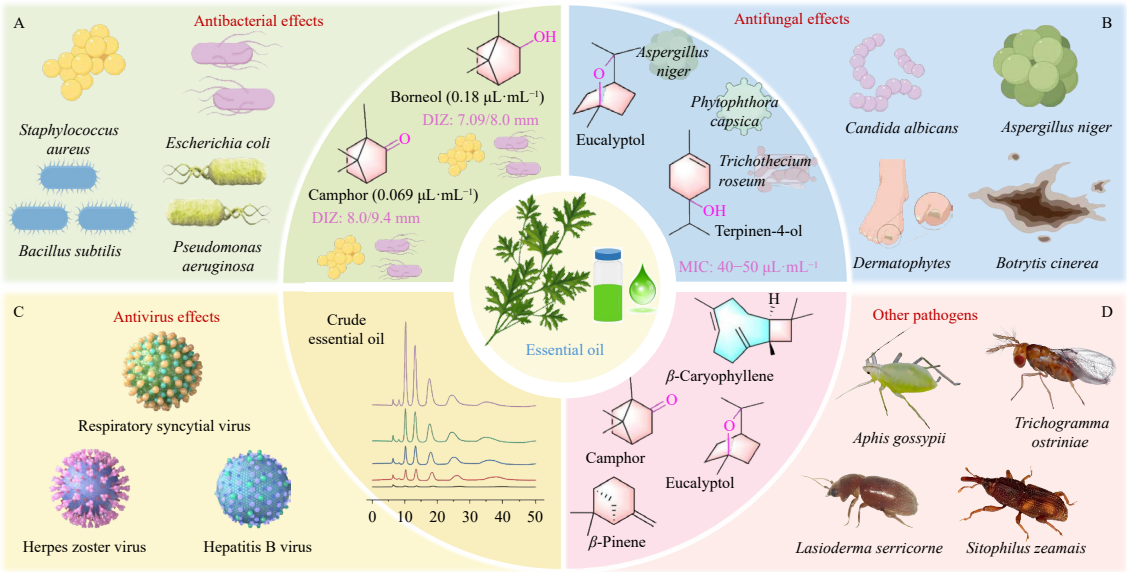


Fig. 5 Summary of anti-pathogenic effects of *A. argyi* essential oil (AAEO) and its active components. (A) Antibacterial effects. (B) Antifungal effects. (C) Antiviral effects. (D) Against other pathogens.

ing ultrasonically assisted extraction exhibited broad-spectrum inhibitory effects against seven pathogenic bacteria, among which *S. aureus* and *S. pneumoniae* were the most sensitive, with an MIC of 3.0 mg·mL^{-1} [32]. The results showed that the antibacterial effects of active fractions of *A. argyi* may offer advantages over water and alcohol extracts but do not match those of AAEO. However, further studies are required to investigate the effective antibacterial sites of *A. argyi*.

(3) Effective monomer components of *A. argyi*

Plants produce various secondary metabolites to adapt to the environment as a result of interactions with biotic and abiotic factors over the course of long-term evolution. Several studies have confirmed the antibacterial activity of these secondary metabolites (Fig. 6). Flavonoids are known to be synthesized by plants in response to microbial infections, have been shown to possess effective antibacterial activity *in vitro* (Fig. 6A). Quercetin and apigenin from *A. argyi* exert antibacterial activity by inhibiting the DNA gyrase of *E.coli* [33]. Studies have also explored the antibacterial effects of eupatilin and jaceosidin, which are important active ingredients in *A. argyi* [34]. Isochlorogenic acid A, the predominant monomeric component of chlorogenic acids in *A. argyi*, demonstrates inhibitory effects on *E. coli* that surpass those of potassium sorbate and sodium benzoate [35] (Fig. 6B). Based on current data, the antibacterial activity of *A. argyi* monomer compounds considerably surpasses that of crude extracts and effective fractions. To study the volatile monomer components based on the spectrum-effect relationship, quality markers for the antibacterial activity of AAEO were identified as camphor and borneol [36]. However, the antibacterial effects of the monomer components were lower than those of AAEO, suggesting that the antibacterial effect of AAEO was synergistic. In summary, the exact antibacterial components of *A. argyi* remain unclear, and there is a lack of research on the antibacterial effects of the monomer components in *A. argyi*, necessitating systematic and in-depth studies.

(4) New materials and preparations of *A. argyi*

Recently, nanomaterials and nanocarriers have emerged as new research topics. Nanomaterials, defined as drugs with particle sizes in the range of 1−100 nm have been developed, through nanofabrication techniques. Carriers of nanomaterials include nano-liposomes, microspheres, microcapsules, nano-emulsions, and sub-microemulsions [37]. Nano-preparations have the properties of a small size, large surface area, thermodynamic instability, and dynamic stability, enabling controlled drug release rates, increased drug targeting in biological systems, reduced drug toxicities, and delayed occurrence of multidrug resistance. Moreover, owing to their small particle size, drug molecules can be delivered across the blood-brain barrier. For example, nanohydrogels loaded AAEO of "Qi ai" in Pluronic F108 surfactant significantly enhance stability and slow-release properties, demonstrating stronger antibacterial activity against *S. aureus* and *E. coli* [38]. Carbon medicine nanocomposites, nanosubstances with multiple pharmacological effects, are a recently discovered component in carbon medicine. Carbon dots, typically small carbon nanoparticles with various surface passivation strategies, have emerged as a new platform for visible/natural light-activated antimicrobial agents [39]. Carbon dots derived from *A. argyi* (ACDs) exhibit selective antibacterial activity against gram-negative bacteria. The bactericidal efficiency of 150 μg·mL^{-1} ACDs for gram-negative bacteria (*E. coli*, *P. aeruginosa*, and *Proteusbacillus vulgaris*) can reach 100% *via* changing the *α*-helix structure of enzymes [40]. Nanomaterials provide a research direction for overcoming the shortcomings of traditional dosage forms and developing new antibacterial formulations of *A. argyi*.

3.1.2. Mechanism of antibacterial effect of *A. argyi*

Several studies have confirmed the antibacterial activity of *A. argyi*. The mechanisms underlying the antibacterial effects of *A. argyi* mainly include: (1) Damaging the integrity of bacterial cell wall and cell membrane; (2) Inhibiting the synthesis of bacterial

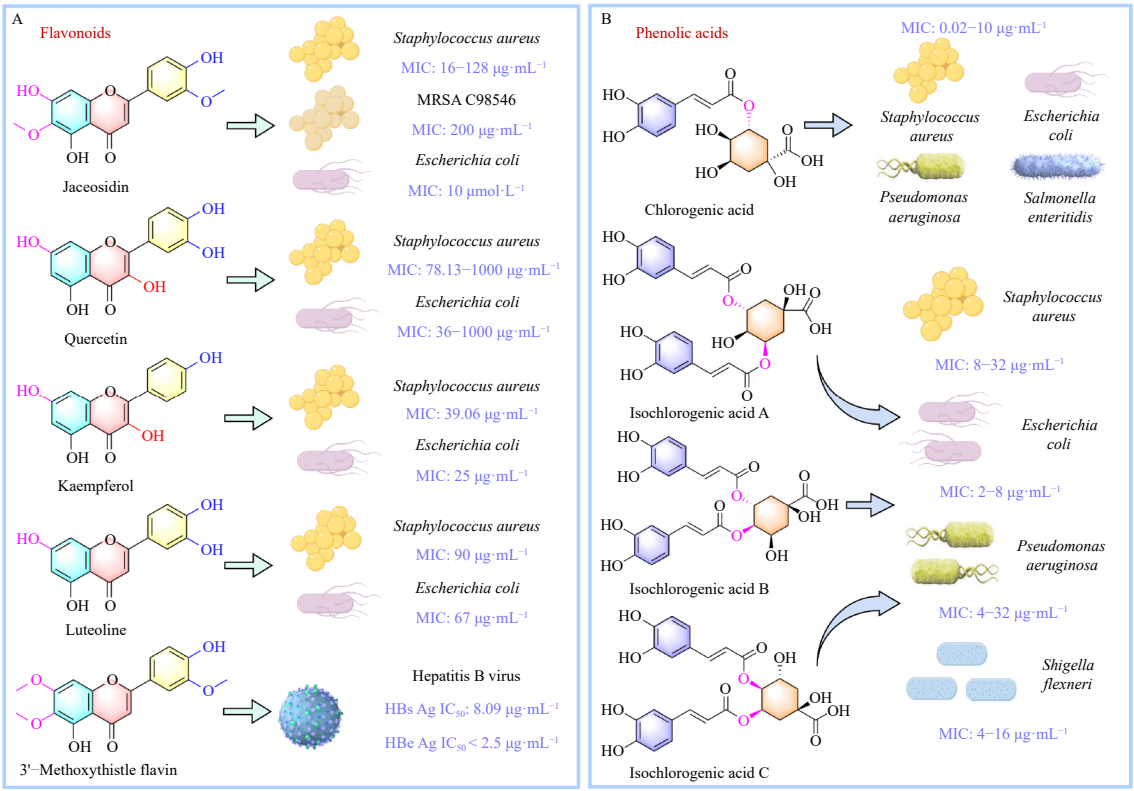


Fig. 6 Summary of anti-pathogenic effects of the nonvolatile components of *A. argyi*. (A) The anti-pathogenic effects of flavonoids. (B) The anti-pathogenic effects of phenolic acids.

nucleic acid [41] (Figs. 7A and 7B). Furthermore, AAEO can destroy the structure of bacterial cell wall and cytoplasmic membrane, resulting in the leakage of intracellular substances such as K^+ and proteins [16, 18]. Studies have hypothesized that the active components of *A. argyi* play an antibacterial role by penetrating the bacterial phospholipid bilayer and destroying cell membrane barrier function. Simultaneously, the active components may fuse with the cell membrane, causing intracellular substances leakage and accumulation [42]. Moreover, the B ring of the flavonoids in *A. argyi* may inhibit bacterial DNA synthesis by participating in the intercalation or hydrogen bonding of nucleic acid. In addition, DNA gyrase may be a direct target of the antibacterial activity of flavonoids. Flavonoids such as quercetin, apigenin, luteolin and kaempferol in *A. argyi* can inhibit bacterial DNA gyrase [33, 43]. Briefly, most mechanistic studies have focused on the antibacterial effect of *A. argyi* by destroying the permeability of the bacterial cell wall and cell membrane and inhibiting DNA synthesis. The specific bacterial enzymes or protein targets of the *A. argyi* need further verification.

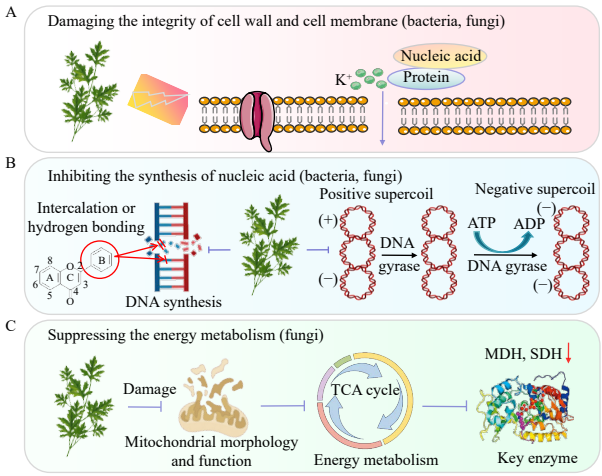


Fig. 7 Schematic diagram of the molecular mechanisms of antibacterial and antifungal activities of *A. argyi*.

3.2. Antifungal activity

Fungi are sporogenous, chloroplast-free eukaryotic organism that are difficult to control with drugs. Studies have revealed that *A. argyi* has an inhibitory effect on common fungi present in the human body, fungi derived from spoiled food, fruits, and vegetables, and crop pathogenic fungi (Table 3). Currently, AAEO is the most reported active antifungal substances in *A. argyi* (Fig. 5B). The most common fungal infections in humans are superficial infections, such as *Epidermophyton floccosum*, which can cause human tinea corporis, jock itch, and tinea pedis. A 30 min AAEO-treatment at 120 μL·mL^{-1} is sufficient to kill *E. floccosum* [44]. *Candida albicans* is an opportunistic pathogenic fungus that causes acute and chronic infections of the skin, mucous membranes, and internal organs. AAEO can induce apoptosis in *C. albicans* through the accumulation of reactive oxygen species and mitochondrial damage [46]. *Aspergillus niger*, a common species of *Aspergillus* fungi, can invade the human body, leading to aspergillosis, sepsis, pneumonia, and aflatoxin production, which induces cancer. It also causes mold in food, grains, fruits, and vegetables. AAEO extracted using SDE had an inhibitory effect on *A. niger*, with an MIC of 6.25 μL·mL^{-1} [16]. Additionally, the extraction method affected the antifungal activity of AAEO. The inhibitory rates of AAEO (1000 mg·L^{-1}) extracted using water distillation on *Botrytis cinerea* and *Alternaria alternate* were 93.3% and 84.7%, respectively, whereas the inhibitory effects of AAEO extracted using supercritical CO_2 were 70.8% and 60.5% [45]. The antifungal activity of the AAEO has been widely reported.

However, the nonvolatile components of *A. argyi* also have antifungal activity. For the first time, we revealed that the water extract of *A. argyi* has an inhibitory effect on *Trichophyton rubrum*, *Trichophyton mentagrophytes*, and *Microsporum gypseum*. Furthermore, the MICs of the 95% ethanol-isolated subfraction against three dermatophytes were 0.3125, 0.625, and 0.3125 mg·mL^{-1}, respectively, suggesting good inhibitory activity [3]. In addition, we also revealed that the subfraction inhibited fungal proliferation by disrupting mitochondrial morphology and function. This is the main molecular mechanism currently reported for the antifungal effect of *A. argyi* (Fig. 7C). Regarding agricultural diseases, we found that the ethyl acetate extract of *A. argyi* (EAAA) inhibited *Verticillium dahliae*, which causes cotton verticillium wilt. EAAA (2.0 mg·mL^{-1}) treatment reduced the spore germination rate to 4.56%. In particular, EAAA can inhibit the activities of malate dehydrogenase (MDH) and succinate dehydrogenase (SDH) in the respiratory metabolism of *V. dahliae* [15]. This may be a solution for fungal drug resistance and provide new insights to control verticillium wilt in crops. In conclusion, these studies indicate that *A. argyi* has antifungal activity, providing a direction for the development and application of *A. argyi* in medicine and agriculture.

3.3. Antiviral activity

Viruses are the smallest and simplest microorganisms. COVID-19 is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and can be transmitted through respiratory droplets and aerosols [47]. *A. argyi*, a common preventive Chinese medicine, can block virus transmission through burning, wearing perfume bags, and fumigation, presenting wide application pro-

Table 3 Summary of antifungal effects of *A. argyi* extracts.

Fungal species	Effective constituent	Inhibitory effect	References
Candida albicans	Essential oil	120.0 μL·mL^{-1} AAEO can kill fungi obviously for 40 min; MIC: 0.5 mL·L^{-1}.	44
Cryptococcus neoformans	Essential oil	120.0 μL·mL^{-1} AAEO can kill fungi obviuosly for 60 min.	44
Aspergillus niger	Essential oil	MIC: 6.25 μL·mL^{-1}	16
Botrytis cinerea	Essential oil	The inhibition rate of 1000.0 mg·L^{-1} AAEO to fungi was 93.3%.	45
Alternaria alternate	Essential oil	The inhibition rate of 1000.0 mg·L^{-1} AAEO to fungi was 84.7%.	45
Trichophyton rubrum	95% Ethanol elution portion	MIC: 0.3125 mg·mL^{-1}	3
Trichophytonmentosum		MIC: 0.625 mg·mL^{-1}	
Microsporium gypsum		MIC: 0.3125 mg·mL^{-1}	
Verticillium dahliae	Ethyl acetate extract	After 2.0 mg·mL^{-1} EAAA treatment, the spore germination rate decreased to 4.56%.	15

spects. On December 10, 2022, the State Administration of Traditional Chinese Medicine issued the "Guidelines for Chinese Medicine Intervention At Home For People Infected With COVID-19", placing "moxibustion therapy" at the top of the recommendations for the rehabilitation of traditional Chinese non-drug therapy [48]. Currently, the antiviral activity of AAEO has gradually attracted the attention of researchers (Table 4 and Fig. 5C). AAEO (120 μL·mL^{-1}) can significantly inhibit the herpes zoster virus within 120 h [44]. Similarly, the AAEO has an anti-respiratory syncytial virus effect (IC_{50}: 3.33 mg·L^{-1}), with a therapeutic index of 9.4 [49]. These studies provide important scientific support for the prevention and control of epidemics (mainly respiratory viruses) using *A. argyi*.

In addition to respiratory viruses, the hepatitis B virus (HBV) is a global public health concern. Currently, the primary clinical anti-HBV drugs used are interferons and nucleosides. Although these two drugs have clear efficacy, acquired drug resistance after long-term usage and adverse reactions still threaten clinical prognosis [53]. Traditional Chinese medicine plays a unique role in the long-term treatment of diseases. In an experimental model of HepG 2.2.15 cells, AAEO and EAAA extracts suppressed HBV by inhibiting the secretion of HBsAg and HBeAg antigens and the replication of HBV DNA [50, 51]. Subsequently, several studies conducted composition analysis and activity screening for EAAA. Five compounds were isolated and identified successively [52], among which 5,4'-dyhydroxyl-6,7,3'-trimethoxyflavone, dammaradienyl acetate, and 5,7,4'-trihydroxy-3',8-dimethoxyflavone were isolated from *A. argyi* for the first time. *In vitro* experiments have found that 3'-methoxythistle flavin, has an inhibitory effect on HBsAg and HBeAg [52]. The mechanism underlying the anti-HBV effect of *A. argyi* extract needs further investigation, which will provide novel insights for developing new anti-HBV drugs and overcoming clinical drug resistance.

3.4. Other pathogens

In addition to inhibiting common pathogenic microorganisms, such as bacteria, fungi, and viruses, *A. argyi* resists mycoplasmas, repels mosquitoes, and avoids crop pests (Fig. 5D). *Mycoplasma pneumoniae* is a pathogen that causes upper and lower respiratory tract infections, and accounts for 20% of all respiratory tract infections. The water extract of *A. argyi* has an inhibitory effect on *M. pneumoniae*, providing an experimental and theoretical basis for the clinical use of traditional Chinese medicine to overcome antibiotic resistance. Plant essential oils are the most widely studied plant insecticides. They are highly selective, safe, and non-toxic to natural enemies and can attract, avoid, resist, and regulate the growth of pests. Studies have found that AAEO can inhibit a variety of crop pests, such as *Lasioderma serricorne*, making it a potential insecticide candidate (Table 5).

4. Development and application of *A. argyi* against pathogens

A. argyi has extensive anti-pathogenic activity; therefore, products of *A. argyi* have been widely developed and used, showing great economic value. The author used the keywords "*Artemisia argyi*", "antibacteria", "antifungus" and "antivirus" to search the relevant patents disclosed from January 2005 to July 2025 in CNKI and other databases, and retrieved 1140 valid patents (Fig. 8A). The number of patents related to the inhibitory effects of *A. argyi* on pathogenic microorganisms is steadily increasing, and has developed rapidly in the past decade. Moreover, statistics on these relevant patents have found that the anti-pathogenic effect of *A. argyi* is widely applied in disinfection products

Table 4 Summary of antivirus effects of *A. argyi* extracts.

Virus species	Effective constituent	Inhibitory effect	References
Herpes zoster virus	Essential oil	120.0 μL·mL^{-1} essentia oil significantly inhibited the virus within 120 h.	44
Respiratory syncytial virus	Essential oil	IC_{50}: 3.33 mg·L^{-1}	49
Hepatitis B virus	Essential oil	The therapeutic index for HBsAg, HBeAg and HBV DNA was 7.7, 6.3, and 4.9.	50
Hepatitis B virus	Ethyl acetate extract	The IC_{50} for HBsAg, HBeAg and HBV DNA was 1.26, 8.06, and 38.97 mg·L^{-1}, and the therapeutic index for the above 3 indexes was 83.2, 13.0, and 2.7.	51
Hepatitis B virus	3'-Methoxythistle flavin	Inhibitory effect on HBs Ag and HBe Ag lines with IC_{50} values of 8.09 mg·L^{-1} and less than 2.5 mg·L^{-1} respectively.	52

Table 5 Summary of *A. argyi* extracts and its active components against other pathogens.

Other pathogens	Effective constituent	Inhibitory effect	References
Mycoplasma pneumoniae	Water extract	MIC: 3.91 mg·mL^{-1}; the serum levels of IL-6, IL-10 and TNF-α in mice infected with *mycoplasma pneumoniae* were affected.	54
Aphis gossypii	*β*-Caryophyllene	LD_{50}: 0.65 × 10^{-1} μg/individual; AFC_{50}: 0.80 × 10^{3} mg·L^{-1}	55, 56
Trichogramma ostriniae	Essential oil	300.0 mg·L^{-1} AAEO has 100% repellent effect.	57
Sitophilus zeamais	Essential oil	After 24 h of action: LD_{50}: 0.024 μL·cm^{-3}	58
Tribolium confusum	Essential oil	After 72 h of action: LD_{50}: 0.03 μL·cm^{-3}	58
Lasioderma serricorne	Essential oil	The repellent rate reached 86.54% within 1 h after 20 times dilution of AAEO.	59
	Essential oil	LD_{50}: 6.42 μg/adult; LC_{50}: 8.04 mg·L^{-1} air	
	Camphor	LD_{50}: 11.30 μg/adult; LC_{50}: 2.91 mg·L^{-1} air	
	Eucalyptol	LD_{50}: 15.58 μg/adult; LC_{50}: 5.18 mg·L^{-1} air	
	β-Caryophyllene	LD_{50}: 6.42 μg/adult	
	β-Pinene	LD_{50}: 6.42 μg/adult; LC_{50}: 29.03 mg·L^{-1} air	

(23.08%), home textile and daily chemical products (33.51%), feed additives (4.64%), biogenic pesticides (4.74%), medical and health products (24.34%), etc. (Fig. 8B). Actually, many related products are available on the market (Fig. 8C).

4.1. Disinfection products

For broad spectrum of anti-pathogenic activity, there are various types of disinfection products using *A. argyi* as raw materials, including air freshener, disinfectant, soap, and hand sanitizer [60]. Disinfection formulae that combine AAEO with other Chinese herbals and pharmaceutical ingredients can improve the disinfection efficacy. Compared to other disinfection products on the market, these formulas can reduce pungent odors, and are suitable for both daily and medical disinfections. Additionally, they can be used as a disinfectants for poultry houses,as they are environmentally friendly, non-toxic and has few side effects, and ensures animal safety.

Furthermore, AAEO has mosquito repellent effects, which can be applied to aromatherapy and mosquito repellent incense to achieve indoor disinfection and mosquito repellent effects [61]. For example, *A. argyi*-based Lanju mosquito incense achieved excellent sales because of its low price and prominent efficacy.

4.2. Home textile and daily chemical products

The terpenoids in the AAEO have unique aromatic characteristics. The cool aroma, combined with the antibacterial and antioxidation functions of AAEO, is widely used in the chemical industry. In combination with other moisturizing and acne-removing ingredients, AAEO can be developed into hand cream [62], and acne-removing cream formulas [63], such as the materia medica "Qi ai" essential oil moisturizing hand creams marketed by the Li Shizhen Pharmaceutical Group Company. At present, most wash supplies on the market are synthetic chemical substances with potential side effects. Combinations of natural Chinese herbs and plant extracts have become increasingly popular among consumers. *A. argyi* can also be combined with whitening, anti-dandruff, anti-itching, and repairing ingredients to develop products such as toothpaste and shampoos [64]. For example, Guang Zhou Bai Cao Tang Pharmaceutical Co. Ltd. has listed an herbal *A. argyi* shampoo.

Cotton fabric is prone to mildew and bacteria when not properly stored. The antibacterial properties of cotton fabric can be enhanced by applying AAEO through appropriate finishing methods. Microcapsules of AAEO, prepared using the coagulation method, achieved antibacterial rates of 97.42% and 95.70% against *E. coli* and *S. aureus*, respectively, after finishing cotton fabrics. The antibacterial rate could still exceed 85% after 35 days of storage and was still above 80% after 50 washes [65]. Researchers have developed antibacterial and antiviral polyester fibers and nonwoven fabrics using *A. argyi* as raw materials [66], providing prospects for the development and utilization of *A. argyi* in the textile field.

4.3. Feed additives

Incorporating an appropriate amount of *A. argyi* into livestock feed during their growth stages can reduce morbidity and promote growth. AAEO has good antibacterial activity against *Aeromonas hydrophila* found in common carp, black carp, and grass carp [19]. Moreover, the water decoction of *A. argyi* has a good comprehensive inhibitory effect on the swine influenza virus [67]. Additionally, *A. argyi* added to feed as an antiviral drug can effectively prevent and treat disease caused by avian influenza [68]. Currently, *A. argyi* and its extract are used as feed additives and are widely used in the rearing of pigs, chickens, fish, poultry, and other livestock. *A. argyi* are abundant in resources, cost-effective, and well-defined in their medicinal effects. They can serve as a simpler and economical Chinese herbal feed additive to achieve large-scale production in the feed industry. This presents considerable economic value and promising development prospects.

4.4. Biogenic pesticides

A. argyi and its extract are natural antibacterial insect repellents and are known as "pollution-free pesticides". AAEO has an inhibitory effect on specific pests during the growth and storage of crops, such as *Trichogramma ostriniae*, *Corcyra cephalonica*, *Sitophilus zeamais*, *Tribolium confusum* and *Lasioderma serricorne* [57, 58, 69]. The co-toxicity coefficient was 250.53 when the ratio of AAEO to the ethanol extract of *Melia azedarach* fruit was 7∶3, significantly increasing the effectiveness of the *M. azedarach* fruit extract [70]. Researchers have developed a pesticide composition based on the flavonoid extract of *A. argyi* [71], and bacteriostatic agents using ethyl acetate and ethanol extracts of *A. argyi* to prevent and control verticillium wilt in cotton [72]. Compared to traditional synthetic pesticides, biological pesticides have the advantages of low toxicity, low residue, and good environmental compatibility, which provide a direction for the large-scale development of environmentally friendly biological pesticides and pesticide synergists.

4.5. Medical and health products

A. argyi has long been regarded as the "holy medicine of the palace cold", traditionally combined with other drugs and used to treat various common gynecological diseases, such as dysmenorrhea, uterine bleeding, fetal dysphoria, irregular menstruation, and bleeding. In recent years, researchers have combined the antibacterial and antiviral effects of *A. argyi* with those of Chinese medicinal ingredients to develop gynecological products. For example, *A. argyi* combined with other Chinese herbs can be formu-

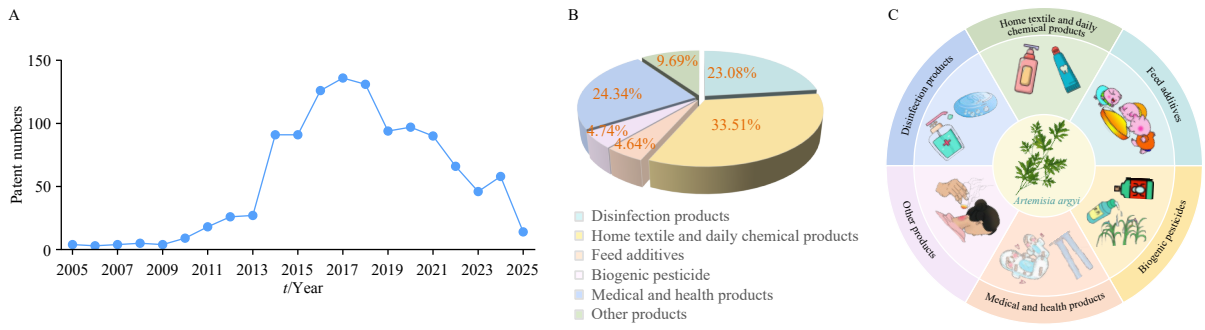


Fig. 8 Statistical analysis of the patents on the anti-pathogenic effect of *A. argyi* from January 2005 to July 2025. (A) The time distribution curve of the patent numbers. (B) Distribution proportion of the application of *A. argyi* in the fields of disinfection products, home textile and daily chemical products, feed additives, biogenic pesticides, medical and health products, etc. (C) Representative products for the application of *A. argyi* against pathogens.

lated into a gynecological gel with broad-spectrum antibacterial activity against *S. aureus*, *E. coli*, *C. albicans*, and mold, used in treating vaginitis, cervicitis, cervical erosion, and other common gynecological diseases [15]. Cervical cancer is the most common malignant gynecological cancer, with its incidence increasingly affecting younger age groups. Most existing therapies cannot achieve a satisfactory clinical prognosis; therefore, effective prevention is the best strategy to reduce incidence. According to clinical data, HPV gel prepared from *A. argyi* can effectively prevent HPV infections without toxic side effects [73]. Additionally, *A. argyi* has pharmacological properties that include warming menstruation, stopping bleeding, dispelling cold, and relieving pain. It can also be incorporated into sanitary napkins and pads [74], which inhibit the growth of pathogens during menstruation and protect women' s health.

4.6. Other products

The process of moxibustion releases a significant amount of positive energy. Once absorbed by the human body, this energy is said to reach the lesion through the meridian, effectively dispelling cold and dampness, treating ailments, and potentially extending lifespan. Moxibustion is widely used in daily life to prevent viral infections. *A. argyi* and its extracts have inhibitory effects on food-pathogenic fungi. Consisting of rich natural antioxidant flavonoids, *A. argyi* can be used for food storage, as a freshkeeping agent, and as a preservative. For example, a microemulsion preservative with antibacterial properties prepared using AAEO as the oil phase effectively reduced the decay rate of cherry fruits and maintained their color, soluble solid content, and water content [75]. In addition, *A. argyi* can also be combined with Western medicine or other Chinese medicine components to form drug complexes, enhancing drug efficacy and reducing drug resistance. For example, the preparation of an isoconazole nitrate spray with *A. argyi* and dichotomous peel as active ingredients significantly improves drug safety [76].

5. Summary and prospect

A. argyi is a medicinal and aromatic herb of great economic value, characterized by a wide distribution and extensive cultivation. Wise ancients long recognized its value, using it for moxibustion, warding off evil, combating dysentery, and expelling roundworms, fully demonstrating its potential in treating infectious diseases. Modern research and applications of *A. argyi* has been more comprehensive and in-depth, further confirming its broad-spectrum activity against common pathogenic microorganisms, including bacteria, fungi, and viruses. Particularly after the outbreak of the novel coronavirus in 2019, the research, development, and utilization of natural antibacterial drug resources such as *A. argyi* surged in China, reaching a peak in 2020. The comprehensive development and utilization of *A. argyi* have yielded remarkable economic and social benefits, and its prospects are even broader.

However, there are also some shortcomings in the research and development of the anti-pathogenic activity of *A. argyi*. First, the composition of *A. argyi* is complex, and the components of *its* extracts vary depending on the plant variety, growh years, and extraction methods, making it difficult to establish a quality evaluation criterion similar to that used for single-component drugs [77]. Second, the pharmacodynamic substances of *A. argyi* and its extracts are not clear, and the underlying mechanisms are not fully understood. In other words, the active ingredients are far from those that participate in the antibacterial effect, the antibacterial spectrum remains unclear. Finally, the development scale and depth of *A. argyi* and extract products are insufficient; few products, such as mugwort sticks and essential oil products, are still in the primary development stage; taken together, the unclear functional components of the anti-pathogenic effect of *A. argyi* extract seriously restrict industrial development. To solve the above bottlenecks, high-throughput and high-sensitivity technologies such as UPLC-Q/TOF-MS and GC-MS can be used to conduct comprehensive, non-targeted chemical composition analysis of *A. argyi* extract to quickly identify known and unknown components. Meanwhile, by comparing the chemical composition profiles of *A. argyi* samples from different varieties, years, and extraction methods, and find out the compound groups that are significantly related to antiviral activity through multivariate statistical analysis (such as PCA, OPLS-DA). This can quickly target active components from massive amounts of data. Moreover, activity tracking and directional separation of target components, and accurate structural analysis and confirmation using nuclear magnetic resonance (NMR) spectroscopy are crucial steps. Additionally, besides searching for the most effective single component, we should also explore main active components and synergistic components. Mechanistically, it should be clarified whether different components produce synergistic effects by acting on different targets of pathogenic microorganisms (such as cell membranes, protein synthesis, energy metabolism, etc.). In summary, future research on the material basis of the anti-pathogenic effect of *A. argyi* will surely move from the initial stage of "crude extracts–overall activity" to the stage of systems biology research of "multi-component–multiple target–collaborative mechanism".

With the development of science and technology, various advanced technologies can be used to study the pharmacodynamic basis and mechanisms of *A. argyi* against pathogenic microorganisms. For example, artificial intelligence and network pharmacology are alternative techniques for studying the possible targets of the action of *A. argyi* against pathogenic microorganisms. High-throughput screening and multiomics sequencing can be used to further study these possible mechanisms. Animal experiments and *in vivo* imaging systems can be used for mechanistic exploration. This will help to better utilize the potential activity of *A. argyi* against pathogenic microorganisms, develop natural antibiotics, and solve the problem of resistance to traditional antibiotics. At the same time, utilizing existing nano- and inclusion technologies is necessary to improve the physical characteristics of the drug and its efficacy. In the future, *A. argyi* will certainly open new avenues for medicinal applications and expand into more fields.

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Declaration of competing interest

These authors have no conflict of interest to declare.

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