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Epilobium hirsutum L. as a Source of Bioactive Polyphenols: Phytochemistry, Antioxidant and Anti-Inflammatory Mechanisms, and Therapeutic Potential

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Abstract: *Epilobium hirsutum L. (Onagraceae) is a perennial medicinal plant traditionally used particularly for inflammatory conditions and disorders of the urogenital tract. Phytochemical and pharmacological interest in this species has increased in recent years, mainly due to its high content of bioactive polyphenolic compounds, including ellagitannins, flavonoids, and phenolic acids. Among these, oenothein B represents one of the most important constituents of the genus Epilobiumand has been associated with multiple biological effects. Experimental studies indicate that E. hirsutum extracts exhibit relevant antioxidant and anti-inflammatory properties, including the scavenging of reactive oxygen species, reduction of oxidative stress, and modulation of mediators and signaling pathways involved in the inflammatory response. In addition, antiproliferative, antimicrobial, and other pharmacological activities with potential therapeutic relevance have also been reported. However, the biological activity of the species may vary depending on the plant part used, harvesting period, environmental conditions, and extraction method, highlighting the importance of phytochemical characterization and extract standardization. This review summarizes the available data on the main bioactive constituents of E. hirsutum, with particular emphasis on its polyphenolic profile, antioxidant and anti-inflammatory mechanisms, and potential therapeutic applications. The major limitations of current research and perspectives for future pharmacological investigations are also discussed.*
Keywords: *Epilobium hirsutum; polyphenols; oenothein B; flavonoids; oxidative stress; antioxidant activity; inflammation; phytotherapy.*

• Introduction

Medicinal plants represent an important source of bioactive compounds with diverse chemical structures and potential therapeutic applications. Among plant secondary metabolites, polyphenols have attracted particular interest due to their antioxidant, anti-inflammatory, antimicrobial and antiproliferative properties. *Epilobium hirsutum L.*, a species belonging to the *Onagraceae* family, exhibits a complex phytochemical profile characterized by ellagitannins, flavonoids and phenolic acids. Oenothein B, a macrocyclic dimeric ellagitannin, is considered one of the most important bioactive compounds associated with this plant. Its polyphenolic constituents may contribute to antioxidant activity, reduction of oxidative processes and modulation of inflammatory responses. However, phytochemical composition and biological activity may vary depending on the plant material, environmental conditions and extraction methods. Moreover, most available evidence originates from in vitro studies and preclinical experimental models, limiting direct clinical extrapolation. This review aims to summarize the phytochemical composition of E. hirsutum, focusing on its major polyphenolic compounds, antioxidant and anti-inflammatory mechanisms, potential therapeutic applications and current research limitations.



Figure 1. *Epilobium hirsutum L.*

• Antioxidant and Anti-inflammatory Mechanisms

The antioxidant activity of Epilobium hirsutum is mainly associated with its polyphenolic constituents, particularly ellagitannins, flavonoids and phenolic acids. These compounds may contribute to free radical neutralization, reduction of lipid peroxidation and chelation of transition metal ions involved in oxidative reactions. Polyphenol-rich extracts may also influence endogenous antioxidant defense systems, including superoxide dismutase, catalase, glutathione peroxidase and intracellular glutathione levels. Modulation of the NRF2 signaling pathway represents another potential mechanism involved in cellular antioxidant protection. The anti-inflammatory potential of E. hirsutum is associated with the modulation of inflammatory mediators and signaling pathways. Polyphenolic compounds may influence NF-κB activation, COX-2 activity and the production of pro-inflammatory cytokines, including tumor necrosis factor-alpha and interleukins. The interaction between NRF2 and NF-κB pathways highlights the relationship between oxidative stress and inflammation. However, further studies are required to establish the relationship between extract composition, administered dose and pharmacological response.

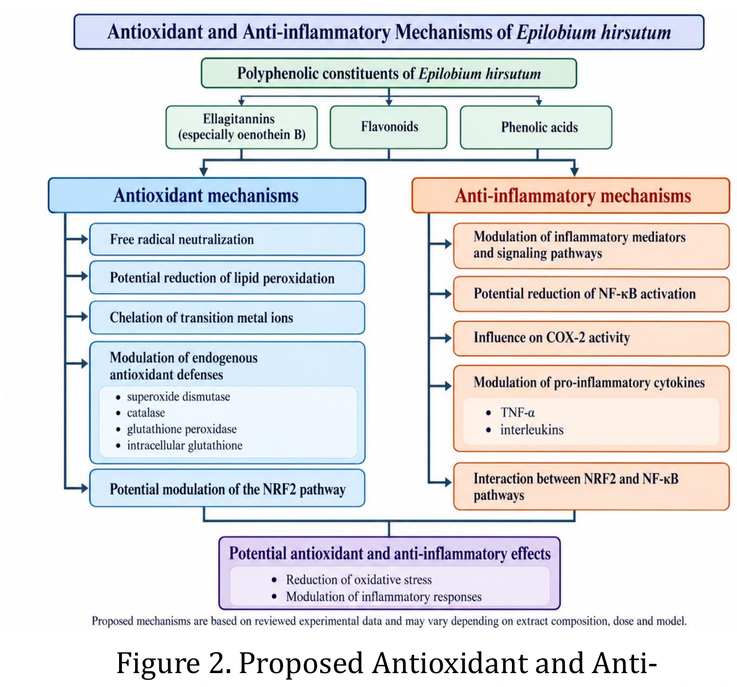


Figure 2. Proposed Antioxidant and Anti-inflammatory Mechanisms of *Epilobium hirsutum L.* Polyphenols.

• Phytochemical Profile of *Epilobium hirsutum L.*

The phytochemical profile of *Epilobium hirsutum L.* is predominantly characterized by polyphenolic compounds, particularly ellagitannins, flavonoids and phenolic acids. Among ellagitannins, oenothein B is considered one of the most important bioactive constituents associated with the genus *Epilobium*, exhibiting antioxidant, anti-inflammatory and antiproliferative activities. Oenothein A has also been reported in certain phytochemical investigations. The flavonoid profile includes myricetin and glycosylated derivatives of quercetin and myricetin, as well as hyperoside, isoquercitrin, avicularin and guajaverin. Phenolic acids, including gallic, ellagic and chlorogenic acids, may also contribute to the biological activity of the extracts. Phytochemical composition varies depending on the plant part, harvesting period, environmental conditions and extraction method. Therefore, extract standardization and the identification of reproducible phytochemical markers are essential for comparing experimental findings and evaluating the therapeutic potential of the species.

• Conclusions

Epilobium hirsutum L. represents a promising source of bioactive polyphenolic compounds, particularly ellagitannins, flavonoids and phenolic acids, with oenothein B identified as one of its major constituents. Available experimental evidence indicates antioxidant and anti-inflammatory properties, alongside potential antiproliferative and antimicrobial activities. However, variability in phytochemical composition, insufficient extract standardization and the predominance of in vitro studies limit the direct comparison of findings and their clinical applicability. Further research involving chemically characterized extracts, rigorous pharmacological and toxicological evaluations, and in vivo studies is necessary to better establish the therapeutic potential of this species, including its possible applications in veterinary medicine.