



# Antimycobacterial and Pharmacological Potential of *Glycyrrhiza glabra*, *Taraxacum officinale*, *Parmelia sulcata* and *Thymus vulgaris*: A Comprehensive Review

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## Abstract

The growing threat of drug-resistant *Mycobacterium tuberculosis* highlights the urgent need for alternative therapeutic strategies. Medicinal plants have long been used in traditional systems and are now being explored for their potential in modern pharmacology. This review investigates four plant species widely used in Central Asian folk medicine-*Glycyrrhiza glabra*, *Taraxacum officinale*, *Parmelia sulcata*, and *Thymus vulgaris* with a focus on their phytochemical composition and pharmacological activities. These plants are rich in flavonoids, terpenoids, phenolic acids, and lichen-derived polyketides, which exhibit antimicrobial, anti-inflammatory, antitussive, and antimycobacterial effects. Compounds such as thymol, glycyrrhizin, and salazinic acid have demonstrated promising activity against *M. tuberculosis*, including resistant strains. The findings support the potential of these species as complementary agents in tuberculosis treatment and encourage further pharmacological and clinical research.

**Keywords:** *Mycobacterium tuberculosis*; Antimicrobial; Antitussive; Antifungal; Anti-inflammatory.

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## 1. Introduction

As of the latest data from the Global Tuberculosis Report 2024, tuberculosis (TB) remains a significant public health challenge worldwide. It is estimated that about 10.8 million people fell ill with TB in 2023, with the disease still being the second leading cause of death from a single infectious agent, after COVID-19.<sup>[1]</sup> Currently, the situation has become particularly acute due to the development of resistance in *Mycobacterium tuberculosis* to both basic and reserve antituberculosis drugs. This has led to the global spread of *M. tuberculosis* strains with multiple (MDR) and broad (XDR) drug resistance.<sup>[2]</sup> The main reasons for drug-resistant tuberculosis (TB), including multi-drug-resistant TB (MDR-TB) and extensively drug-resistant TB (XDR-TB), include improper treatment, inconsistent medication adherence, poor management of TB programs, coinfections such as HIV,

socioeconomic factors etc.<sup>[3]</sup> Kazakhstan remains one of the high-burden countries for drug-resistant tuberculosis (TB). The country reported 2,500 to 3,000 estimated new cases of multidrug-resistant or rifampicin-resistant TB (MDR/RR-TB) in 2023.<sup>[1]</sup> While the global incidence of drug-resistant TB has remained relatively stable, regions including Central Asia have seen significant efforts to manage and reduce this burden.<sup>[4]</sup>

With the limited efficacy of standard antibiotics, there is a growing interest in herbal remedies as alternative or adjuvant therapeutic agents. Many plants used in traditional medicine contain biologically active compounds with proven antimicrobial, anti-inflammatory and immunomodulatory activity. Despite Kazakhstan's rich biodiversity and centuries-long tradition of using plants in folk medicine, the antituberculosis potential of local species remains poorly understood.<sup>[5]</sup> Although plant preparations are actively studied as a source of new antimicrobial agents in world practice, in Kazakhstan only a few plant species have been subjected to detailed pharmacological analysis in terms of their activity against *Mycobacterium tuberculosis*.<sup>[6]</sup> Therefore, there is a need for in-depth study of natural sources with antituberculosis effect growing in Kazakhstan for further

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development of medicines based on them. This study aims to fill this gap by systematically analyzing the pharmacological potential of local medicinal plants *Glycyrrhiza glabra*, *Taraxacum officinale*, *Parmelia sulcata*, *Thymus vulgaris* as alternative or adjunct therapies for tuberculosis treatment. While the properties of these plants have been studied previously, this review is the first to systematize data on their antimycobacterial activity in the Central Asian context, analyzing their combined potential for tuberculosis treatment, which is rare in other publications. A distinctive feature of this review is the systematic compilation of data on their chemical composition, extraction methods, pharmacological effects, and potential synergy with modern anti-tuberculosis drugs. Particular attention is given to the lichen *Parmelia sulcata*, which is rarely included in such reviews, thereby broadening the understanding of natural sources of antimycobacterial compounds. Furthermore, this review integrates traditional knowledge with contemporary scientific evidence, offering concrete directions for further preclinical and clinical research.

*Glycyrrhiza glabra*, commonly known as licorice, is a perennial herb native to the Mediterranean region and parts of Asia, including Iran, India, and parts of China. The plant is primarily grown in these regions, thriving in well-drained, sandy soils under warm conditions.<sup>[7]</sup> In traditional Chinese medicine, licorice root is known as “Gancao” and is used to harmonize other ingredients in herbal formulas, reduce toxicity, and treat coughs, sore throats, and digestive issues.<sup>[8]</sup> Historically, licorice has been used in European folk medicine for its expectorant and anti-inflammatory properties, especially for treating bronchitis, gastritis, and ulcers. It was also used as a sweetening agent in various preparations.<sup>[9]</sup> Licorice root continues to be used today for its anti-inflammatory, soothing, and adaptogenic properties. It is included in many natural remedies for coughs, sore throats, and digestive complaints.<sup>[10]</sup> The main part used for medicinal purposes is roots and rhizomes. The root of licorice is rich in bioactive compounds like glycyrrhizin, flavonoids, and saponins. These compounds contribute to the root's anti-inflammatory, antimicrobial, cough suppressant and expectorant and antiviral properties. The roots can be processed into extracts, teas, powders, or syrups and are included in traditional and modern herbal medicine.<sup>[11]</sup>

*Taraxacum officinale*, commonly known as dandelion, is a perennial herbaceous plant from the Asteraceae family. It has deeply toothed leaves that form a basal rosette, a hollow stem containing milky latex, and bright yellow composite flowers that later turn into spherical seed heads (known as “dandelion clocks”).<sup>[12]</sup> Dandelions are widely distributed across temperate regions of the world, including Europe,

North America, and Asia. In Central Asia, *Taraxacum officinale* is widely used in traditional medicine.<sup>[13]</sup> Various parts of the plant - roots, leaves, flowers, and latex - are utilized for different medicinal purposes.<sup>[14]</sup> Dandelions contain diverse bioactive compounds like flavonoids, phenolic acids, triterpenoids, and sesquiterpene lactones. These compounds contribute to the anti-inflammatory, antibacterial, antifungal properties.<sup>[15]</sup>

*Parmelia sulcata* is a species of fruticose lichen belonging to the family Parmeliaceae. It is commonly known as ruffled shield lichen due to its characteristic appearance and texture.<sup>[16]</sup> *Parmelia sulcata* is found predominantly in temperate regions of the world, including parts of North America, Europe, Asia, and Australia. It grows in a variety of environments, such as forests, woodlands, rocky outcrops, and tree trunks, where it prefers shaded, moist conditions.<sup>[17]</sup> *Parmelia sulcata* and other types of lichens have been used in traditional medicine in various countries, particularly in regions where lichens are widely available and recognized for their therapeutic properties.<sup>[18]</sup> For example, in traditional Chinese medicine, various species of lichens, including *Parmelia sulcata*, are used to treat liver, stomach, and skin diseases. Lichens are believed to be beneficial for enhancing immune function.<sup>[19]</sup> In traditional Indian medicine, particularly in Ayurveda, *Parmelia sulcata* are used for combating bacterial and fungal infections.<sup>[16]</sup> In Russia and CIS countries, lichens, including *Parmelia sulcata*, have traditionally been used to treat colds and respiratory issues. Scientific research has revealed several pharmacological properties of *Parmelia sulcata*, some of which align with its traditional uses: antibacterial, antifungal, antiviral, anti-inflammatory, antioxidant, and hepato-protective properties.<sup>[20]</sup>

*Thymus vulgaris* is a flowering plant in the mint family Lamiaceae, commonly known as thyme or garden thyme. Thyme is widely grown in Europe (including France, Spain, Italy, and Bulgaria), North America, Asia, and other temperate regions for use in cooking and medicine.<sup>[21]</sup> *Thymus vulgaris* has many healing properties: it exhibits antiseptic, antimicrobial, astringent, anthelmintic, carminative, disinfectant and tonic effects. In the traditional medicine of the Middle East, the plant is used as herbal teas for the treatment of respiratory tract diseases (cough, bronchitis and asthma), as well as as antiseptic poultices for wounds.<sup>[22]</sup> Historically used by the Greeks and Romans for respiratory and digestive ailments, also employed in baths for relaxation and wound healing. Incorporated into Ayurvedic medicine to alleviate respiratory issues, enhance digestion, and treat infections. In Central Asia It is brewed in herbal teas for colds, digestive complaints, and to improve overall vitality and used in poultices for joint pain and skin ailments.<sup>[23]</sup> In medicine, various parts of common thyme are utilized for their therapeutic properties. The leaves are the most widely used part of the plant for medicinal purposes. They contain essential oils, flavonoids, tannins, and other bioactive

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compounds that provide a range of therapeutic effects. Thyme flowers also contain essential oils and are rich in antioxidants.<sup>[24]</sup>

## 2. Materials and methods

To achieve the stated objective, we conducted a search and analysis of scientific publications on the pharmacological properties and traditional uses of various plants growing in Central Asia, covering studies from 2000 to 2025. Although the main focus is on Central Asian plants, key studies from other regions demonstrating the universality of the pharmacological properties of these species are also included for completeness of the analysis. All works included in the review were indexed in databases such as Google Scholar, PubMed, Science Direct, Researchgate, and other online collections were used.

The selected publications were available in English, Kazakh, and Russian and included full versions of articles with clearly formulated and statistically supported conclusions. Exclusion criteria for the review were conference abstracts, newspaper articles, and personal communications. After reading the titles, abstracts, and full reports, around 153 papers about phytochemical research and pharmacological effects of *Glycyrrhiza glabra*, *Taraxacum officinale*, *Thymus vulgaris*, *Parmelia sulcata* were finally included.

## 3. Chemical constituents

Unlike traditional drug discovery, which relies on large-scale screening or computational modeling, bioactivity-guided fractionation is mainly used to isolate active compounds from medicinal plants. This method involves extracting compounds from plant material, separating them into fractions, and analyzing their structures using techniques such as infrared spectroscopy (IR), mass spectrometry (MS), and nuclear magnetic resonance spectroscopy (NMR). Finally, the bioactivity of these compounds is tested against mycobacteria.

### 3.1 *Taraxacum officinale*

Dandelion (genus *Taraxacum*) contains a variety of chemical components, among which sesquiterpene lactones (including  $\alpha$ -pinene, guaiacol, and patchouli lactones), phenolic acids, triterpenoids, polysaccharides, phytosterols, and essential oils pre-dominate.<sup>[25]</sup> In addition, the plant serves as a valuable source of vitamins, choline, minerals and trace elements. Of particular importance are polyphenolic compounds such as chlorogenic acid, quercetin, chicory acid and hydroxycinnamic acids with their derivatives, which are found in significant quantities in the flowers, leaves and roots of dandelion.<sup>[26]</sup> Dandelion contains abundant triterpenoids, including compounds like taraxasterol, pseudotaraxasterol, lupeol, and their acetates.<sup>[13]</sup> Flavonoids are an important group of biologically active compounds of dandelion, which includes quercetin, rutin, luteolin and their glycosides. These compounds perform key functions in the processes of plant

growth, development, and antimicrobial protection.<sup>[27]</sup> Studies have shown differences in the sterol composition of different parts of dandelion: pollen contains  $\beta$ -sitosterol, stigmasterol, and alkanesterol, while  $\beta$ -sitosterol and its derivative,  $\beta$ -sitosterol- $\beta$ -d-glucoside, predominate in the roots.<sup>[28]</sup> Special attention should be paid to *Taraxacum officinale* polysaccharides, represented by a complex of monosaccharides, including arabinose, glucose, galactose, fructose, xylose, mannose and their glycoside forms.<sup>[29]</sup> Using high-performance liquid chromatography (HPLC), mass spectrometry (MS), and nuclear magnetic resonance (NMR) analysis, Kisiel and Barszcz isolated five sesquiterpene lactones from dandelion roots. These included tetrahydro-ridentin B, taraxacolide-O- $\beta$ -glycopyranoside, ainslioside, 11 $\beta$ -13-dihydrolactucin, and ixerine D. Additionally, syringin, dihydrosyringin, dihydroconiferin, and benzyl glucoside were identified.<sup>[30]</sup>

### 3.2 *Glycyrrhiza glabra*

Numerous studies have identified a wide variety of secondary metabolites in *Glycyrrhiza* species, emphasizing its potential for anti-inflammatory, antimicrobial, antioxidant, and other medicinal uses. The key bioactive compounds found in *Glycyrrhiza glabra* include flavonoids, isoflavonoids, chalcones, saponins, triterpenes, coumarins, phenolic compounds, volatile constituents, and essential oils.<sup>[31]</sup> The flavonoid profile of *G. glabra* roots consists of liquiritin, rhamnoliquiritin, liquiritigenin, prenyllicoflavone A, glucoliquiritin apioside, shinflavanone, licopyranocoumarin, glisoflavone, licoaryl-coumarin, and coumarin-GU-12.<sup>[32]</sup> Among the isoflavonoids, key compounds include glabridin, glabrone, glyzarin, and galbrene,<sup>[33]</sup> while the chalcone group comprises isoliquiritin, isoliquiritigenin, neoisoliquiritin, licuraside, glabrolide, licoflavonol, glychionide A.<sup>[34]</sup> Additionally, saponins, particularly glycyrrhizin, are among the major bioactive constituents in licorice.<sup>[35]</sup> The triterpenes found in licorice include liquiritic acid, glycyrrhetol,<sup>[36]</sup> glabrolide, uralsaponin B, apioglycyrrhizin, araboglycyrrhizin,<sup>[37]</sup> and licorice acid.<sup>[38]</sup> *G. glabra* also contains coumarins, including liqcoumarin, glabrocoumarone A and B,<sup>[39]</sup> herniarin,<sup>[40]</sup> umbelliferone, and glycocoumarin.<sup>[41]</sup> Chemical analysis revealed a number of volatile compounds in licorice, such as pentanol, tetramethylpyrazine, hexanol, and terpinene-4-ol,<sup>[42]</sup> as well as linalool oxides (forms A and B).<sup>[43]</sup> The use of the HPLC method to study the methanol extract of the plant made it possible to identify various organic acids: acetic, propanoic, fumaric, citric, butyric, malic and tartaric.

### 3.3 *Parmelia sulcata*

The genus *Parmelia* includes 71 species of lichens, which are symbiotic associations of Ascomycota fungi and cyanobacteria.<sup>[44]</sup> In traditional Indian and Ayurvedic medicine, these lichens are used to treat respiratory (bronchitis, asthma), skin (ulcers, boils), cardiovascular (angina pectoris) and other diseases.<sup>[45,46]</sup> Their chemical composition includes polysaccharides, terpenoids, steroids, and especially valuable

phenolic compounds, lichen acids, which have pronounced biological activity.<sup>[47]</sup> Lichens produce secondary metabolites such as atranorin, fumarprotocetraric acid, gyrophoric acid, lecanoric acid, physodic acid, protocetraric acid, stictic acid and usnic acid showed antibacterial and antifungal activity.<sup>[48]</sup> The two major components of the extracts were identified as salazinic acid and atranorin as confirmed by infra-red spectroscopy.<sup>[49]</sup> The study successfully characterized the phenolic profile of *Parmelia sulcata* and *Parmelia vagans* using HPLC, providing valuable data on their chemical composition.<sup>[44]</sup>

### 3.4 *Thymus vulgaris*

*T. vulgaris* contains many chemical compounds, which are divided into phenolic substances, terpenoids, flavonoids, steroids, alkaloids, tannins and saponins. Most of these substances are volatile compounds extracted from the essential oil of the plant. Phytochemical analysis was performed primarily by gas chromatography with mass spectrometry (GC-MS) and high performance liquid chromatography/thin layer chromatography (HPLC/TLC).<sup>[50–52]</sup> Using GC-MS, 24 compounds were found in thyme oil, mainly related to terpenes and aromatic substances. The key components were thymol, camphene, caryophyllene, humulene,  $\alpha$ -terpeniol, and p-cymene.<sup>[53]</sup> Among all the volatile compounds identified, thymol, carvacrol, geraniol, linalool,  $\alpha$ - and  $\beta$ -pinene, p-cymene, and  $\gamma$ -terpinene have the most pronounced pharmacological activity.<sup>[54–56]</sup> The use of NMR and HPLC-PDA-MS for the analysis of the dichloro-methane extract of the aboveground parts of *Thymus vulgaris* made it possible to identify five known substances: thymol, oleanolic acid, ursolic acid, circumaritin and xanthomicrol. Previous studies have also confirmed the presence of rosemary, caffeic, p-coumaric, geranium, p-hydroxybenzoic, gentisic, syringic, and ferulic acids.<sup>[57]</sup> GC-MS analysis additionally revealed essential compounds such as methyl ester of 2-methylbutanoic acid, bornyl acetate and geranylpropanoate. To determine their pharmacological properties, most of these substances require individual study.<sup>[58]</sup>

Overall, the biologically active compounds found have been discovered in select plants, showcasing the rich potential of these plants in the field of natural medicine (Table 1). These compounds, often associated with antitussive, antimicrobial, anti-inflammatory, antifungal properties, offer promising avenues for pharmaceutical research and the development of novel drugs.

## 4. Pharmacological activities of found compounds from four plants

A comprehensive investigation of *Glycyrrhiza glabra*, *Thymus vulgaris*, *Taraxacum officinale*, and *Parmelia sulcata* is crucial to better understand the diversity of their bioactive compounds and their mechanisms of action. These species demonstrate a broad spectrum of biological effects—including anti-inflammatory, antimicrobial, anti-fungal, anti-

tussive, and antimycobacterial activities—primarily attributed to the presence of flavonoids, terpenes, acids, and other phenolic compounds. As illustrated in Fig. 1, these plants hold significant potential for the development of novel therapeutic agents and should be prioritized in future phytochemical and pharmacological studies.

### 4.1 Antimicrobial activity

#### 4.1.1 *Taraxacum officinale*

In the work of Qian *et al.* (2014), *Taraxacum officinale* oligosaccharides were obtained by hydrolysis with hydrogen peroxide (concentration 100 mg/ml), and their antibacterial activity was evaluated using both agar diffusion and MIC (minimum inhibitory concentration) assays. The agar diffusion test revealed inhibition zones with diameters of 16.15 mm for *Staphylococcus aureus*, 13.21 mm for *Escherichia coli*, and 12.04 mm for *Bacillus subtilis*, confirming their antimicrobial properties (the control group used sterile water). Additionally, the MIC values were determined as follows 3.125 mg/ml for *S. aureus*, 6.25 mg/ml for *B. subtilis*, 12.5 mg/ml for *E. coli*.<sup>[62]</sup> In the study by Arokiyaraj *et al.* (2015) studied the antimicrobial properties of silver nanoparticles synthesized using *Taraxacum officinale* inflorescence extract. The agar diffusion method using streptomycin as a control showed growth suppression zones with a diameter of 10 mm for *Enterococcus faecalis* and 11 mm for *Pseudomonas aeruginosa*, which indicates moderate bactericidal activity of nanoparticles. The determined values of the MIC were 25 mcg/ml for *E. faecalis* and 50 mcg/ml for *P. aeruginosa*, demonstrating a more pronounced effectiveness against the Gram-positive microorganism *E. faecalis* compared with the Gram-negative *P. aeruginosa*.<sup>[91]</sup> The antibacterial activity of the ethyl acetate extract of *Taraxacum officinale* leaves was demonstrated on clinical isolates of *Aeromonas hydrophila*, *Salmonella typhi*, *Staphylococcus aureus*, *Bacillus cereus* and *Escherichia coli* in comparison with drug control (cephalotin, 30 mcg/ml, inhibition zone 12 mm). At an extract concentration of 20 mg/ml, the inhibition zones ranged from 14 mm (*S. typhi*) to 18 mm (*B. cereus*).<sup>[60]</sup> Phytochemical analysis revealed the presence of alkaloids, tannins, and flavonoids, which are likely responsible for the observed antimicrobial activity. The methanol and chloroform extracts were active against all bacterial strains tested, including *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, and *Micrococcus luteus*. The greatest antibacterial activity was recorded for the methanol extract against *S. aureus* ( $13.0 \pm 0.5$  mm) with MIC 0.78 mg/ml, while the hexane extract showed the greatest effectiveness against *E. coli* ( $14.0 \pm 0.6$  mm).<sup>[92]</sup> The study investigated the antimicrobial activity of various *Taraxacum officinale* extracts against five bacterial strains. Methanolic extracts and ethyl acetate extract demonstrated antimicrobial activity against *S. pyogenes* (28.67–29.00 mm) and *S. aureus* (24.00–26.33 mm), respectively. Additionally, the ethyl acetate extract also

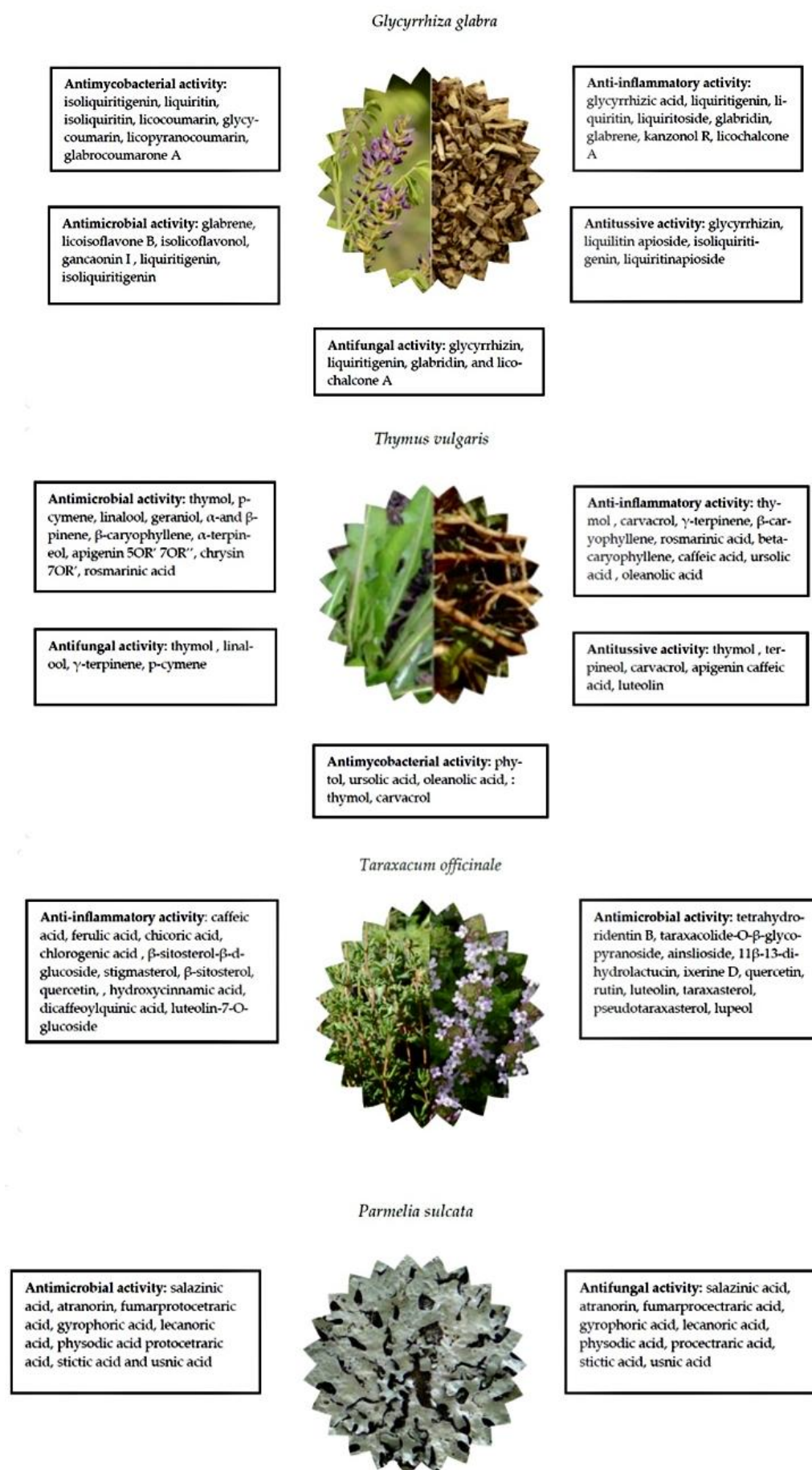


**Fig. 1:** Bioactive compounds and therapeutic potentials of selected medicinal plants.

**Table 1:** Extracted biologically active compounds from *Taraxacum officinale*, *Glycyrrhiza glabra*, *Parmelia sulcata*, *Thymus vulgaris*.

| Extracts                           | Part used    | Bioactive Compounds                         | Pharmacology Activity            | Quality of Control                | Country     | References |
|------------------------------------|--------------|---------------------------------------------|----------------------------------|-----------------------------------|-------------|------------|
| <i>Taraxacum officinale</i>        |              |                                             |                                  |                                   |             |            |
| Aqueous                            | Leaves       | Phenolic compounds, flavonoids, triterpenes | Anti-inflammatory                | Spectrophotometry, HPLC           | Croatia     | [59]       |
| Ethyl acetate                      | Leaves       | Phenolic compounds                          | Antimicrobial                    | Spectrophotometry                 | Iraq        | [60]       |
| Ethanol/aqueous(70:30)             | Whole plant  | Flavonoids                                  | Anti-inflammatory                | Spectrophotometry                 | South Korea | [61]       |
| Methanolic, chloroform             | Roots        | Alkaloids, tannins, flavonoids              | Antimicrobial                    | -                                 | Pakistan    | [42]       |
| Pydrogen peroxide                  |              | Oligosaccharide                             | Antimicrobial                    | UV spectrophotometry, FT-IR, HPLC | China       | [62]       |
| N-hexane, ethylacetate             | Leaves       | Sesquiterpene lactones                      | Antimicrobial                    | GC-MS, NMR                        | Chile       | [63]       |
| Chloroform, hexane                 | Leaves       | Sterols                                     | Antiviral                        | Spectroscopy                      | Venezuela   | [64]       |
| Methanolic                         | Aerial parts | Flavonoids                                  | Antiviral                        | -                                 | Pakistan    | [65]       |
| Aqueous                            | Whole plant  | Phenolic compounds                          | Antioxidant                      | Spectroscopy, DPPH                | Kazakhstan  | [66]       |
| Ethanol                            | Roots        | Sterols                                     | -                                | GC-MS, HPLC                       | Kyrgyzstan  | [67]       |
| Aqueous                            | Roots        | Polysaccharides                             | -                                | Spectroscopy                      | Uzbekistan  | [68]       |
| Aqueous                            | Aerial parts | Sterols, triterpenes                        | Antioxidant                      | Folina-Chocalteu, FRAP, DPPH      | Kazakhstan  | [69]       |
| <i>Glycyrrhiza glabra</i>          |              |                                             |                                  |                                   |             |            |
| Aqueous                            | Leaves       | Terpenoids                                  | Anti-inflammatory                | HPLC-MS                           | China       | [70]       |
| Methanolic                         | Root         | Saponins                                    | Antimicrobial, anti-inflammatory | HPLC                              | India       | [71]       |
| Ethanollic                         | Root         | Flavonoids                                  | Antimicrobial                    | HPLC-MS                           | South Korea | [72]       |
| Methanolic                         | Root         | Organic acids                               | Anti-inflammatory                | HPLC                              | Egypt       | [73]       |
| Methanolic, aqueous                | Radix        | Flavonoids                                  | Antitussive, expectorant         | HPLC, TLC                         | Japan       | [36]       |
| Methanolic, aqueous, ethyl acetate | Full plant   | Triterpenoid saponins                       | Antitussive, expectorant         | HPLC, NMR                         | China       | [74]       |
| Methanolic                         | Root         | Coumarins                                   | Antimicrobial, anti-inflammatory | NMR                               | Japan       | [33,11]    |
| Hydromethanolic                    | Root         | Flavonoids                                  | Antimicrobial                    | CC                                | Japan       | [75]       |

| Extracts                        | Part used                | Bioactive Compounds               | Pharmacology Activity      | Quality of Control            | Country      | References |
|---------------------------------|--------------------------|-----------------------------------|----------------------------|-------------------------------|--------------|------------|
| Carbon dioxide                  | Root                     | Saponins, mono- and disaccharides | Antimicrobial              | GC-MS                         | Kazakhstan   | [76]       |
| Aqueous                         | Aerial parts             | Triterpenoid saponins, flavonoids | Antioxidant                | Folina-Chocalteu, FRAP, DPPH  | Kazakhstan   | [69]       |
| Ethanollic                      | Aerial parts             | Flavonoids                        | Anti-inflammatory          | TLC, spectroscopy             | Uzbekistan   | [77]       |
| Ethanol/aqueous (70:30)         | Roots, rhizomes          | Triterpenoid saponins             | Anti-inflammatory          | HPLC, TLC, spectroscopy       | Uzbekistan   | [78]       |
| Aqueous                         | Roots, rhizomes          | Flavonoids                        | Antioxidant                | HPLC, FRAP, DPPH              | Kyrgyzstan   | [79]       |
| <i>Parmelia sulcata</i>         |                          |                                   |                            |                               |              |            |
| Aqueous                         | -                        | Polyketides                       | Antimicrobial, antifungal  | TLC, microscopy               | Serbia       | [48]       |
| Acetone, methanolic, chloroform | -                        | Polyketides                       | Antifungal                 | HPLC, TLC                     | Turkey       | [80]       |
| Acetone, methanolic, aqueous    | -                        | Polyketides                       | Antimicrobial              | TLC, spectrophotometry        | Serbia       | [81]       |
| Methanolic                      | -                        | Flavonoids, phenolics             | Antimicrobial              | TLC, UV-Vis spectroscopy      | Serbia       | [82]       |
| Ethylacetate                    | -                        | Flavonoids, phenolics             | Antimicrobial              | GC-MS, FT-IR, NMR             | India        | [16]       |
| Acetone                         | -                        | Polyketides                       | Antimicrobial              | TLC, spectrophotometry        | Turkey       | [83]       |
| Methanolic                      | -                        | Polyketides                       | Antimicrobial              | GC-MS                         | Serbia       | [84]       |
| <i>Thymus vulgaris</i>          |                          |                                   |                            |                               |              |            |
| Aqueous                         | Aerial parts/stem/leaves | Essential oils                    | Antimicrobial, antitussive | TLC, GC-MS                    | USA          | [45]       |
| Aqueous                         | Leaves                   | Terpenoids, aromatic compounds    | -                          | GC-MS                         | Saudi Arabia | [43]       |
| Dichloromethane                 | Aerial parts             | Terpenoids                        | Antityrosinase             | NMR, HPLC-PDA-MS              | Greece       | [57]       |
| Ethanol/aqueous (30:70)         | Leaves                   | Phenolic compounds                | Antimicrobial              | UV spectrophotometry.         | Algeria      | [85]       |
| Essential oil                   | -                        | Terpenoids                        | Anti-inflammatory          | GC-MS                         | USA          | [86]       |
| Essential oil                   | -                        | Phenolic compounds                | Antifungal                 | TLC, UV-Vis spectrophotometry | Greece       | [87]       |
| Methanolic, hexane              | Aerial parts             | Terpenoids, phytosterols          | Antimicrobial              | GC-MS, NMR                    | Mexico       | [88]       |
| Hexane                          | Aerial parts             | Terpenoids                        | -                          | GC-MS                         | Kazakhstan   | [89]       |
| Chloroform/methanol (2:1)       | Aerial parts             | Fatty acids                       | -                          | GC-MS                         | Kazakhstan   | [90]       |

showed a effect against *S. pneumoniae* (21.75–22.67 mm).<sup>[93]</sup> In the study, taraxasterol, a pentacyclic triterpene from the roots of *Taraxacum officinale*, demonstrated in vitro activity against *Mycobacterium tuberculosis* with MIC = 64 µg/ml. This substance is of interest for further research, especially in the context of possible synergy with traditional anti-tuberculosis drugs.<sup>[94]</sup>

#### 4.1.2 *Glycyrrhiza glabra*

The methanolic extract of *Glycyrrhiza glabra* was tested against 12 bacterial strains, with most exhibiting susceptibility to the extract. Notably, it demonstrated potent antimicrobial effects against *Staphylococcus aureus*, producing a 22 mm inhibition zone. Additionally, *G. glabra* displayed antibacterial properties against *Bacillus subtilis* and *Escherichia coli*. Studies suggest that its strong antimicrobial efficacy is attributed to the presence of glabrene, licoisoflavone B, isolicoflavonol, and gancaonin I, which actively inhibit these microorganisms.<sup>[95]</sup> In another study, the antibacterial properties of aqueous and alcoholic extracts from *Glycyrrhiza glabra* root were evaluated using the disk diffusion technique on Mueller-Hinton Agar (MHA). The alcoholic extract, obtained through percolation of *G. glabra* roots, exhibited the strongest antimicrobial effect, forming zones of bacterial growth suppression against *E. coli*, *E. faecalis*, *B. cereus*, *P. fluorescens*, and *S. aureus*. The largest inhibition zone, measuring 15 mm, was observed for *E. coli*, *E. faecalis*, and *B. cereus*.<sup>[96]</sup> Therefore, modern research confirms that optimization of extraction is critical for enhancing the yield and activity of key phytochemicals.<sup>[97]</sup> Ethanolic and aqueous extracts of *Glycyrrhiza glabra* leaves demonstrated significant antimicrobial activity, with the ethanolic extract showing superior efficacy. The extracts were particularly effective against *Staphylococcus aureus* (MIC = 1.25 mg/mL, IC<sub>50</sub> = 0.62 mg/mL) and *Candida albicans* (MIC = 2.5 mg/mL, IC<sub>50</sub> = 1.25 mg/mL). The ethanolic extract produced a 12.5 mm inhibition zone against *C. albicans*, while the aqueous extract showed a 14.5 mm zone. Leaf extracts exhibited stronger activity than root extracts, suggesting their potential as natural antimicrobial agents.<sup>[72]</sup> Ethanol extract of *Glycyrrhiza glabra* root demonstrates high antibacterial activity, especially against *Staphylococcus aureus* (MIC = 1.25 mg/ml), which confirms its potential as a natural antimicrobial agent. The highest efficacy is observed against Gram-positive bacteria, whereas Gram-negative strains (*E. coli*, *P. aeruginosa*) require higher concentrations of the extract (MIC = 2.5–5 mg/ml).<sup>[98]</sup> In a recent in vivo study, an inhaled preparation of dry powder based on liposomes with licorice extract was created. When it was aerosolized into mice, about 46% of the administered dose reached the lungs, and after 24 hours, about 16% of the drug remained in the lungs, which was accompanied by a statistically significant decrease in bacterial load in the lungs and spleen of *M. tuberculosis*-infected mice.<sup>[99]</sup> This study confirms the potential of nanotechnology, including functional

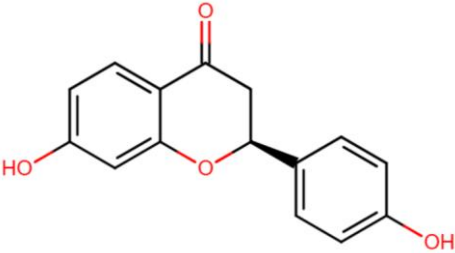
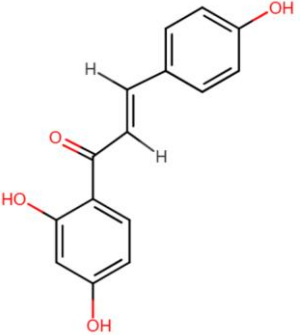
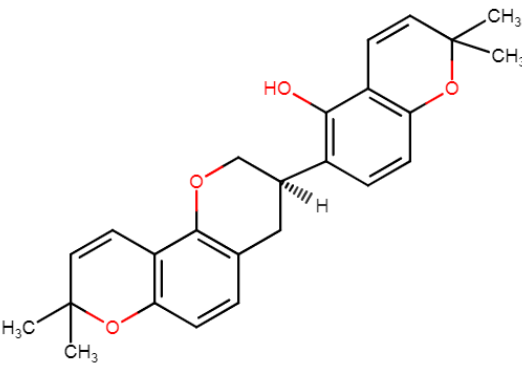
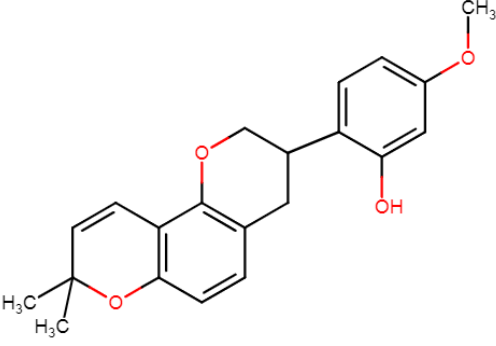
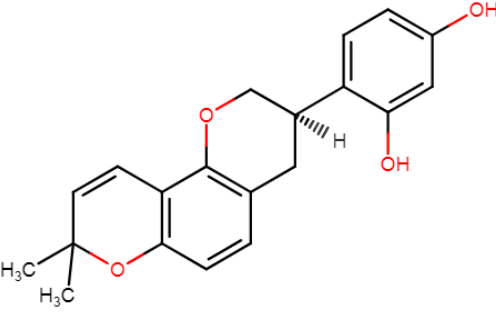
antimicrobial nanomaterials,<sup>[100]</sup> to improve the targeted delivery of plant-based antimycobacterial agents. Additionally, the acetone extract of *Glycyrrhiza glabra*, obtained via Soxhlet extraction, was tested against *Mycobacterium tuberculosis* H37Rv using REMA and colony count methods. The extract showed MIC = 0.97–1.95 µg/mL (REMA) and 5 µg/mL (colony count), with an MBC of 15 µg/mL. It was more effective than isoniazid (7.81–15.62 µg/mL) and ethambutol (15.62–31.25 µg/mL) but less potent than rifampicin (<1 µg/mL). The results suggest *G. glabra* as a potential anti-tubercular drug or adjunct therapy (Table 2).<sup>[101]</sup>

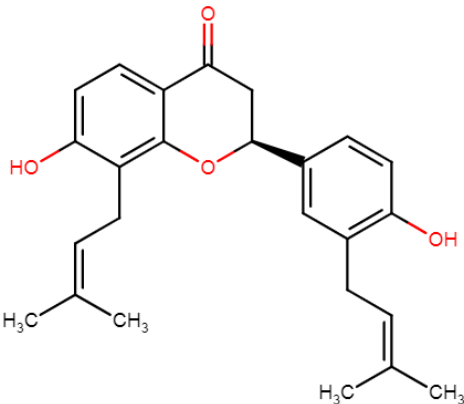
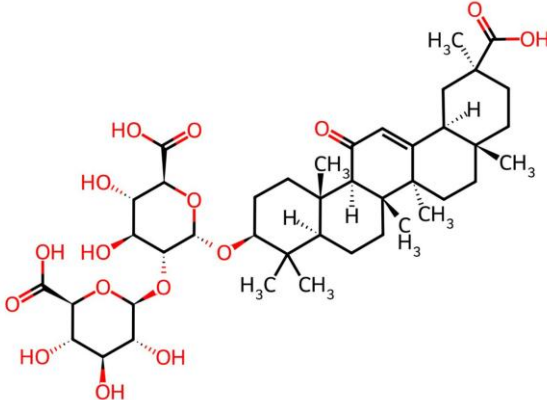
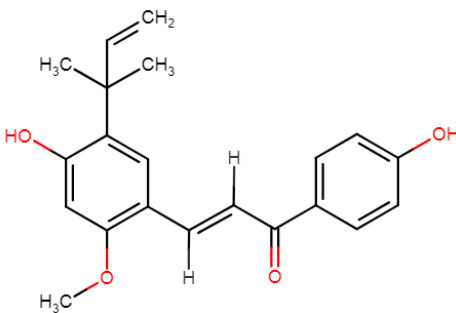
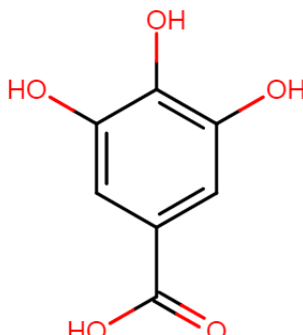
#### 4.1.3 *Parmelia sulcata*

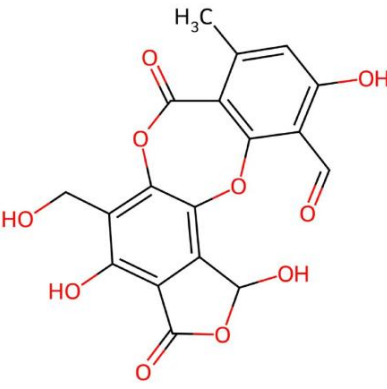
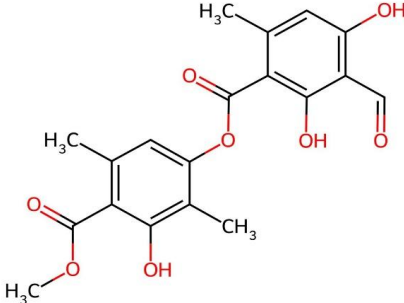
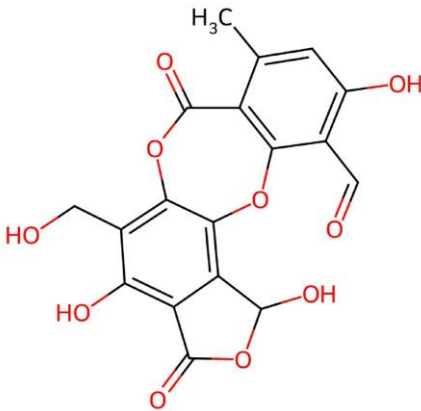
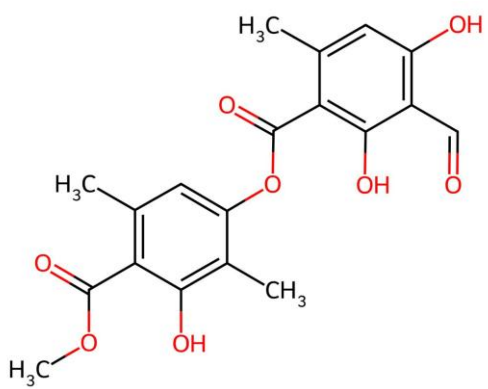
The study evaluated the antimicrobial activity of extracts of petroleum ether, acetone, chloroform, diethyl ether and methanol, as well as salazic acid against a wide range of microorganisms, including *Bacillus cereus*, *B. subtilis*, *Aeromonas hydrophila*, *Proteus vulgaris*, *Streptococcus faecalis*, *Staphylococcus aureus*, *Penicillium notatum*, *Aspergillus niger*, *Candida glabrata*, *C. albicans*, *Yersinia enterocolitica*, *Listeria monocytogenes* and *Aspergillus fumigatus*. Salicylic acid showed the greatest effectiveness, showing mini-mum inhibitory concentrations (MIC) in the range of 0.5–8 micrograms/ml for all tested strains. The methanol extract had a broad-spectrum effect with MICs of 16–64 micrograms/ml against bacteria and 32–128 micrograms/ml against fungi. Acetone and chloroform extracts demonstrated average activity (MIC 32–128 micrograms/ml), whereas diethyl ether extract had a selective inhibitory effect with MIC 64–256 micrograms/ml.<sup>[102]</sup> The study of methanol and acetone extracts of lichens of Parmeliaceae revealed their broad-spectrum antimicrobial activity in the diffusion test. Methanol extracts showed a more pronounced inhibitory effect (growth suppression zones 12–18 mm) compared with acetone extracts (8–14 mm), demonstrating maximum effectiveness against *Bacillus subtilis* (18.2 mm) and *Candida albicans* (16.8 mm). At the same time, *Staphylococcus aureus* turned out to be completely resistant. The observed consistent inhibition of the growth of fungal pathogens (*Aspergillus*, *Fusarium*, *Penicillium* sp.) indicates the presence of bioactive compounds in need of additional phytochemical study.<sup>[103]</sup> The acetone extract showed the greatest activity against *B. subtilis* (25 mm) and *E. coli* (24 mm), while the aqueous extract of *P. sulcata* showed no inhibitory effect on the tested microorganisms.<sup>[73]</sup> In a study by Gandhi *et al.*, the ethyl acetate fraction of *P. sulcata* was evaluated against different bacterial *Klebsiella pneumoniae*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis* and fungal strains *Aspergillus fumigatus*, *Candida albicans* involving microdilution method.<sup>[75]</sup> In an article by N.Y. Sariözlü, methanol and acetone extracts of *Parmelia sulcata* showed inhibitory activity against *Mycobacterium tuberculosis*. The MIC was 8–16 µg/mL, which is comparable to the effect of

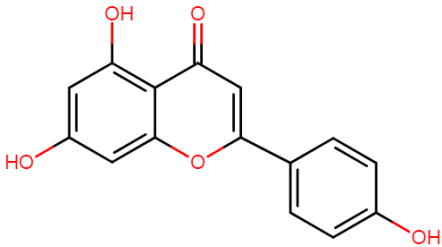
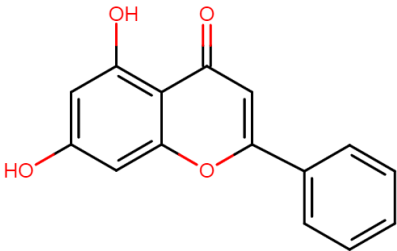
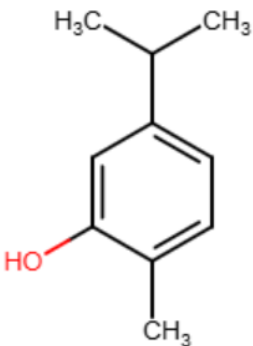
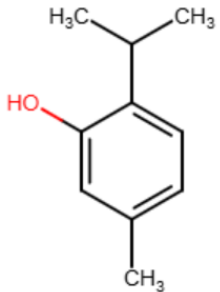
**Table 2:** Antimicrobial activity of *Taraxacum officinale*, *Glycyrrhiza glabra*, *Parmelia sulcata*, *Thymus vulgaris*.

| Bioactive Compounds       | Structures | Strains                                                                             | Zones of Inhibition (mm)            | References |
|---------------------------|------------|-------------------------------------------------------------------------------------|-------------------------------------|------------|
| <i>Glycyrrhiza glabra</i> |            |                                                                                     |                                     |            |
| Glabrene                  |            | <i>Staphylococcus aureus</i><br><i>Bacillus subtilis</i><br><i>Escherichia coli</i> | 22 ± 0.06<br>16 ± 0.06<br>16 ± 0.06 | [114]      |
| Licoisoflavone B          |            | <i>Staphylococcus aureus</i><br><i>Bacillus subtilis</i><br><i>Escherichia coli</i> | 22 ± 0.06<br>16 ± 0.06<br>16 ± 0.06 | [114]      |
| Isolicoflavonol           |            | <i>Staphylococcus aureus</i><br><i>Bacillus subtilis</i><br><i>Escherichia coli</i> | 22 ± 0.06<br>16 ± 0.06<br>16 ± 0.06 | [114]      |
| Gancaonin I               |            | <i>Staphylococcus aureus</i><br><i>Bacillus subtilis</i><br><i>Escherichia coli</i> | 22 ± 0.06<br>16 ± 0.06<br>16 ± 0.06 | [114]      |

| Bioactive Compounds  | Structures                                                                          | Strains                                                | Zones of Inhibition (mm) | References |
|----------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------|--------------------------|------------|
| Liquiritigenin       |    | <i>Enterococcus faecalis</i><br><i>Bacillus cereus</i> | 15 ± 0.02<br>15 ± 0.02   | [115]      |
| Isoliquiritigenin    |    | <i>Enterococcus faecalis</i><br><i>Bacillus cereus</i> | 15 ± 0.02<br>15 ± 0.02   | [115]      |
| Hispaglabridin B     |   | <i>Candida albicans</i>                                | 14,5 ± 0.02              | [116]      |
| 4'-O-methylglabridin |  | <i>Candida albicans</i>                                | 14,5 ± 0.02              | [116]      |
| Glabridin            |  | <i>Candida albicans</i>                                | 14,5 ± 0.02              | [116]      |

| Bioactive Compounds | Structures                                                                          | Strains                                                                                                            | Zones of Inhibition (mm)                     | References |
|---------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------|------------|
| 3-hydroxyglabrol    |    | <i>Candida albicans</i>                                                                                            | 14,5 ± 0.02                                  | [116]      |
| Glycyrrhizin        |   | <i>Bacillus coagulans</i>                                                                                          | 12 ± 0.02                                    | [71]       |
| Licochalcone A      |  | <i>Mycobacterium tuberculosis</i>                                                                                  | 18-25 ± 0.02                                 | [99]       |
| Inulin              | -                                                                                   | <i>Taraxacum officinale</i><br><i>Staphylococcus aureus</i><br><i>Escherichia coli</i><br><i>Bacillus subtilis</i> | 16,15 ± 0.05<br>13,21 ± 0.05<br>12,04 ± 0.05 | [62]       |
| Gallic acid         |  | <i>Salmonella typhi</i><br><i>Bacillus cereus</i>                                                                  | 14 ± 0.02<br>18 ± 0.02                       | [60]       |

| Bioactive Compounds     | Structures                                                                          | Strains                                                                                                                                          | Zones of Inhibition (mm)                                           | References |
|-------------------------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|------------|
| <i>Parmelia sulcata</i> |                                                                                     |                                                                                                                                                  |                                                                    |            |
| Salazinic acid          |    | <i>Bacillus subtilis</i><br><i>Escherichia coli</i>                                                                                              | 25 ± 0.05<br>24 ± 0.05                                             | [73]       |
| Atranorin               |   | <i>Bacillus subtilis</i><br><i>Escherichia coli</i>                                                                                              | 25 ± 0.05<br>24 ± 0.05                                             | [73]       |
| Salazinic acid          |  | <i>Klebsiella pneumoniae</i><br><i>Pseudomonas aeruginosa</i><br><i>Enterococcus sp.</i><br><i>Micrococcus luteus</i><br><i>Candida albicans</i> | 19.0 ± 1.0<br>17.7 ± 0.6<br>16.3 ± 1.5<br>16.7 ± 1.2<br>15.3 ± 1.5 | [77]       |
| Atranorin               |  | <i>Bacillus mycoides</i><br><i>Staphylococcus aureus</i><br><i>Aspergillus flavus</i>                                                            | 28 ± 1.5<br>26 ± 1.2<br>23 ± 1.0                                   | [117]      |

| Bioactive Compounds    | Structures                                                                          | Strains                                                                                                    | Zones of Inhibition (mm)                              | References |
|------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|------------|
| <i>Thymus vulgaris</i> |                                                                                     |                                                                                                            |                                                       |            |
| Apigenin 5OR' 7OR''    |    | <i>Staphylococcus aureus</i><br><i>Escherichia coli</i>                                                    | 15 ± 0.06<br>16 ± 0.17                                | [48]       |
| Chrysin 7 OR'          |    | <i>Escherichia coli</i><br><i>Staphylococcus aureus</i>                                                    | 18 ± 0.22<br>15 ± 0.06                                | [48]       |
| Carvacrol              |   | <i>Streptococcus pyogenes</i><br><i>Streptococcus pneumoniae</i>                                           | 14± 0.05<br>13± 0.05                                  | [118]      |
| Thymol                 |  | <i>Listeria monocytogenes</i><br><i>Bacillus cereus</i><br><i>Yersinia spp.</i><br><i>Salmonella typhi</i> | 38.00 ± 1.0<br>35 ± 1.0<br>28.00 ± 1.0<br>25.33 ± 1.5 | [119]      |

rifampicin (MIC 1-4 µg/mL) and isoniazid (MIC 0.5-2 µg/mL). The extract in combination with standard drugs showed a synergistic effect, enhancing their activity.<sup>[104]</sup> These findings complement the current trend of searching for new antimicrobial agents from non-standard sources, whether lichens or synthesized compounds exhibiting specific activity.<sup>[105]</sup>

#### 4.1.4 *Thymus vulgaris*

Plant extracts of *T. vulgaris* has traditionally been used to treat

various respiratory diseases, including bronchitis, asthma, whooping cough and pharyngitis. Tea based on this plant was particularly popular for relieving the symptoms of coughs and colds.<sup>[106]</sup> The flowering parts of the plant have also been used in folk medicine to treat colds, respiratory infections, and sore throats.<sup>[107]</sup> Modern phytochemical studies have confirmed the presence of biologically active components in extracts - carvacrol and γ-terpinene, which have pronounced antiviral and anti-inflammatory properties, which explains the effectiveness of traditional use.<sup>[108,109]</sup> Chromatographic and

spectral analysis made it possible to identify six flavonoids with pronounced antimicrobial activity in thyme. These compounds demonstrated the greatest effectiveness against *S. aureus*, forming inhibition zones with a diameter of 10-15 mm, whereas for *E. coli* this figure was 8-18 mm. Hydroxylated flavonoids were particularly active, in particular chrysin 7OR', which showed growth suppression zones of 15 mm for *S. aureus* and 18 mm for *E. coli*.<sup>[95]</sup> The study of the methanol extract of *T. vulgaris* against the methicillin-resistant strain of *S. aureus* (MRSA) deserves special attention. In vivo experiments with bacterial cultures isolated from infected mouse tissues showed minimum inhibitory concentrations (MIC) of 2.93 CFU for throat strains and 3.83 CFU for lung isolates.<sup>[110]</sup> Numerous studies confirm the pronounced antimicrobial efficacy of extracts and essential oils of *Thymus vulgaris*. Of particular interest is their activity against polyresistant strains of microorganisms. Thyme essential oil shows a pronounced suppressive effect on multidrug-resistant strains of *Staphylococcus aureus* (MRSA), forming inhibition zones of 35-40 mm at concentrations of 2.8-11.5 micrograms/ml, which significantly exceeds the effectiveness of cefotaxime (MIC 32 micrograms/ml,  $p < 0.05$ ).<sup>[111]</sup> GC/MS analysis revealed that the main bioactive components are thymol, p-cymene and linalool. Antimycobacterial activity deserves special attention. Hexane and methanol extracts exhibit moderate action against *Mycobacterium tuberculosis* (MIC 25 micrograms/ml for the H37Rv strain), while phytol and triterpenic acids demonstrate activity against MDR strains with MIC 6.25-12.5 micrograms/ml.<sup>[90]</sup> The essential oil shows exceptional effectiveness - complete suppression of the growth of *M. tuberculosis* is already observed at a concentration of 1 microgram/ml, with a total MIC range of 0.5-40 micrograms/ml, including polyresistant strains.<sup>[112]</sup> According to a 2023 systematic review comparing 13 medicinal plants, *Thymus vulgaris* essential oil demonstrated the highest antimycobacterial activity (MIC 0.5-40 micrograms/ml), surpassing the effectiveness of standard anti-tuberculosis drugs (isoniazid, streptomycin).<sup>[113]</sup> These data highlight the significant therapeutic potential of thyme in the fight against resistant bacterial and mycobacterial infections.

According to the data from the table on the antimicrobial activity of *Taraxacum officinale*, *Glycyrrhiza glabra*, *Parmelia sulcata* and *Thymus vulgaris* extracts, it shows that all four plants have pronounced antimicrobial properties, but the degree and spectrum of activity vary. The highest efficacy was demonstrated by extracts of *Thymus vulgaris* and *Parmelia sulcata*, which are active against a wide range of pathogens, including resistant strains (MRSA, *M. tuberculosis*) and fungi (*C. albicans*), due to the high content of biologically active substances such as thymol, carvacrol and salicylic acid. *Glycyrrhiza glabra* and *Taraxacum officinale* showed selective activity mainly against Gram-positive bacteria, especially *S. aureus* and *B. subtilis*, while licorice also showed potential against mycobacteria. All extracts are

characterized by a more pronounced activity against Gram-positive microorganisms compared to gram-negative ones. The data obtained provides a basis for further applied research aimed at creating effective drugs, ranging from local antiseptic forms to systemic therapeutic agents.<sup>[120,121]</sup>

## 4.2 Anti-Tussive activity

### 4.2.1 *Glycyrrhiza glabra*

A clinical trial by Hashim M. evaluated the bronchorelaxant effects of *Glycyrrhiza glabra*, olibanum, and prednisolone in 18 patients per group over 21 days. Pulmonary function tests showed improvement in FEV1% (licorice: 62.30±7.22 to 81.10±11.0, olibanum: 61.33±6.04 to 72.45±5.8) and FVC, with reduced asthma attacks. Licorice provided greater symptomatic relief than olibanum, alleviated throat irritation, and acted as an expectorant by stimulating tracheal mucus secretion, enhancing its bronchoprotective properties.<sup>[122]</sup> Licorice powder, extracted using 95% ethanol or water, has been found effective in treating sore throat, cough, and bronchial catarrh. It acts as both an anti-tussive and expectorant, aiding in the loosening and removal of congestion in the upper respiratory tract by stimulating tracheal mucus secretion.<sup>[74]</sup> Research identified liquiritin apioside as a key compound in licorice methanolic extract. A study using an ammonia-induced cough model in mice found that liquiritin apioside, liquiritin, and liquiritigenin (50 mg/kg) reduced cough frequency by 30–78% and showed strong anti-tussive and expectorant effects. Meanwhile, isoliquiritin apioside, isoliquiritigenin, and glycyrrhetic acid exhibited moderate antitussive activity.<sup>[123]</sup> A study evaluated the anti-cough effects of a water-extracted polymeric fraction (WE) from *Glycyrrhiza glabra* using a citric acid-induced cough model in guinea pigs. The arabinogalactan-enriched fraction showed potent antitussive activity, with 50 mg/kg orally significantly reducing cough frequency, surpassing codeine in effectiveness. This suggests WE as a promising natural cough remedy.<sup>[124]</sup>

### 4.2.2 *Thymus vulgaris*

*Thymus vulgaris* is used to cure respiratory diseases. The essence extracted from thyme leaves helps to relieve coughing and short-term bronchitis. The leaves contain flavonoids that relax the throat muscles involved in coughing and lessen inflammation. Thyme relaxes the muscles of the trachea and bronchi and also opens up airways. The result is less coughing and increased comfort.<sup>[125]</sup> In a study by Schönknecht K. *et al.* (2016), researchers examined the effectiveness of a combined preparation containing thyme extract, primrose extract, and thymol for treating cough associated with respiratory infections. The findings demonstrated that this herbal combination significantly improved symptoms including cough, dyspnea, and shortness of breath while also reducing the duration of illness. Notably, the therapeutic efficacy of this phyto-complex proved comparable to the synthetic drug ambroxol. These results

support the potential of plant-based extracts as a safe alternative to synthetic antitussive medications.<sup>[126]</sup>

### 4.3 Anti-Fungal activity

#### 4.3.1 *Taraxacum officinale*

The antifungal activity of the various concentrations of ethyl acetate extracts of *Taraxacum officinale* against the various strains of fungi such as *Aspergillus niger* and *Candida albicans* revealed that the extract inhibited the growth of the fungi at different concentrations. The zones of inhibition for *Aspergillus niger* and *Candida albicans* at 80 mg/ml was  $17 \pm 0.15$  and  $15 \pm 0.02$  mm respectively.<sup>[127]</sup>

#### 4.3.2 *Glycyrrhiza glabra*

Hydroalcoholic extracts derived from the roots and rhizomes of *Glycyrrhiza glabra* were assessed for their antifungal activity. Their efficacy was tested against 19 strains of *Candida* using the disc diffusion method. Zones of inhibition measured between 1.0 and 1.2 cm for *C. albicans* and *C. parapsilosis*, 1.0–1.3 cm for *C. tropicalis*, and approximately 1.2 cm for *C. glabrata*.<sup>[128]</sup> The lower MIC value of the 80% methanolic extract (40.2 mg/mL) compared to fluconazole (140 mg/mL) further confirms its stronger inhibitory effect on *A. niger* growth in this study.<sup>[129]</sup> In another study, *Glycyrrhiza glabra* and its extracts demonstrated strong fungicidal effects against phytopathogenic fungi, primarily due to their rich content of phenolic compounds, including flavonoids, isoflavonoids, and chalcones. Among these, glabridin exhibited notable antifungal activity against ten species of phytopathogenic fungi. It was particularly effective against *Sclerotinia sclerotiorum*, with an  $EC_{50}$  of 6.78  $\mu$ g/mL, making it 8 times more potent than azoxystrobin  $EC_{50}$  of 57.39  $\mu$ g/mL. Furthermore, in vivo bioassays confirmed that glabridin successfully inhibited *S. sclerotiorum*, highlighting its potential as a promising natural fungicide.<sup>[130]</sup>

#### 4.3.3 *Parmelia sulcata*

The study on the antifungal activity of *Parmelia sulcata*, and evaluated the inhibitory effects of their extracts against various fungal strains. Among the tested lichens, *Parmelia sulcata* demonstrated notable antifungal effects, particularly against *Candida albicans* and *Aspergillus niger*. The study highlights the potential of lichen-derived compounds as natural antifungal agents, suggesting their use in pharmaceutical and cosmetic applications.<sup>[131]</sup> The study on *Parmelia sulcata* by A. Gandhi and K. Umamahesh also investigated its antifungal activity. The ethyl acetate extract of the lichen was tested against various fungal strains, including *Candida albicans* and *Aspergillus niger*. The lichen extract showed a significantly larger inhibition zone (22.5 mm) compared to the standard drug (18.3 mm), demonstrating stronger in vitro antifungal activity. The presence of phenolic and flavonoid compounds in the extract is believed to contribute to its antifungal properties.<sup>[16]</sup> For antifungal activity, *Parmelia sulcata* demonstrated the

highest zone of inhibition ( $28.60 \pm 0.33$  mm), followed by *Evernia mesomorpha*, *Sticta lambata*, *Usnea subfloridiana*, *Collema furfuraceum*, and *Pheophysia* against *Aspergillus* species. FTIR analysis confirmed the presence of bioactive compounds such as phenols, aldehydes, carboxylic acids, and nitro compounds, which contribute to the antimicrobial effects. Overall, the study suggests that these lichen species could be potential natural antimicrobial agents against multidrug-resistant bacteria and pathogenic fungi, emphasizing their medicinal significance.<sup>[132]</sup>

#### 4.3.4 *Thymus vulgaris*

Scalas *et al.* (2018) assessed the antifungal activity against *Cryptococcus neoformans* where MIC and MFC were found to be in the range of 56–1.12 mg/ml, in accordance with the standards fluconazole, itraconazole, and voriconazole. But individual antifungal assay showed profound results with thymol (0.02–0.08 mg/ml).<sup>[133]</sup> Further, a group of 183 clinical isolates of *Candida albicans* and 76 isolates of *C. glabrata* species were tested for sensitivity towards *T. vulgaris* L. extract. Both MIC and minimum fungicidal concentration (MFC) were found to be in the range of 0.04–22.9 mg/ml for all the isolates. In the time kill assay, thyme oil reduced the fungal growth in the initial hours (4–8).<sup>[134]</sup> Thyme essential oil was found to be effective against fungal species including *Sclerotinia sclerotiorum*, *Botrytis cinerea*, *Phytophthora parasitica*, *Pythium aphanidermatum*, *Fusarium oxysporum*, *Alternaria brassicae*, *Trichoderma aggressivum* f.sp. *europaeum*, and *Cladobotryum mycophilum*. The sensitivity of these fungi were assessed with the radial growth inhibition assay, which revealed an inhibitory value ranging from 13.9 to 41.4 mm at 5% concentration and ED50 values ranging from 9.3 to 18.0% for all the species tested.<sup>[135]</sup> The data presented collectively highlight the key advantage of natural antifungal agents, which lies in their complex action on several targets simultaneously and their favorable safety profile, distinguishing them from a number of synthetic analogues.<sup>[136]</sup>

### 4.4 Anti-Inflammatory effects

#### 4.4.1 *Taraxacum officinale*

Very recent animal studies additionally rumored protecting anti-inflammatory effects of dandelion on acute lung injury induced by LPS in mice. Dandelion inhibits the assembly of inflammatory cytokines (TNF- $\alpha$  and IL-6) in bronchoalveolar lavage fluid six hours after injury induction and reduces the number of neutrophils and also the wet weight of lungs after twenty-four hours.<sup>[137]</sup> An abundance of luteolin in *Taraxacum* has been proven to have higher anti-inflammatory properties, according to recent studies.<sup>[138]</sup> *Taraxacum*'s anti-inflammatory mechanism may be connected to its capacity to decrease the mRNA expression of inflammatory factors (COX-2, TNF- $\alpha$ , IL-6, and IL-1) in a dose-dependent manner.<sup>[58]</sup> The aqueous extracts of *Taraxacum officinale* exhibit therapeutic effects on acute lung injury in mice.<sup>[139]</sup>

#### 4.4.2 *Glycyrrhiza glabra*

The anti-inflammatory effect of the hydroalcoholic extract of *Glycyrrhiza glabra* root was investigated using a carrageenan-induced paw edema model in rats. The extract was administered orally at doses of 100, 200, and 300 mg/kg. The highest inhibitory effect (46.86%) was observed at a 200 mg/kg dose, along with a dose-dependent reduction in leukocyte migration. The results were comparable to indomethacin (10 mg/kg), confirming the extract's significant anti-inflammatory properties.<sup>[71]</sup> Several secondary metabolites isolated from rhizomes of *Glycyrrhiza glabra* were investigated for the COX-2 inhibitory activity using Cayman COX (ovine) inhibitory screening assay. A few molecules showed potent COX-2 inhibitory activity which may be beneficial as anti-inflammatory agents.<sup>[140]</sup> Glycyrrhizin exhibited anti-inflammatory activity, similar to hydrocortisone due to inhibition of phospholipase A2 activity, glycyrrhizic acid inhibited cyclooxygenase activity and prostaglandin formation (specifically prostaglandin E2), as well as indirectly inhibiting platelet aggregation.<sup>[141]</sup> In the study, glycyrrhizin reduced the severity of inflammation in mice in a model of acute pulmonary injury (induced by liposaccharides). Glycyrrhizin treatment reduced the levels of pro-inflammatory mediators (TNF- $\alpha$ , IL-1 $\beta$ , IL-6, IL-18, PGE2) and the permeability of the alveolar wall, as well as the activity of the enzyme myeloperoxidase.<sup>[142]</sup>

#### 4.4.3 *Thymus vulgaris*

The anti-inflammatory activity of *T. vulgaris* EOs can be mainly attributed to its main compound, thymol. In an in vivo study, Abdelli *et al.* (2017) analysed thyme oil in a dose dependent manner (100, 200 and 400 mg/kg) against mice with carrageenan-induced paw edema to determine the anti-inflammatory activity. Paw thickness was found reducing at a dose of 400 mg/kg. Results were in accordance with both the controls Tween 80 and diclofenac.<sup>[143]</sup> Additionally, thyme has been found to downregulate the expression of cyclooxygenase-2 (COX-2) and lipoxygenase (LOX), enzymes involved in the inflammatory response that catalyze the production of inflammatory mediators like prostaglandins and leukotrienes.<sup>[144]</sup> In Habashy NH *et al.* study *Thymus vulgaris* extracts showed both the antioxidant and anti-inflammatory activities. Effect of thymol and carvacrol on inflammatory transcription factors.<sup>[145]</sup> Gholijani N *et al.* determined the effects of the critical components of *Thymus vulgaris* essential oil, thymol, and carvacrol in 2016.<sup>[146]</sup>

### 5. Conclusion and future prospects

The analysis of the pharmacological properties of *Glycyrrhiza glabra*, *Taraxacum officinale*, *Parmelia sulcata* and *Thymus vulgaris* confirms their significant potential as sources of biologically active compounds with antimicrobial, antimicrobial and anti-inflammatory activity. Together, these plants are of interest for further study in the composition of combined phytopreparations designed for synergistic action

with traditional anti-tuberculosis drugs. In addition, a promising direction is to study their interaction with probiotic strains to enhance their immunomodulatory and antimicrobial effects. Based on the literature analysis, extraction methods are currently being optimized, aimed at maximizing the extraction of biologically active compounds with antimycobacterial activity. In the future, it is planned to develop medicines of natural source with proven antimycobacterial efficacy.

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### Conflict of Interest

There is no conflict to declare.

### Supporting Information

Not applicable.

### CRedit Statement

**Irina Ratnikova** and **Guzel Bozhbanbayeva**: Supervision, Writing and Editing, Coordinated the writing of the paper and made corrections to the review work. **Sundetgali Kalmakhanov** and **Amankeldi Sadanov**: Conceptualization, Writing, Visualization, Presented the idea for writing the review. **Baiken Baimakhanova**, **Erik Shorabayev**, **Aknur Turgumbayeva** and **Akerke Amirkhanova**: Participated in the review's writing and revision.

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