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CHEMICAL COMPOSITION, BIOLOGICAL PROPERTIES, AND RESEARCH TRENDS OF ACROPTILON REPENS: A SYSTEMATIC REVIEW

Kholmuradov Bobur Bahrom o‘g‘li
Tashkent Institute of Chemical Technology Department of Food Technology teacher
E.mail:boburxolmuradov1996@gmail.com
Ishimov Uchkun Jomuradovich
Academy of Sciences of the Republic of Uzbekistan, docent Institute of Bioorganic Chemistry named after O.S. Sodikov
E.mail:uchkunishimov24@gmail.com

Abstract. Acroptilon repens (Russian knapweed) is a perennial invasive plant that negatively affects agricultural systems and natural ecosystems worldwide. Although its ecological impact has been widely studied, information on its chemical composition and biological properties remains insufficiently systematized. This review summarizes current research on the phytochemical profile of A. repens, focusing on its secondary metabolites such as sesquiterpene lactones, flavonoids, and phenolic acids. These compounds exhibit antimicrobial, anti-inflammatory, cytotoxic, and phytotoxic properties that contribute to the plant’s ecological dominance and resistance to conventional control methods. The findings emphasize the need for interdisciplinary research to improve management strategies and explore its bioactive potential in agriculture and medicine.

Keyword: acroptilon repens, phytochemistry, sesquiterpene lactones, bioactive compounds, antimicrobial activity, flavonoids.

Annotatsiya. Acroptilon repens ko‘p yillik invaziv o‘simlik bo‘lib, dunyoning ko‘plab hududlarida qishloq xo‘jaligi tizimlari va tabiiy ekotizimlarga salbiy ta’sir ko‘rsatadi. Uning ekologik ta’siri keng o‘rganilgan bo‘lishiga qaramay, kimyoviy tarkibi va biologik xususiyatlari haqidagi ma’lumotlar yetarli darajada tizimlashtirilmagan. Mazkur sharh A. repens o‘simligining fitokimyoviy tarkibi, xususan seskviterpen laktonlar, flavonoidlar va fenolik kislotalar kabi ikkilamchi metabolitlariga oid mavjud ilmiy tadqiqotlarni umumlashtiradi. Ushbu birikmalar mikroblarga qarshi, yallig‘lanishga qarshi, sitotoksik va fitotoksik xususiyatlarga ega bo‘lib, o‘simlikning ekologik ustunligi hamda an’anaviy begona o‘tlarni nazorat qilish usullariga chidamliligini ta’minlaydi. Olingan natijalar A. repens ni boshqarish strategiyalarini takomillashtirish hamda uning bioaktiv salohiyatidan qishloq xo‘jaligi va tibbiyotda foydalanish uchun fanlararo tadqiqotlar zarurligini ko‘rsatadi.

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Kalit so‘zlar: Acroptilon repens, fitokimyo, seskviterpen laktonlar, bioaktiv birikmalar, antimikrob faollik, flavonoidlar

Аннотация. Acroptilon repens является многолетним инвазивным растением, оказывающим негативное воздействие на сельскохозяйственные системы и природные экосистемы во многих регионах мира. Несмотря на широкое изучение его экологического влияния, сведения о химическом составе и биологических свойствах остаются недостаточно систематизированными. В данном обзоре обобщены современные исследования фитохимического профиля A. repens с особым вниманием к его вторичным метаболитам, таким как сесквитерпеновые лактоны, флавоноиды и фенольные кислоты. Эти соединения обладают антимикробными, противовоспалительными, цитотоксическими и фитотоксическими свойствами, что способствует экологическому доминированию растения и его устойчивости к традиционным методам борьбы с сорняками. Полученные результаты подчеркивают необходимость междисциплинарных исследований для совершенствования стратегий управления и изучения биоактивного потенциала данного растения в сельском хозяйстве и медицине.

Ключевые слова: Acroptilon repens, фитохимия, сесквитерпеновые лактоны, биоактивные соединения, антимикробная активность, флавоноиды

INTRODUCTION

Acroptilon repens (Russian knapweed) is a perennial herbaceous plant native to Central Asia and Eastern Europe; however, it has become a notorious invasive species in North America, Australia, and other regions [1]. Its rapid spread and long-term persistence in disturbed ecosystems have raised serious ecological and agricultural concerns, as the species aggressively competes with native vegetation and cultivated crops, often forming dense monocultures that reduce biodiversity and land productivity [2]. The high resilience of A. repens is attributed to its deep and extensive root system, prolific seed production, and strong allelopathic properties, which enable it to suppress neighboring vegetation through chemical interference [3]. Despite its reputation as a noxious weed, A. repens has attracted growing scientific interest due to its rich phytochemical composition, particularly sesquiterpene lactones and flavonoids, which exhibit notable biological activities [4].

The chemical profile of A. repens has been partially characterized, with studies identifying compounds such as repin, acroptilin, and cynaropicrin that contribute to its allelopathic and pharmacological effects [5]. These secondary metabolites have demonstrated antimicrobial, anti-inflammatory, and cytotoxic activities, suggesting potential applications in medicine and agriculture [6].

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Nevertheless, the mechanisms underlying their ecological interactions and therapeutic potential remain incompletely understood. For instance, while the allelopathic effects of A. repens on crop species have been documented, the specific biochemical pathways responsible for its phytotoxicity are still under investigation [7]. Similarly, the pharmacological potential of the plant has not yet been systematically explored, leaving significant gaps in our understanding of its bioactive constituents and their modes of action [6, 8].

Research gaps persist in several areas, including the ecological consequences of A. repens invasion, the molecular basis of its allelopathy, and the optimization of strategies for its control. Current management approaches often rely on herbicides and mechanical removal, but these methods are increasingly challenged by herbicide resistance and environmental concerns [9, 10]. Furthermore, the dual nature of A. repens—as both a harmful invader and a source of valuable bioactive compounds—presents a unique opportunity for interdisciplinary research. Bridging these gaps could lead to innovative solutions for invasive species management while unlocking the plant's untapped medicinal and agrochemical potential [11].

The motivation for this review stems from the need to consolidate fragmented knowledge on A. repens and highlight its multifaceted roles in ecology, agriculture, and pharmacology. By synthesizing existing research, we aim to identify key trends, unresolved questions, and future directions for investigation. This work contributes to the broader scientific discourse on invasive species by offering a comprehensive analysis of A. repens, emphasizing both its challenges and opportunities [12]. The findings may inform policy decisions, guide sustainable management practices, and inspire novel applications of its bioactive compounds.

The remainder of this paper is organized as follows: Section 2 outlines the methodology employed for the systematic literature review. Section 3 presents the results, including research trends, biological and pharmacological properties of A. repens, its ecological impacts, allelopathic mechanisms, and current weed management strategies. Section 4 discusses the implications of these findings, and Section 5 concludes the review with reflections on future research directions.

METHODOLOGY

This systematic review was conducted in accordance with PRISMA guidelines to ensure transparency and reliability in the selection and analysis of relevant studies. Major scientific databases, including PubMed, Web of Science, Scopus, ScienceDirect, and SpringerLink, were systematically searched to obtain comprehensive data related to the phytochemistry, biological activity, ecological impact, and control strategies of Acroptilon repens. Google Scholar was also used

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as a supplementary source to identify relevant studies not indexed in primary databases. The search process combined the term Acroptilon repens with keywords such as “chemical composition,” “phytochemistry,” and “research,” while excluding review articles, surveys, and meta-analyses to focus on original research. The analysis was organized to examine the plant’s biological and pharmacological properties, ecological impacts as an invasive species, allelopathic mechanisms, and weed management strategies. Only peer-reviewed studies published in English were included, while articles with insufficient data or not directly related to the research objectives were excluded to maintain methodological accuracy.The initial literature search yielded 393 records. After removing 193 duplicate entries, the remaining studies were screened based on their titles and abstracts, leading to the exclusion of 206 records that were not relevant to the scope of the review. Subsequently, 12 articles were selected for full-text assessment.

RESULTS

Research trends in Acroptilon repens indicate a noticeable shift in scientific focus over time. Prior to 2022, most studies primarily examined its ecological impact as an invasive species, emphasizing its aggressive spread, competitive dominance, and negative effects on biodiversity. These investigations identified key mechanisms of invasion, particularly allelopathy and resource competition. However, limited attention was given to the plant’s biological and pharmacological potential during this period. Since 2022, increasing interest has emerged in the phytochemical composition of A. repens, highlighting its dual role as both an invasive species and a potential source of bioactive compounds. Despite this progress, research on allelopathic pathways and sustainable management strategies remains insufficient.

The biological and pharmacological properties of A. repens are mainly associated with its diverse secondary metabolites, including sesquiterpene lactones, flavonoids, and phenolic compounds. These substances exhibit antimicrobial, cytotoxic, and phytotoxic activities that contribute to both the plant’s ecological dominance and its medicinal relevance.

Table-1.

Biological and pharmacological activities of Acroptilon repens

Activity	Key compounds	Observed effects
Antimicrobial	Repin, acroptilin	Inhibition of bacterial growth
Antifungal	Cynaropicrin	Suppression of fungal development

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Cytotoxic	Sesquiterpene lactones	Toxicity against cancer cells
Allelopathic	Phenolic acids	Inhibition of plant germination
Antioxidant	Flavonoids	Free radical scavenging

Experimental studies confirm that extracts from A. repens possess antimicrobial activity against bacterial and fungal pathogens. In addition, sesquiterpene lactones demonstrate cytotoxic effects, while phenolic compounds suppress seed germination and root growth of competing plant species. These allelopathic interactions enhance the plant's competitive advantage and complicate weed management practices.

Ecologically, A. repens forms dense monocultures that reduce native plant diversity and disrupt ecosystem structure. The plant modifies soil chemistry and microbial communities through root exudates, affecting nutrient cycling and limiting ecosystem recovery. These soil-mediated effects may persist for extended periods, making restoration challenging.

Table-2.

Ecological impacts of Acroptilon repens invasion

Impact category	**Mechanism**	**Management implications**
Reduction in biodiversity	Allelopathic suppression	Targeted restoration needed
Soil modification	Root exudates	Soil amendments required
Biochemical interference	Novel metabolites	Bioherbicide development
Land productivity loss	Dense monocultures	Integrated control strategies

Allelopathy plays a central role in the invasive success of A. repens by releasing phytotoxic compounds that inhibit neighboring vegetation. Managing this species remains difficult due to its deep root system and resistance to conventional methods. Integrated management strategies combining chemical, mechanical, and biological approaches are considered the most effective. Early detection and timely intervention are essential for limiting its spread. However, long-term ecological impacts of control measures and soil microbial responses require further investigation to develop sustainable management practices.

DISCUSSION

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The findings of this study demonstrate that the invasive success of Acroptilon repens is closely associated with its chemical composition and biological activity. The presence of secondary metabolites such as sesquiterpene lactones, flavonoids, and phenolic acids plays a significant role in enhancing the plant's allelopathic properties and ecological competitiveness. These compounds inhibit the germination and growth of neighboring plant species, allowing A. repens to dominate invaded ecosystems and reduce biodiversity.

In addition to its ecological impact, the plant exhibits notable antimicrobial, cytotoxic, and antioxidant activities, indicating its potential application in pharmaceutical and agricultural fields. The dual nature of A. repens as both a harmful invasive species and a source of valuable bioactive compounds presents new opportunities for interdisciplinary research. However, current weed management strategies remain limited in effectiveness due to the plant's deep root system and chemical resistance to conventional herbicides.

Therefore, future research should focus on developing integrated management approaches that consider both ecological restoration and the utilization of bioactive compounds. Understanding the molecular mechanisms underlying the plant's allelopathic activity may contribute to the development of environmentally friendly bioherbicides and sustainable weed control methods.

CONCLUSION

In conclusion, Acroptilon repens is a highly invasive plant species whose ecological dominance is largely determined by its chemical composition and biological activity. Secondary metabolites such as sesquiterpene lactones and phenolic compounds contribute significantly to its allelopathic effects and resistance to traditional weed management strategies. At the same time, these bioactive compounds exhibit promising antimicrobial and antioxidant properties with potential applications in agriculture and medicine.

The results highlight the importance of adopting interdisciplinary research approaches that integrate ecological, chemical, and biological perspectives. Effective management of A. repens requires the implementation of sustainable strategies that address both its invasive characteristics and its potential as a source of biologically active substances. Further studies are recommended to investigate the molecular mechanisms of its bioactivity and to develop innovative, eco-friendly control methods.

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