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DUYTAN UNIVERSITY

Phytochemical profiling of *Echinacea* Genus: A mini review of chemical constituents of selected species

Đặc điểm hóa thực vật của chi *Echinacea*: tổng quan ngắn về thành phần hóa học của một số loài

Truong Thi Diem Quynh[a], Tran Thi Diem Thuy[b], Pham Vu Khiem[c], Nguyen Viet Thien[d,e], Ha Hai Anh[b,f,*]
Trương Thị Diễm Quỳnh[a], Trần Thị Diễm Thùy[b], Phạm Vũ Khiêm[c], Nguyễn Việt Thiên[d,e], Hà Hải Anh[b,f,*]

[a]*K24YDH5, College of Medicine and Pharmacy, Duy Tan University, Da Nang, 550000, Vietnam*
[a]*K24YDH5, Trường Y Dược, Đại học Duy Tân, Đà Nẵng, Việt Nam*
[b]*Faculty of Pharmacy, College of Medicine and Pharmacy, Duy Tan University, Da Nang, 550000, Vietnam*
[b]*Khoa Dược, Trường Y Dược, Đại học Duy Tân, Đà Nẵng, Việt Nam*
[c]*Herbitech technology Co., Ltd, Ha Noi, 100000, Vietnam*
[c]*Công ty TNHH Công nghệ Herbitech, Hà Nội, Việt Nam*
[d]*Quang Nam Department of Health, Quang Nam, 560000, Vietnam*
[d]*Sở Y tế Quảng Nam, Quảng Nam, Việt Nam*
[e]*Viet Institute of Medicine and Pharmacy, Ho Chi Minh City, 700000, Vietnam*
[e]*Viện Y Dược Việt, TP. Hồ Chí Minh, Việt Nam*
[f]*Da Nang Pharmaceutical Association, Da Nang, 550000, Vietnam*
[f]*Hội Dược học Đà Nẵng, Đà Nẵng, Việt Nam*

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Abstract

The *Echinacea* genus is known for its medicinal properties, particularly its immune-stimulating effects. Thus, it makes a significant focus of phytochemical research. This literature review provides a short overview of the chemical constituents found within the *Echinacea* genus, with a primary emphasis on *E. purpurea*, *E. angustifolia*, and *E. pallida*, the three most extensively studied species. The constituents discussed include alkamides, polysaccharides, glycoproteins, phenolic compounds, and flavonoids, which are derived from various plant parts, such as roots, stems, leaves, and flowers. Detailed insights into the structural diversity, distribution, and biological significance of these compounds are presented. Additionally, key differentiating markers for species identification are highlighted, aiding researchers and herbal practitioners in understanding the chemical complexities of *Echinacea* species. This review offers information for the development of herbal medicines and supplements, shedding light on the potential therapeutic benefits of chemical constituents of these species.

Keywords: Echinacea; E. purpurea; E. angustifolia; E. pallida; chemical constituents.

[*] *Corresponding Author:* Ha Hai Anh
Email: hahaianh@dtu.edu.vn

Tóm tắt

Chi *Echinacea* được biết đến với khả năng sử dụng làm thuốc, đặc biệt là khả năng kích thích hệ miễn dịch. Vì vậy, chi này là một trọng điểm quan trọng trong nghiên cứu về hóa học cây cỏ. Bài tổng quan này cung cấp một cái nhìn tổng thể về các thành phần hóa học được tìm thấy trong chi *Echinacea*, tập trung chủ yếu vào *E. purpurea, E. angustifolia* và *E. pallida*, ba loài phổ biến nhất, đã có nhiều nghiên cứu được triển khai. Các thành phần được thảo luận bao gồm alkamid, polysaccharid, glycoprotein, các hợp chất phenolic và flavonoid, có thể chiết xuất từ nhiều bộ phận dùng khác nhau, chẳng hạn như rễ, thân, lá và hoa. Bài viết cũng cung cấp thông tin chi tiết về sự đa dạng về cấu trúc, phân bố và ý nghĩa sinh học của những hợp chất này. Ngoài ra, những dấu hiệu khác biệt quan trọng để nhận biết các loài thông qua thành phần hóa học cũng được nêu đề cập, giúp các nhà nghiên cứu và các chuyên gia về thảo dược hiểu sâu về sự phức tạp về hóa học của các loài *Echinacea*. Bài tổng quan này cung cấp thông tin nhằm thúc đẩy phát triển các loại thuốc thảo dược và thực phẩm bổ sung, đồng thời làm sáng tỏ về tiềm năng lợi ích trong trị liệu từ những thành phần hóa học trong nhóm cây thuốc này.

Từ khóa: Echinacea; E. purpurea; E. angustifolia; E. pallida; thành phần hóa học.

1. Introduction

The genus *Echinacea*, comprising several species commonly known as coneflowers, has garnered substantial attention in both botanical and pharmaceutical research due to its immune-stimulating properties and diverse pharmacological effects [9,12]. Among the *Echinacea* species, *E. purpurea*, *E. angustifolia*, and *E. pallida* have emerged as focal points of investigation, predominantly for their roles in traditional herbal medicine (Figure 1) [4,9,16]. These species exhibit a remarkable versatility in terms of their medicinal applications, with various plant parts, including roots, stems, leaves, and flowers, being employed to harness their therapeutic potential.

Echinacea purpurea *Echinacea angustifolia* *Echinacea pallida*

Figure 1: Flowers of *E. purpurea, E. angustifolia and E. pallida*

With the valuable characteristics mentioned above, the *Echinacea* genus is in high demand globally, resulting in substantial import and export volumes [25]. Vietnam boasts a diverse ecosystem that is well-suited for the cultivation and development of medicinal plants, characterized by a rich biodiversity [3,13]. However, Vietnam has not yet engaged in the promising *Echinacea* medicinal herb market. Researching the phytochemical characteristics of *Echinacea* species holds the potential to enhance our knowledge base and provide a foundation for subsequent experimental studies aimed at identifying the most suitable species for cultivating medicinal herbs within local regions.

Reports on the phytochemistry of *Echinacea* are primarily limited to three important species: *E. purpurea*, *E. angustifolia*, and *E. pallida*, which are utilized in medicine due to their immune-stimulating properties and various pharmacological effects. Plant parts used include the roots, stems, leaves, and flowers, with *E. purpurea* being more commonly used than *E. angustifolia* and *E. pallida* [2]. From the extracted *Echinacea* species, several groups

of important compounds have been identified, including alkamides, polysaccharides, glycoproteins, flavonoids, and phenolic compounds [7].

Alkamides

Alkamides, also known as alkylamides, are amides of fatty acids isolated from the *Echinacea* genus. They possess a distinctive structure, comprising an amide head and a hydrocarbon tail derived from various fatty acids with differing chain lengths and numbers of double and triple bonds [6]. Structurally, alkamides are naturally occurring compounds formed by linking straight-chain aliphatic acids, primarily unsaturated, to various amines through amide bonds. Apart from a few saturated derivatives, alkamides include pure olefinic compounds and compounds with both olefinic and acetylenic bonds. Originating from oleic acid (C18), the acid portions are modified by extending the chain to C28 or shortening through oxidative cleavage to C4. The presence of 2-methylbutylamine, a cyclic amine, is characteristic of the Asteraceae family. Alkamides reported from *E. angustifolia* and *E. purpurea* are mainly acetylenic, with a few pure olefinic structures. Alkamides are characteristic chemical constituents in the roots of *E. angustifolia* and the whole plant of *E. purpurea*. However, *E. pallida* roots lack alkamide compounds but contain polyacetylenes [15]. In the n-hexane extract of *E. purpurea* roots, 10 alkamides have been isolated, with majority containing isobutylamide and 2-methylbutylamide. Chloroform extraction of *E. purpurea* roots resulted in the purification and isolation of alkamides, with the majority of these compounds containing 2,4-dienoic structures [4-6,21].

Polysaccharides

Two polysaccharides (PS I and PS II) have been isolated from the aerial parts of *E. purpurea*. Their structures were identified as 4-O-methyl-glucuronoarabinoxylan (average MW 35,000) and acidic arabinorhamnogalactan (MW 50,000). Polysaccharides isolated from *E. purpurea* roots exhibit a similar composition to those from its aerial parts. Leaves and stems of *E. purpurea* contain a polysaccharide resembling pectin, while *E. angustifolia* roots are reported to contain 5.9% inulin [4,9,21].

Glycoproteins

Three glycoproteins with molecular weights of 17,000, 21,000, and 30,000, containing approximately 3% protein, have been isolated from the roots of *E. angustifolia* and *E. purpurea*. ELISA assays revealed that the main protein components in the roots of *E. angustifolia* and *E. purpurea* are aspartate, glycine, glutamate, and alanine, while the major sugars identified are arabinose (64% to 84%), galactose (1.9% to 5.3%), and glucosamine (6%). However, *E. pallida* roots contain fewer glycoproteins compared to the roots or any other part of *E. purpurea* and *E. angustifolia* [2,4,21].

Phenolic compounds

Derivatives of caffeic acid represent a major group of phenolic constituents found in all *Echinacea* species. Among the two main derivatives of caffeic acid, chicoric acid exhibits greater pharmacological effects compared to echinacoside. Additionally, small amounts of chlorogenic acid and isochlorogenic acid have been identified in both the leaves and roots of *E. angustifolia* and *E. pallida*. Some representative structures of phenolic compounds found in the *Echinacea* genus are chicoric acid, echinacoside, chlorogenic acid and isochlorogenic acid [17,21-22].

Caffeoylquinic and caffeoyltartaric esters constitute characteristic phenolic components of *E. angustifolia*, *E. purpurea*, and *E. pallida*.

Each species exhibits distinct features, with varying caffeoyl conjugation patterns in different plant parts.

Chicoric acid is ubiquitously distributed throughout the entire *Echinacea* plant, while echinacoside is primarily concentrated in the roots, with smaller amounts found in the flowers and leaves of species within the *Echinacea* genus. The content of chicoric acid is notably higher in *E. purpurea* compared to *E. angustifolia* and *E. pallida*.

The roots of *E. angustifolia* primarily contain echinacoside as the major caffeoyl component, lacking chicoric acid. This species is further characterized by the presence of cynarin (1,3-dicaffeoylcaffeoyl quinic acid) and 1,5-dicaffeoylquinic acid in its roots, distinguishing it from both *E. purpurea* and *E. pallida*. Similarly, the absence of echinacoside in the rootstocks of *E. purpurea* and *E. pallida* serves as a distinguishing feature from *E. angustifolia* [11,23,26].

Moreover, it has been demonstrated that *E. purpurea* leaves contain methyl esters of chicoric acid, namely, 2-caffeoyl-3-feruloyltartaric acid, 2,3-diferuloyltartaric acid, 2-feruloyltartaric acid, and 2-caffeoyl-3-p-coumaroyltartaric acid. Notably, *E. purpurea* lacks echinacoside [17,21].

Flavonoids

The concentration of flavonoids in the three *Echinacea* species is relatively low. Common flavonoids found in *Echinacea* leaves include luteolin, kaempferol, quercetin, quercetin-7-galactoside, luteolin-7-glucoside, kaempferol-3-glucoside, quercetin-3-arabinoside, quercetin-3-galactoside, quercetin-3-xyloside, quercetin-3-glucoside, kaempferol-3-rutinoside, rutin, and isorhamnetin-3-rutinoside. Rutin is a major flavonoid present in the leaves of *E. angustifolia*, *E. purpurea*, and *E. pallida*. The typical structures of some flavonoids can be found as phenonic compounds, such as luteolin, rutosid, kaempferol, quercetin, isorhamnetin and its derivatives [21].

Anthocyanins contribute predominantly to the plant pigmentation found in the flowers of *Echinacea* species. The main anthocyanins identified are cyanidin-3-O-β-glucopyranoside and cyanidin-3-O-6-malonyl-β-D-glucopyranoside [16,21]. The absence of polyacetylenes from the roots of *E. angustifolia* and *E. purpurea* serves to distinguish products derived from *E. pallida* from those of the two aforementioned species. In comparison to echinacoside and chicoric acid, both chlorogenic and isochlorogenic acids are relatively minor constituents in the *Echinacea* genus.

Furthermore, *E. purpurea* leaves contain methyl esters of chicoric acid, such as 2-caffeoyl-3-feruloyltartaric acid, 2,3-diferuloyltartaric acid, 2-feruloyltartaric acid, and 2-caffeoyl-3-p-coumaroyltartaric acid, whereas echinacoside is not present in *E. purpurea*. Conversely, *E. angustifolia* roots are characterized by echinacoside without chicoric acid, while the presence of cynarin (1,3-dicaffeoylcaffeoyl quinic acid) and 1,5-dicaffeoylquinic acid in its roots distinguishes it from both *E. purpurea* and *E. pallida*. These differences serve as key markers for species differentiation [11,23,26].

2. The distribution of chemical compounds within different parts of *Echinacea*

The distribution of chemical compounds within different parts of *Echinacea* plants reveals interesting variations and potential implications for their medicinal properties. The distribution of chemical compounds within different parts of *Echinacea* plants highlights the complexity of its phytochemical profile [5,21]. This complexity may have implications for the overall therapeutic potential of the herb,

and suggests that different parts of the plant could be utilized for specific medicinal purposes. Further research is needed to explore the specific health benefits associated with each compound and plant part.

The main chemical composition of *Echinacea purpurea*, as reported by previous studies [4-5,8,21], outlined in Table 1. These chemical constituents are of significant importance in both botanical and pharmaceutical research, as they underlie the potential therapeutic properties associated with *E. purpurea*. The chemical composition of *E. purpurea* is characterized by a wide range of bioactive compounds distributed across different plant parts. The root, with its alkamides and glycoproteins, appears to be a particularly valuable source of bioactive compounds. Additionally, the presence of polysaccharides, caffeic acid derivatives, and volatile oils in various plant parts underscores the complexity of the chemical profile of *E. purpurea*.

Table 1. Summary of chemical components found in some parts of *E. purpurea*

No.	Compound/group	Part(s)
1	Alkamide	Root, aerial part
2	Glycoprotein	Root
3	Polysaccharides, including PSI and PSII Pectin-like polysaccharide	Aerial part Leaves and stems
4	* Derivatives of caffeic acid: - Chicoric acid (acid 2,3-dicaffeoyl tartaric) - Caftaric acid (acid 2-caffeoyltartaric), chlorogenic acid.	Root, aerial part - Chicoric acid is more abundant in the flowers compared to the leaves and stems - Leaf: methyl esters of chicoric acid
5	- Volatile oils: ~0,2% - Caryophyllene (2,1%), Humulene (0,6%) and Caryophyllene epoxide (1,3%). - α-pinene, α-phellandrene, β-farnesene, myrcene, limonene, carvomenthene, caryophyllene.	Root

The chemical composition of *Echinacea angustifolia*, as summarized from earlier studies [14,21], presented in Table 2. The chemical composition of *E. angustifolia* demonstrates a diverse array of bioactive compounds distributed across various plant parts. This distribution underscores the importance of selecting the appropriate plant part for medicinal or research purposes. The root, with its high content of alkamides, glycoproteins, and phenolic compounds, is a valuable source of bioactive compounds and is commonly utilized in traditional herbal medicine. The presence of inulin in the root and additional phenolic compounds in the leaves further adds to the potential therapeutic value of the plants. Comprehensive research is needed to investigate the synergistic interactions among these compounds and their specific health benefits. This detailed knowledge of chemical composition of *E. angustifolia* is essential for harnessing its full potential in herbal medicine and pharmaceutical applications.

Table 2. Summary of chemical components found in some parts of *E. angustifolia*

No.	Compound/group	Part(s)
1	Alkamide	Root
2	Glycoprotein	Root
3	Polysaccharid (inulin 5%)	Root
4	*Phenolic: - Echinacoside (caffeoyl derivative) - Phenylethanoid glycosid	Root
	*Other phenolic: - Chlorogenic acid - Isochlorogenic acid	Leave and root
5	- Volatile oils: α-phellandrene.	Root

The chemical composition of *E. pallida*, as summarized from previous studies [21,24], to be outlined in Table 3. The chemical composition of *E. pallida* is characterized by a variety of bioactive compounds distributed across different plant parts. The root, in particular, appears to be rich in polyacetylenes, hydrocarbons, chicoric acid, and phenylethanoid glycosides, all of which may play essential roles in the defense mechanisms and other potential medicinal properties of the herbs. Additionally, the presence of phenolic compounds such as chlorogenic acid and isochlorogenic acid in both leaves and roots highlights the complexity of chemical profile of *E. pallida*.

Table 3. Summary of chemical components found in some parts of *E. pallida*

No.	Compound/group	Part(s)
1	- Major hydrocacbons: + Ketoankene + Ketoalkyne + Other polyacetylenes	Root
2	Chicoric acid (Acid 2,3-dicaffeoyl tartaric).	Root
3	- Phenolic: Phenylethanoid glycoside.	Root
4	*Phenolic - Chlorogenic acid - Isochlorogenic acid	Leave and root

3. Chemical compositions of three common *Echinacea* species and its potential bioactivities

The sharing chemical composition of all three *Echinacea* species (*E. purpurea*, *E. angustifolia*, and *E. pallida*) [4,8,10,19-21], as summarized in Table 4, reveals a complex array of bioactive compounds, and they underpin the therapeutic potential and biological activity associated with *Echinacea*.

Table 4. Chemical components of the genus *Echinacea* and potential bioactivities

No.	Compound/group	Potential bioactivities
1	Alkamide	Immunomodulation and anti-inflammatory effects
2	Volatile oils Terpenoid: α-pinene, β-pinene, β-myrcene, ocimene, limonene, camphene, terpinene	Terpenoids have diverse pharmacological properties, including antimicrobial and anti-inflammatory effects
3	Phenolic compounds, such as chicoric acid and echinacoside	known for antioxidant properties and may contribute to the overall medicinal effects of the plants.
4	Flavonoids (luteolin, kaempferol, quercetin, quercetin-7-galactoside, luteolin-7-glucoside, kaempferol-3-glucoside, quercetin-3-arabinoside, quercetin-3-galactoside, quercetin-3-xyloside, quercetin-3-glucoside, kaempferol-3-rutinoside, rutoside and isorahmnetin-3-rutinoside).	Known for their antioxidant and anti-inflammatory properties Although their concentration is relatively low, they may still contribute to the overall health benefits of *Echinacea*
5	Anthocyanins: (responsible for the vibrant pigmentation of *Echinacea* flowers): cyanidin-3-O-β-glucopyanoside and cyanidin-3-O-6-malonyl-β-D-glucopyranoside.	These compounds are of particular interest for their potential antioxidant and anti-inflammatory properties

Due to the important role of *Echinacea* and the significance of its chemical constituents, various studies have employed biotechnological methods to enhance the yield of certain bioactive compounds, with a particular focus on the caffeic derivatives group[1,18-19,22,24]. The Figure 2 illustrates the molecular structures of compounds derived from *Echinacea*, demonstrating their potential production through biotechnological methods [22]. In particular, the compounds echinacoside, cynarin, and chlorogenic acid are highlighted as important chemical components with substantial potential for further growth in the pharmaceutical and cosmetics industries [8,18,22]. Biotechnological approaches offer a promising avenue for the sustainable and controlled synthesis of these bioactive compounds, ensuring a reliable source for pharmaceutical and nutraceutical industries.

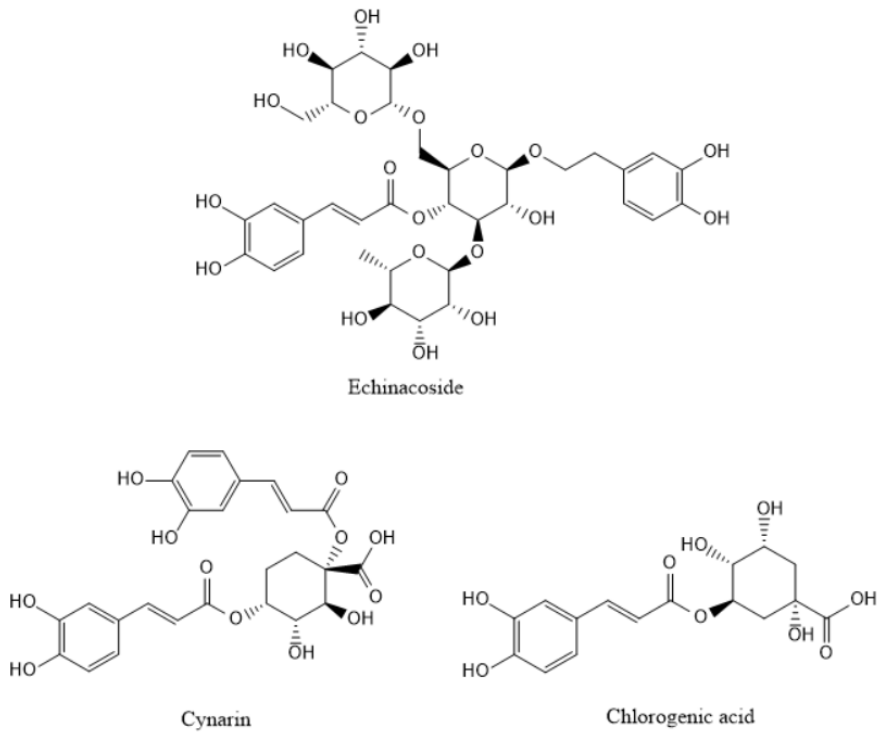

Figure 2: Chemical structures of echinacea-derived compounds biosynthesized for use in pharmaceutical and cosmetics industries

4. Conclusion

Overall, the distribution of these chemical compounds across different plant parts of *Echinacea* species highlights the importance of considering the specific plant part used for medicinal or research purposes. The roots, with their high concentration of phenolic compounds and terpenoids, may be particularly valuable for traditional medicinal applications. Conversely, the leaves and flowers, with their flavonoid and anthocyanin content, may also contribute to the overall therapeutic potential of *Echinacea*. Further research is needed to explore the synergistic interactions of these compounds and their specific health benefits. This detailed understanding of chemical composition of *Echinacea* may aid in harnessing its full potential in herbal medicine and pharmaceuticals.

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