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Central Asian Medicinal Plants as Emerging Sources of Antimicrobial Natural Products Against Multidrug-Resistant Pathogens: A Narrative Review

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ABSTRACT: Antimicrobial resistance (AMR) has been described by the World Health Organization as one of the most pressing global public health threats of the current decade, with resistant infections projected to cause substantially increased mortality in the coming years if the current, markedly slowed pace of new antibiotic discovery is not reversed. Plant-derived natural products have re-emerged as a major focus of anti-infective drug discovery, both as stand-alone antimicrobial agents and as adjuvants capable of restoring susceptibility to existing antibiotics against resistant pathogens. Central Asia, and Uzbekistan in particular, harbours an exceptionally rich and comparatively underexplored medicinal flora that has historically supplied globally important antimicrobial raw materials, most notably liquorice (Glycyrrhiza glabra). This review synthesises recent (2020-2026) evidence on the antimicrobial activity of several Central Asian plant genera against clinically important multidrug-resistant (MDR) pathogens, including methicillin-resistant Staphylococcus aureus (MRSA), extended-spectrum beta-lactamase-producing Enterobacteriaceae, and MDR Pseudomonas aeruginosa and Acinetobacter baumannii. We discuss documented activity and putative mechanisms for Glycyrrhiza glabra, whose isoflavonoid glabridin has recently been shown to disrupt MRSA biofilm formation and whose chromatographic fractions contain compounds

active against multiple MDR Gram-negative and Gram-positive pathogens; for Ferula species, whose sesquiterpene coumarins possess documented antibacterial and antifungal activity; for Peganum harmala, whose β-carboline alkaloids exhibit broad-spectrum antimicrobial effects; and for Mentha asiatica, a Central-Asian-native mint species whose essential oil constituents have been specifically reviewed for antimicrobial potential in the context of rising antibiotic resistance. We conclude that Central Asian flora constitutes a genuine, still largely untapped reservoir for anti-infective natural product discovery, but that the evidence base remains overwhelmingly preclinical and in vitro, and that standardised susceptibility testing against well-characterised MDR clinical isolates, mechanistic studies, and eventual translational and combination-therapy studies with existing antibiotics represent priority directions for future research.

1. INTRODUCTION

Antimicrobial resistance is now widely recognised as one of the defining public health challenges of the twenty-first century. Contemporary estimates place the annual global burden of deaths attributable to antimicrobial resistance in the hundreds of thousands, with projections indicating substantially larger annual mortality within the coming decades if current resistance trends and the markedly slowed pace of novel antibiotic discovery and regulatory approval are not reversed (Baranova et al., 2023; Unnam et al., 2025). This gap between the accelerating emergence of resistant pathogens, particularly the Gram-positive and Gram-negative organisms collectively referred to under the ESKAPE acronym, and the comparatively stagnant pipeline of genuinely novel antimicrobial chemical scaffolds has renewed sustained international scientific interest in plant-derived natural products as a source of both stand-alone antimicrobial agents and adjuvant compounds capable of potentiating existing antibiotics against otherwise resistant organisms (Unnam et al., 2025).

Historically, plants have supplied a substantial proportion of clinically used anti-infective agents and their chemical scaffolds, and recent systematic reviews of the 2018-2022 literature alone have documented a continuing, active stream of newly characterised plant-derived antibacterial, antivirulence, and antibiofilm natural products (Chassagne et al., 2021; Woo et al., 2023). Within this broader context, Central Asia occupies a distinctive position: the region's exceptional floristic diversity and long, continuous ethnomedical tradition, discussed in detail in our companion review of the region's general ethnopharmacology, include several genera of documented historical and continuing global pharmaceutical significance, most notably Glycyrrhiza (liquorice), for which Uzbekistan remains among the principal producing countries worldwide. Despite this, the specific antimicrobial-resistance-relevant literature on Central Asian medicinal flora remains comparatively fragmented and has not, to our knowledge, been previously synthesised as a dedicated narrative review. The present review addresses this gap by synthesising recent evidence, with particular emphasis on studies published between 2020 and 2026, concerning the activity of several pharmacologically significant Central Asian plant genera against clinically relevant multidrug-resistant bacterial pathogens.

2. METHODS

This narrative review draws on peer-reviewed in vitro and preclinical studies concerning the antimicrobial activity of Central Asian medicinal plant genera against multidrug-resistant bacterial pathogens, identified through searches of PubMed, Scopus, and Google Scholar using combinations of the terms "antimicrobial resistance", "multidrug-resistant", "MRSA", "ESBL", "antibacterial", together with genus-specific terms for the taxa discussed below and the terms "Central Asia" and "Uzbekistan" where applicable. Given the comparative scarcity of region-specific antimicrobial-resistance literature identified, studies conducted on the relevant genus using plant material sourced from other regions are also discussed where they provide mechanistically or clinically relevant evidence directly applicable to the same species present in Central Asian flora, with the geographic origin of study material noted explicitly throughout.

3. GLYCYRRHIZA GLABRA (LIQUORICE)

Glycyrrhiza glabra possesses, among the genera reviewed here, by far the most developed evidence base specifically relevant to multidrug-resistant pathogens. A 2021 evaluation of sixty plant extracts against clinical isolates of methicillin-resistant and methicillin-susceptible Staphylococcus aureus (MRSA and MSSA), extended-spectrum beta-lactamase-producing Escherichia coli, and multidrug-resistant Pseudomonas aeruginosa identified G. glabra among ten extracts exhibiting the highest antibacterial

activity overall, with a documented inhibition zone of 13.1 mm against MRSA and 15.4 mm against MSSA isolates (Bataineh et al., 2021). A separate chromatographic fractionation study of G. glabra extracts identified two specific bioactive compounds, aldehydo isoophiopogonone and liquiritigenin, with confirmed activity against a panel of multidrug-resistant clinical isolates including Escherichia coli, Acinetobacter baumannii, Staphylococcus aureus, and Pseudomonas aeruginosa, providing compound-level rather than merely crude-extract-level evidence of antimicrobial activity relevant to resistant pathogens (Rahman et al., 2018).

Mechanistically, the most detailed recent evidence concerns glabridin, a prenylated isoflavan specific to G. glabra. A 2026 review in Frontiers in Pharmacology detailed evidence that glabridin acts against MRSA not primarily through direct bactericidal killing but by disrupting biofilm formation, reprogramming the bacterial cell-surface proteome in a manner that shifts MRSA away from an adhesion- and matrix-production-competent, biofilm-permissive state toward a more antibiotic-susceptible planktonic phenotype, a mechanism of particular clinical relevance given that biofilm-associated MRSA infections of wounds and indwelling medical devices are notoriously difficult to eradicate with conventional antibiotic therapy alone (Rafiq et al., 2026). The same review further notes that related polyphenolic compounds from Glycyrrhiza uralensis, a species also present across parts of Central Asia, have separately been reported to inhibit biofilm formation by other clinically relevant bacterial species, reinforcing anti-biofilm activity as a recurring theme across the genus rather than a property isolated to G. glabra alone (Rafiq et al., 2026).

4. FERULA SPECIES

Ferula species, discussed in detail for their broader phytochemistry in our companion ethnopharmacological review, are characterised principally by sesquiterpene coumarins and related terpenoid constituents that have documented antibacterial and antifungal activity alongside their better-studied cytotoxic and anti-inflammatory properties (Sonigra & Meena, 2021). While dedicated testing of Central Asian Ferula material specifically against defined multidrug-resistant clinical isolates remains limited relative to the Glycyrrhiza literature, the genus's oleo-gum-resins have a long history of use as antiseptic agents in regional traditional medicine, and characterised sesquiterpene coumarins from Ferula roots possess demonstrated in vitro antimicrobial activity against both bacterial and fungal test organisms (Sonigra & Meena, 2021), providing a plausible phytochemical basis for more targeted future evaluation against defined resistant clinical isolates specifically.

5. PEGANUM HARMALA

Peganum harmala, discussed above for its broader ethnomedicinal role in Central Asia, contains as its principal bioactive constituents the β-carboline alkaloids harmine and harmaline, together with related quinazoline alkaloids, which possess well-documented broad-spectrum antimicrobial activity against both Gram-positive and Gram-negative bacteria in the wider pharmacological literature, alongside antifungal and antiparasitic effects (Moloudizargari et al., 2013). The plant's traditional use as a fumigant, in which seed smoke is believed to possess purifying properties against illness, may plausibly reflect an empirically discovered antimicrobial or air-disinfecting property of the volatilised alkaloids and other combustion products, though this specific hypothesis has not, to our knowledge, been formally tested using modern microbiological methodology and represents a clear candidate for future investigation bridging ethnomedical practice and mechanistic microbiology.

6. MENTHA ASIATICA

Mentha asiatica Boriss., a mint species native to Central Asia, was the subject of a dedicated 2025 review specifically synthesising evidence on its antimicrobial potential in the context of rising global antibiotic resistance (Baimakhanova et al., 2025). The species' essential oil, characterised principally by menthol, menthone, and carvone alongside a range of sesquiterpenes and other terpenoids, demonstrates a broad spectrum of antimicrobial activity attributed to this combination of volatile constituents, with the reviewing authors explicitly situating the plant's traditional ethnomedicinal use within the contemporary search for natural alternatives to conventional antibiotics (Baimakhanova et al., 2025). As a species native specifically to the Central Asian region rather than merely present within it, M. asiatica represents a particularly direct example of regional flora with both documented traditional use and an emerging, dedicated modern antimicrobial evidence base.

7. MEDICINAL MACROFUNGI

Beyond vascular plants, the documented diversity of medicinal macrofungi associated with Uzbekistan's forest ecosystems, discussed in our companion ethnopharmacological review, represents a further, largely unexplored potential source of

antimicrobial natural products specifically relevant to the resistance context (Gafforov et al., 2023). Medicinal Basidiomycete fungi more broadly are well established in the international literature as sources of antimicrobial polysaccharides, triterpenoids, and phenolic compounds; whether the specific macrofungal species catalogued in Uzbekistan possess activity against defined multidrug-resistant clinical isolates has not, to our knowledge, yet been directly tested, and represents a clear and tractable priority for future regional research building on the existing biodiversity and taxonomic groundwork already completed (Gafforov et al., 2023).

8. MECHANISMS AND TRANSLATIONAL CONSIDERATIONS

Across the genera reviewed, the mechanistic evidence, where available, points toward several recurring modes of action distinct from the direct bactericidal mechanisms of most conventional antibiotics: disruption of biofilm formation and bacterial surface adhesion, as documented for Glycyrrhiza glabra-derived glabridin against MRSA; broad-spectrum membrane and metabolic disruption attributed to volatile terpenoid constituents, as characterised for Mentha asiatica essential oil; and alkaloid-mediated antimicrobial effects of a still incompletely characterised mechanism for Peganum harmala. This mechanistic diversity is itself of translational interest, since natural products acting through biofilm disruption or membrane-level effects, rather than through the specific enzymatic or ribosomal targets exploited by most conventional antibiotics, may in principle be less susceptible to the resistance mechanisms, such as target-site mutation and efflux-pump-mediated resistance, that most commonly underlie clinical antibiotic failure, though this hypothesis requires direct experimental testing specific to each compound and pathogen combination rather than assumption.

Notwithstanding this mechanistic promise, the evidence reviewed here remains almost entirely preclinical, comprising crude-extract disc-diffusion and minimum-inhibitory-concentration assays together with a smaller number of compound-level and mechanistic studies, with essentially no identified evidence from animal infection models or clinical trials specific to Central Asian plant material tested against defined multidrug-resistant pathogens. Priority directions for future work therefore include standardised susceptibility testing of Central Asian plant material against well-characterised, genotypically defined MDR clinical isolate panels; formal synergy testing in combination with clinically used antibiotics, an approach of particular relevance given the biofilm-disruption mechanism documented for glabridin, which may plausibly restore antibiotic susceptibility in combination therapy even where the natural product itself lacks strong stand-alone bactericidal activity; and, ultimately, appropriately designed in vivo efficacy and safety studies as a bridge toward eventual clinical evaluation.

9. CONCLUSION

Central Asian medicinal flora, and Glycyrrhiza glabra in particular, constitutes a genuine and, for several of the genera reviewed here, still substantially underexplored source of natural products with documented activity against clinically important multidrug-resistant bacterial pathogens including MRSA and MDR Gram-negative organisms. The recent characterisation of specific active compounds and, for glabridin, a plausible biofilm-disruption mechanism of action, moves this evidence base beyond simple crude-extract screening toward a more mechanistically grounded and translationally credible foundation. Realising this potential as a genuine contribution to the global antimicrobial resistance response will require expanded, standardised testing against well-defined resistant clinical isolates, mechanistic studies for the less-characterised genera discussed here, and, critically, a sustained research trajectory from preclinical characterisation toward properly designed combination-therapy and in vivo efficacy studies.

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