ABC AHP NCNPR
Botanical Adulterants Prevention Program
American Botanical Council • the American Herbal Pharmacopoeia • the University of Mississippi's National Center for Natural Products Research

Echinacea (*Echinacea purpurea*, *Echinacea angustifolia*, and *Echinacea pallida*) Laboratory Guidance Document


Echinacea purpurea
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Echinacea angustifolia
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Echinacea pallida
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Citation (JAMA style): Harput Döner ÜŞ, Gafner S. Echinacea (*Echinacea purpurea*, *Echinacea angustifolia*, and *Echinacea pallida*) laboratory guidance document. Austin, TX: ABC-AHP-NCNPR Botanical Adulterants Prevention Program. 2026.

Keywords: Adulteration, *Echinacea*, coneflower, *Echinacea purpurea, Echinacea angustifolia*, *Echinacea pallida.*

1. Purpose

For centuries, *Echinacea* species (Asteraceae), including the aerial parts and roots of *Echinacea purpurea* and the roots of *Echinacea angustifolia* and *Echinacea pallida* as well as other species (e.g., *E. tennesseensis*), have been used in North America and Canada as

traditional herbal remedies. Although *Echinacea* is well known in both traditional and modern herbal medicine, incidences of adulteration and fluctuating product quality have arisen in parallel with the growing global demand. Historically, there have been reports of adulteration with species such as *Parthenium integrifolium*, *Lespedeza capitata*, *Eryngium aquaticum*, *Rudbeckia nitida*, *Helianthus annuus*, *Echinacea atrorubens*, *Liatris aspera*, and *Liatris punctata* by numerous authors, though these have not been reported as recent occurrences.[1-3] Common issues for adulteration in *Echinacea* in the current marketplace include confusion among *Echinacea* species, various *Cistanche* species with overlapping phenylethanoid profiles, and the dilution of ingredients with substantial amounts of undisclosed excipients.[3,4] Such practices compromise product quality and efficacy. The purpose of this Laboratory Guidance Document (LGD) is to review and compare analytical techniques for their usefulness to distinguish authentic *Echinacea* raw material and extracts from adulterant species. By using this document in conjunction with existing Botanical Adulterants Prevention Bulletins and comprehensive monographs (American Herbal Pharmacopoeia, United States Pharmacopeia and European Pharmacopoeia), product integrity can be enhanced in *Echinacea* products to help ensure therapeutic benefits and labeling compliance.



Echinacea pallida and *Echinacea paradoxa*
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2. Scope

The analytical methods described in this paper are reviewed with the specific purpose of identifying the strengths and limitations of current laboratory analytical methods for differentiating *Echinacea* ingredients and finished products from their potential adulterants. This LGD also addresses potential mislabeling due to confusion among different *Echinacea* species and the correct identification of both aerial and root materials. Methods are evaluated and compared directly, and their advantages and disadvantages are discussed to help with method selection.

Analysts can use this review to select the appropriate fit-for-purpose techniques based on the composition of their specific *Echinacea* products. Within this LGD, the positive evaluation of a method for testing *Echinacea* material in a product's particular matrix does not reduce or remove the responsibility of laboratory personnel to demonstrate adequate method performance for their ingredient/product using accepted protocols. Such protocols are outlined in the US Food and Drug Administration's (FDA) Final Rule for Current Good Manufacturing Practices for Dietary Supplements (21 CFR Part 111) and by Association of Official Analytical Chemists (AOAC) International, International Organization for Standardization (ISO), World Health Organization (WHO), International Council for Harmonization (ICH), and national pharmacopeial bodies, as may be applicable, depending on the regulatory requirements of the country in which the *Echinacea* ingredients are offered for sale, re-sale, and/or processing into finished consumer products.

3. Common and Scientific Names

Echinacea species are known by a wide range of common names globally. Table 1 provides a list of these vernacular names across several languages to facilitate identification in international markets.

3.1 Latin binomial: *Echinacea purpurea* (L.) Moench, *Echinacea angustifolia* DC., *Echinacea pallida* (Nutt.) Nutt[9-11]

3.2 Synonyms:

Echinacea purpurea: Brauneria purpurea (L.) Britton, *Echinacea intermedia* Lindl. Ex Paxton, *Echinacea purpurea* f. *liggettii* Steyerm., *Echinacea purpurea* f. *purpurea, Echinacea purpurea* var. *arkansana* Steyerm., *Echinacea purpurea* var. *purpurea, Echinacea serotina* (Nutt.) D.Don ex G.Don, *Helichroa purpurea* Raf., *Rudbeckia purpurea* L., *Rudbeckia purpurea* var. *purpurea*[12,13]

Echinacea angustifolia: *Echinacea angustifolia* var. *strigosa* McGregor, *Echinacea pallida* var. *strigosa* (R.L.McGregor) Gandhi,[14] *Echinacea pallida* var. *angustifolia* (DC.) Cronquist,[15] *Brauneria angustifolia* (DC.) A.Heller[16]

Echinacea pallida: Brauneria pallida (Nutt.) Britton, *Echinacea pallida* f. *albida* Steyerm., *Echinacea pallida* f. *pallida, Echinacea pallida* var. *pallida, Rudbeckia pallida* Nutt.[8]

3.3 Botanical family: Asteraceae

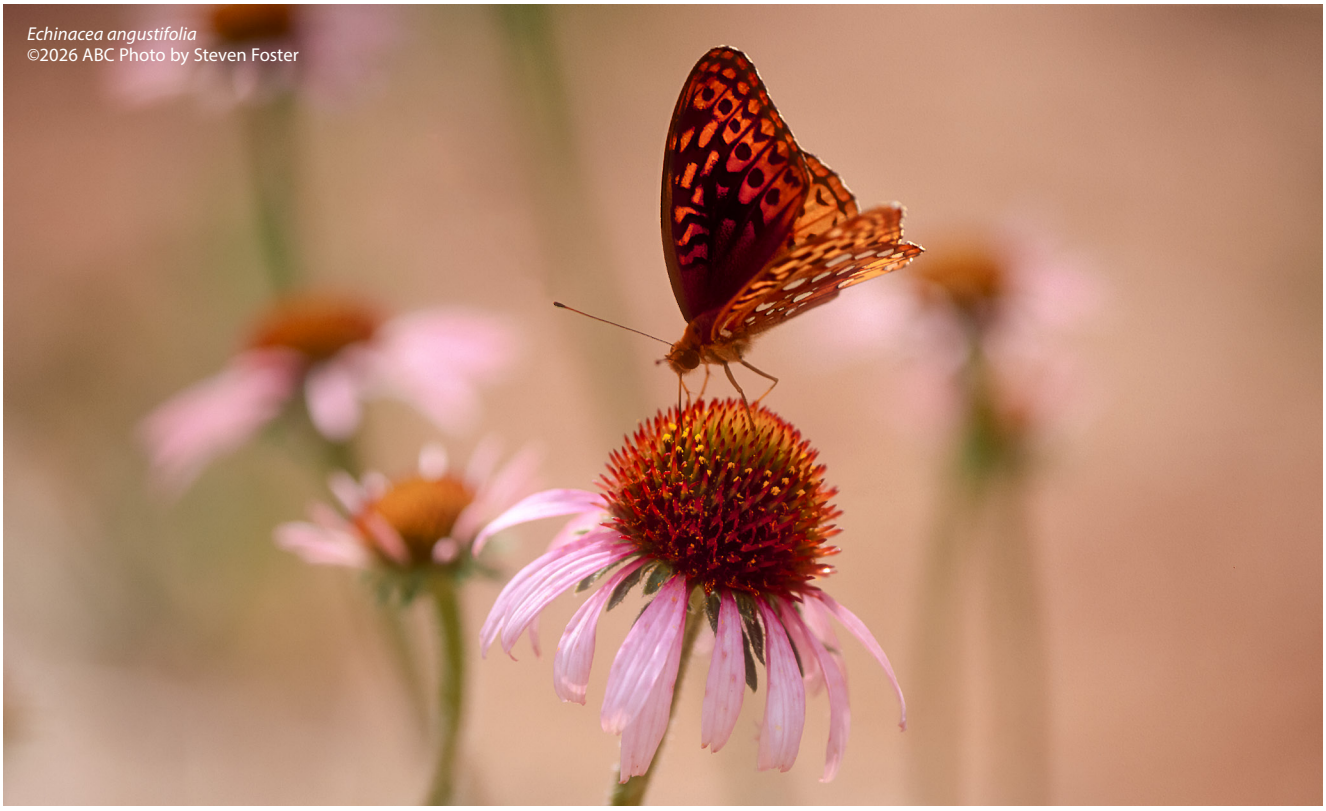
Table 1. Common Names of Echinacea in Different Languages[5]

	E. purpurea	***E. angustifolia***	***E. pallida***
English	Eastern purple coneflower, Missouri snakeroot, snakeroot, broadleaved purple coneflower, scurvy root, Indian head, comb flower, hedge hog[6]	Purple coneflower, narrow-leaved purple coneflower, Kansas snakeroot, snakeroot, scurvy root, comb flower, hedge hog[7]	Pale purple coneflower[8]
French	Echinacée pourpre, echinacée pourpre de l'Est, echinacée purpurea, rudbeckie pourpre	Echinacée à feuilles étroites, echinacée angustifolia, echinacée pourpre à feuilles étroites, sanicel du Kansas	Echinacée à fleurs pales, echinacée pale, echinacée pallida, echinacée pourpre pâle
German	Purpurfarbener Sonnenhut, roter Sonnenhut, Purpursonnenhutwurzel (root), Purpursonnenhutkraut (herb)	Schmalblättriger Sonnenhut, schmalblättriger Igelkopf, schmalblättrige Sonnenhutwurzel (root)	Blasser Sonnenhut, blasse Kegelblume, blasser Igelkopf
Chinese	紫花松果菊 Zǐhuā sōng guǒ jú	狭叶松果菊 Xiá yè sōng guǒ jú	淡紫松果菊 Dàn zǐ sōng guǒ jú
Japanese	ムラサキバレンギク 紫馬簾菊 Murasakibarengiku	ホソババレンギク 細葉馬簾菊 Hosobabarengiku	-
Danish	Purpursolhat, havepurpursolhat	Smalbladet solhat	Solhat
Dutch	Rode zonnehoed	Smalbladige zonnehoed	Egelzonnehoed
Italian	*Echinacea purpurea*	*Echinacea angustifolia*	*Echinacea pallida*
Russian	ЭХИНАЦЕИ ПУРПУРНОЙ	ЭХИНАЦЕИ УЗКОЛИСТНОЙ	ЭХИНАЦЕИ БЛЕДНОЙ
Ukrainian	ехінацея пурпурова	ехінацея вузьколиста	ехінацея бліда
Spanish	Equinácea púrpura	Equinácea de hoja estrecha	Equinácea pálida
Swedish	Röd solhatt	Smalbladig läkerudbeckia, liten läkerudbeckia, smalbladig solhatt	Blek solhatt, läkerudbeckia

4. Botanical Description

Echinacea species are perennial herbaceous plants belonging to the family Asteraceae that are native to North America and Canada. Detailed descriptions and illustrations can be found in non-official and official pharmacopeias such as the American Herbal Pharmacopoeia (AHP), the official United States Pharmacopeia (USP) and the European Pharmacopeia (Ph. Eur.), and other publications.[17-22] According to the AHP, since wild populations of *E. purpurea* are scattered and often of low density, all commercial supplies of this species are cultivated.[23] On the other hand, commercial supplies of *E. angustifolia* and *E. pallida* roots come from both wild sources and cultivated fields.[24,25] Since *Echinacea* plants are native to North America, all wildcrafted material originates exclusively from this region, and all commercial *Echinacea* materials from Europe are cultivated species. The most widely accepted classification of the *Echinacea* genus follows McGregor (1968), who identified nine species and two varieties of *Echinacea*.[21]

Based on morphological criteria, cultivation and hybridization experiments, and cytological data, McGregor treated *E. pallida, E. angustifolia*, and *E. purpurea* as separate species, although Binns et al (2002) do not support McGregor's classification at the species level.[22] *Echinacea angustifolia* and *E. pallida,* sharing many similar morphological features, are frequently confused in the medicinal plant market. In fact, *E. angustifolia* was once classified as a variety of *E. pallida*.[20] Because of this confusion, many early studies referring to *E. angustifolia* or *E. purpurea* may have actually used *E. pallida.* Therefore, research published before 1987 should be interpreted carefully, considering the updated species distinctions. To avoid further confusion, McGregor's taxonomy, now essentially adopted by the Flora of North America, is used officially.[26] Detailed descriptions of the morphological characteristics of the three main *Echinacea* species in commerce are provided in the AHP-ABC-NCNPR Botanical Adulterants Prevention Program's (BAPP's) echinacea bulletin.[5] It should be noted that many of the identifying morphological characters of *Echinacea* species are variable, especially among wild populations. It should also be noted that, organoleptically, the flavor of *E. angustifolia* differs markedly from that of *E. pallida*; *E. angustifolia* is characterized by an acrid flavor accompanied by a numbing effect on



Echinacea angustifolia
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the tongue, whereas that of *E. pallida* is purely acrid and lacks any numbing effect. The AHP monographs for *E. purpurea, E. pallida,* and *E. angustifolia* provide detailed written, illustrative, and photographic differentiation of the species to ensure accurate botanical identification.[23-25]

5. Adulterants and Confounding Materials

Echinacea species, particularly *E. purpurea*, are subject to adulteration with various plant materials that can compromise the quality and efficacy of *Echinacea* products. In former years, roots of American feverfew (also called prairie dock; *Parthenium integrifolium* L., Asteraceae) have been a common adulterant of *Echinacea* root products due to morphological similarities when cut and sifted, although they possess distinctly different flavor and fragrance characteristics. Its presence in commercial *Echinacea* products has been documented as far back as the early 1900s.[1,2] Roots of other plant species, such as *Lespedeza capitata* (Fabaceae),[2,3,27-29] *Eryngium aquaticum* (Apiaceae),[2,3,27-30] and several members of the family Asteraceae, e.g., *Rudbeckia nitida*,[2,3,27,28,30] *Helianthus annuus,*[2,3,27-29] *Echinacea atrorubens,*[1] *Liatris aspera,*[2,3,28] and *Liatris punctata*[1] are also listed as historic adulterants for *Echinacea* species, but no such occurrences have been reported in the past 20 years.

More common than adulteration with plant species outside the *Echinacea* genus are species mix-ups within the *Echinacea* genus itself. The roots of *E. angustifolia*, *E. pallida, and E. atrorubens* [31,32] are sometimes incorrectly identified due to their botanical and morphological similarities.[20] *Echinacea purpurea* roots, which sell for about a quarter of the cost of *E. angustifolia*, may be used for economically motivated adulteration of the more expensive species. Furthermore, dilution of *Echinacea* products with substantial amounts of excipients or carriers such as rice (*Oryza sativa,* Poaceae) starch is a concern in commercial *Echinacea* products.[4,33] In 2020, an investigation by herbal dietary supplement manufacturer NOW Foods (Bloomingdale, Illinois) identified adulteration of an *E. angustifolia* extract with Cistanche species, which, like *E. angustifolia*, contain echinacoside.[3,33,34] *Cistanche* is a perennial parasitic plant belonging to the Orobanchaceae family. It is found in temperate regions of Asia, including North-Central China (Inner Mongolia, Xinjiang

Table 2. Scientific and Common Names of Current and Historical *Echinacea* Adulterants and Excipients Used to Dilute *Echinacea* Products

Species	Synonym(s)[a,b,c]	Family	Common name[b,c,d]
Parthenium integrifolium	*Parthenium amplectens* *Parthenium auriculatum* *Parthenium hispidum* *Parthenium repens* *Parthenium radfordii*	Asteraceae	American feverfew, wild quinine, prairie dock
Echinacea atrorubens	*Rudbeckia atrorubens* *Brauneria atrorubens*	Asteraceae	Topeka purple coneflower
Cistanche deserticola	*Cistanche deserticola* var. *flabellata*	Orobanchaceae	Desert ginseng,[36] desert living cistanche,[37] *rou cong rong* (Chinese pinyin)
Cistanche tubulosa	*Cistanche carnosa* *Cistanche phelypaea,* *Cistanche tinctoria Phelypaea tubulosa*	Orobanchaceae	Desert hyacinth,[38] *guan hua rou cong rong* (Chinese pinyin)
Oryza sativa		Poaceae	Rice

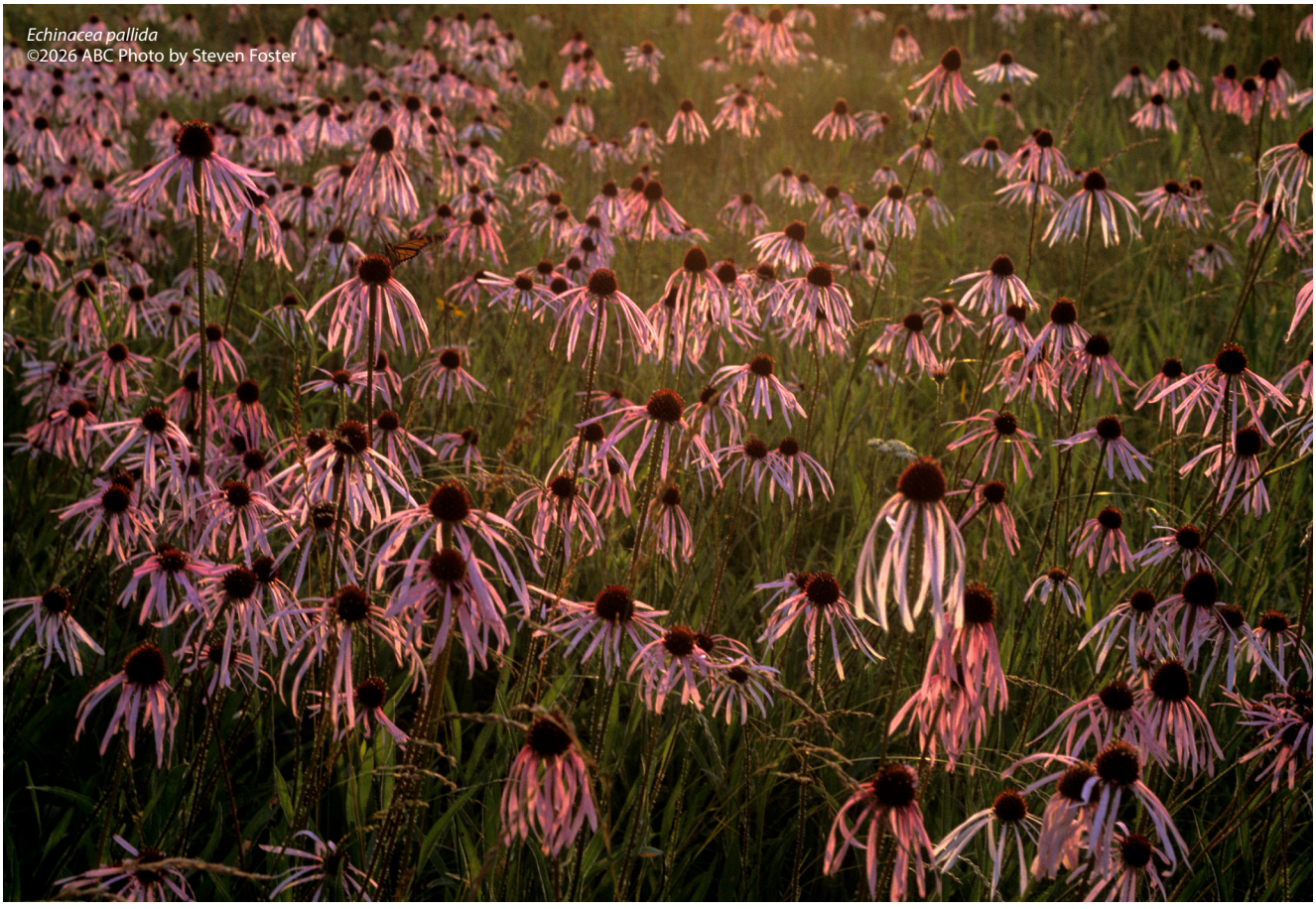
[a]According to World Flora Online[39]
[b]According to USDA Plants Database[40]
[c]According to Kew Science, Medicinal Plant Names Services[16]
[d]According to Flora of China[41]

Uyghur Autonomous Region) and Mongolia.[35-37] *Cistanche deserticola* is listed in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) Appendix II. Its trade is allowed but subject to licensing controls.[36] In addition, low-quality *Echinacea* extracts have previously been reported to be fortified with artichoke-derived (*Cynara cardunculus*, Asteraceae) dicaffeoylquinic acids and cynarin, which can be easily detected by high-performance liquid chromatography (HPLC) analysis (N. Feuillère [Givaudan] email to S. Gafner, November 6, 2025).

6. Identification and Distinction Using Macroanatomical Characteristics

Botanical descriptions for *Echinacea* species and their potential adulterants are presented in Section 4 of this Laboratory Guidance Document.

Parthenium integrifolium L. (Asteraceae) is a common historical adulterant of *Echinacea*, and although such adulteration is no longer believed to occur, manufacturers of echinacea ingredients and products may still see a need to test for its absence. A single *P. integrifolium* root can weigh up to ten times more than one *E. purpurea* root, making it relatively easy to gather large volumes of *P. integrifolium* root.[20,23,31] Above-ground parts of *P. integrifolium* do not resemble those of any *Echinacea* species. However, its taproot looks similar to the roots of *E. pallida* and *E. angustifolia* and has some resemblance to the fibrous root of *E. purpurea*. *Echinacea pallida* has a rhizome and root structure that is very similar to *E. angustifolia*, which has a short rhizome with thickened, tapering roots and a few thickened lateral roots. *Echinacea purpurea* has a large rhizome and numerous thin lateral roots, whereas *E. atrorubens* typically shows only a taproot.[31] When assessed by adequately trained personnel, these species and their potential adulterants can be definitively differentiated based on macroscopic and organoleptic characteristics, including differences in form, color, and taste features, particularly when authenticated botanical reference material (BRM) is used for comparison.



Echinacea pallida
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Echinacea purpurea
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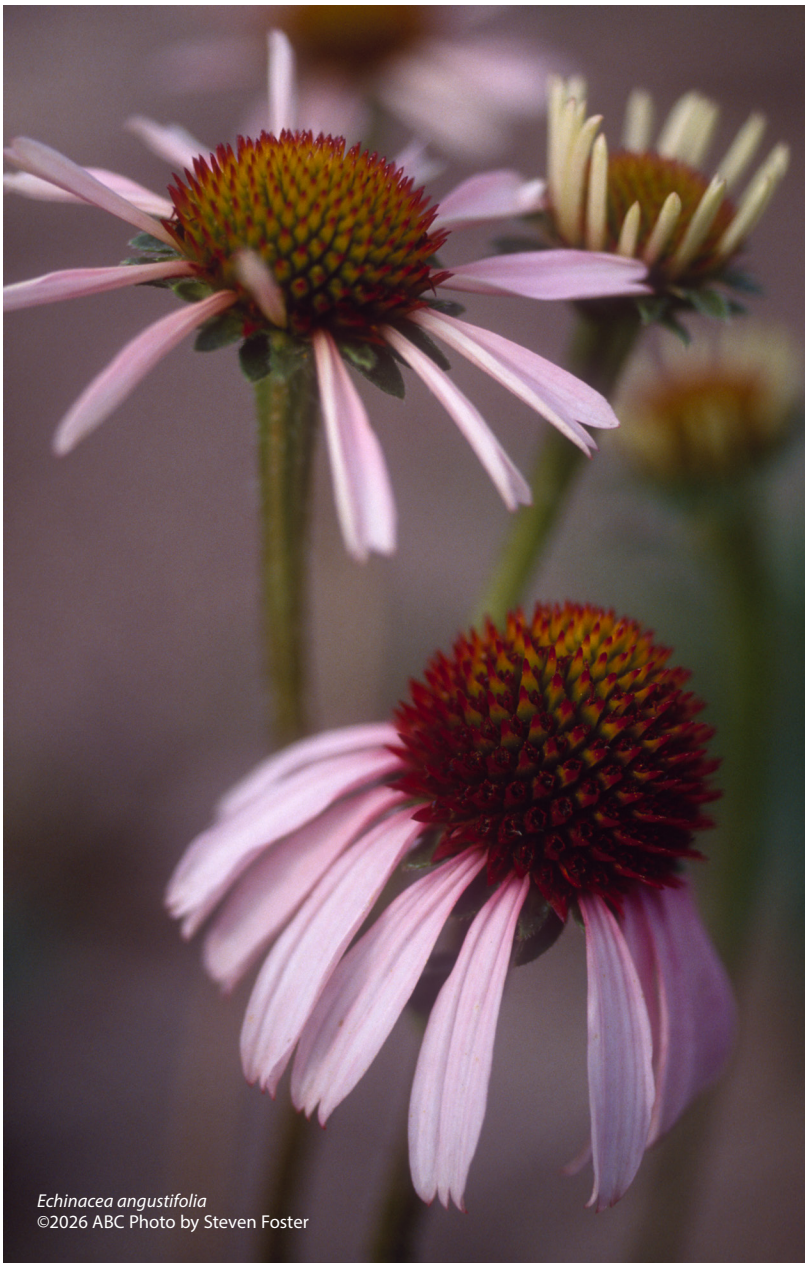
7. Identification and Distinction using Microanatomical Characteristics

Detailed microscopic comparison of *E. purpurea, E. angustifolia, E. pallida, E. atrorubens,* and *P. integrifolium* are found in several references.[20,31,42] The AHP monographs for the roots of *E. angustifolia*, *E. pallida*, and *E. purpurea* include detailed microscopic differentiation of each species, as well as *P. integrifolium*.[23-25] The microscopic differences among the roots of *E. angustifolia, E. pallida*, and *E. atrorubens* are not sufficient for species differentiation. However, both the root and rhizome of *E. purpurea* differ considerably from the other *Echinacea* species and *P. integrifolium*.[31]

Compared to the roots of other *Echinacea* species, the root of *P. integrifolium* is characterized by a radiate structure consisting of a highly regular network of phytomelanin-coated fibers associated with vessels. This distinguishes *P. integrifolium* from *Echinacea* species, where phytomelanin is typically found on sclereids rather than fibers. In the secondary xylem of *P. integrifolium,* sclereids are low in abundance, restricted primarily to the medullary rays, while the tissue contains the least amount of parenchyma compared to *Echinacea* roots. Despite these anatomical differences in cross-section, purity assessment of powdered materials remains difficult.[20,23,31] The absence of phytomelanin in *E. purpurea* roots cannot be used as a diagnostic feature in powders, because phytomelanin-coated sclereids are present in the rhizomes of this species, which may be included in the sample.[31] *Cistanche* species, which belong to a different botanical family (Orobanchaceae), are holoparasitic plants and do not share anatomical features with *Echinacea*. Their microscopic characteristics, including the absence of normal root vascular structure and the presence of parasitic tissues, have been described in detail.[43,44] These microanatomical differences make *Cistanche* species readily distinguishable from *Echinacea* species.

Comments: Botanical microscopy can help to detect the presence of undeclared excipients and fillers in crude powdered echinacea plant

materials and in powdered extracts. It is also suitable to verify the presence of undeclared aerial parts in root material. However, *Echinacea* species distinction by microscopy is very difficult and the results of such tests need to be confirmed with chromatographic, spectroscopic, or genetic methods. Due to the lack of characteristic anatomical structures, microscopy is not suitable to verify the authenticity of ingredients made with extracts.



Echinacea angustifolia
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8. Organoleptic Identification

Echinacea purpurea, E. angustifolia, and *E. pallida* share a similar earthy, acrid, and slightly aromatic aroma. However, they can be distinguished by their taste and sensory effects. *Echinacea purpurea* and *E. angustifolia* roots have a slightly aromatic, cool taste that is initially sweeter then turns bitter, creating a tingling and numbing sensation on the tongue due to the presence of alkamides. In contrast, *E. pallida* has a slightly sweet taste that turns bitter and astringent but notably lacks the numbing and tingling sensations observed in the other two species.[17,23-25] Distinct from the *Echinacea* species, *C. deserticola* exhibits a sweet and slightly salty taste.[45]

Comments: The organoleptic evaluation of powdered *Echinacea* roots, or certain echinacea liquid extracts, can give hints about their identity but it is not sufficient for authentication as a stand-alone assay.

9. Genetic Identification and Distinction

In addition to determining phylogenetic relationships, DNA-based identification techniques have been used in many studies to authenticate *Echinacea* species and detect adulteration. Among these, DNA fingerprinting techniques such as Random Amplified Polymorphic DNA (RAPD) allow the identification of taxa, the determination of phylogenetic relationships, and intra-specific diversity at a molecular genetic level.[46] Wolf et al demonstrated the utility of the RAPD technique for the discrimination of *E. purpurea, E. angustifolia*, and *E. pallida* using two different primers (A-17 and M-02).[47] Kapteyn and Simon later reported an additional 17 RAPD markers capable of differentiating various commercially relevant *Echinacea* species and *E. atrorubens*. This method also enabled detection of adulteration of *E. angustifolia* with *P. integrifolium* by analyzing DNA samples extracted from the combined tissue of both species.[48] This method works best on high-quality DNA. Due to several technical

limitations and advanced molecular techniques, RAPD analysis is no longer the genetic method of choice for *Echinacea* authentication.

There are currently nine recognized species in the genus *Echinacea*. Due to very low molecular divergence among closely related species, traditional DNA barcoding has not been successful for differentiation of *Echinacea* species. It generally fails when multiple species are present in a mixture.[29,30,49] Raclariu et al[28] applied DNA metabarcoding (targeting the nrITS region) for the determination of species diversity in *Echinacea* herbal products in addition to high-performance thin layer chromatography (HPTLC) for chemical profiling. They analyzed 53 herbal products including single (35) and multi-ingredient (18) food supplements. These consisted of herbal teas (nine loose teas and eight bagged teas), capsules (16), tablets (13), and extracts (7). Fifteen products, including three herbal teas, three capsules, five tablets, and four extracts were excluded from further analyses due to failure to yield sequence reads or molecular taxonomic units after applying the quality-filtering criteria.[28] This approach allowed the determination of *Echinacea* at the genus level. The selection of specific regions is very important for diagnostic results. DNA metabarcoding revealed a high rate of discrepancy between labeled and detected ingredients, identifying numerous undeclared plant species. However, it is unclear whether these species may stem from accidental contamination during the various processing stages and fall within permissible limits for foreign organic matter (often set at 2% by pharmacopeial monographs). Nevertheless, the results showed a lack of discriminatory resolution at the species level; i.e., the authors were unable to determine which species of *Echinacea* was in a product.[28] Supporting this, Handy et al found DNA metabarcoding less useful for *Echinacea* species in supplements.[4]

Zhang et al[29] used full chloroplast genomes to distinguish between all nine reported *Echinacea* species. Their study demonstrated that complete chloroplast genomes could effectively differentiate all nine species and clarify relationships among the species. Chloroplast genomes therefore can provide valuable data for DNA-based identification assays. This is especially true for closely related species, such as those of *Echinacea*, that cannot be currently identified using DNA barcoding markers.[29] However, high quality DNA is required for whole chloroplast genome sequencing, which limits its usefulness for more processed materials, particularly extracts.

Handy et al[4] used genome skimming to evaluate 20 commercially available *Echinacea* finished product dietary supplements, together with DNA metabarcoding (using nrITS1 and nrITS2 markers). These two genetic approaches were combined with HPLC with ultraviolet and visual detection (HPLC-UV/Vis). While DNA metabarcoding was able to resolve only seven products to the family level, genome skimming successfully identified nine of 20 samples to the species and one sample to the genus level. Genome skimming analysis allowed identification of additional ingredients that could not be identified by HPLC-UV. For example, one product was found to contain a different *Echinacea* species entirely (*E. laevigata* instead of *E. purpurea*). In addition, the genome skimming identified rice in three products (not listed on the label, although frequently used as an excipient) and goldenseal (*Hydrastis canadensis* L., Ranunculaceae) root in one product (which was included on the label). Relative proportions of the DNA of different species could also be determined. For example, one sample contained 88% *E. angustifolia* and 12% *Oryza sativa* DNA, another sample contained 95% *O. sativa* and 5% *E. purpurea* DNA, and one sample had 55% *E. purpurea* and 45% *O. sativa* DNA. These percentages reflect genomic abundance rather than the physical quantity of the ingredients.

Comments: RAPD is one of the genetic methods that have been used for identification of *Echinacea* species and to detect adulteration.[47,48] However, its low reproducibility and requirement of relatively unprocessed DNA limits its application for large-scale testing of heavily processed products.

Traditional DNA barcoding works best on single-ingredient herbal materials that have not been heavily processed. Once a plant is extracted or undergoes multiple processing steps, its DNA can be damaged, degraded, or mixed, making conventional DNA barcoding less effective.[49] In addition, due to very low molecular divergence



Echinacea purpurea
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among closely related *Echinacea* species, DNA barcoding is generally unable to reliably differentiate individual *Echinacea* species. DNA metabarcoding overcomes these limitations and allows the identification of multiple species in complex samples by detecting DNA from various sources. This method can be used to detect non-*Echinacea* DNA in a product and potentially reveal discrepancies with the label claim.[28] Whole chloroplast genome sequencing and genome skimming offer significant advantages over DNA metabarcoding, allowing identification of *Echinacea* to the species level. Both approaches sequence the entire chloroplast genome and thus provide a more comprehensive and accurate dataset than barcoding/metabarcoding methods. However, both whole chloroplast genome sequencing and genome skimming require intact DNA, so these methods may not be appropriate for medium or highly processed plant ingredients. Another limitation of genetic DNA methods is that they are unable to identify and distinguish plant parts. To fully ensure the quality and the authenticity of *Echinacea*, a combination of analytical methods is necessary for comprehensive authentication and quality control of raw material and finished products.[4,28]

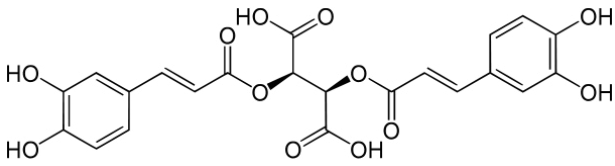
10. Chemical Identification and Distinction

There are many analytical methods available for identifying commercial *Echinacea* products and potential adulterants based on their chemistry. These methods are cited in the Laboratory Methods section below (Section 10.2). Distinction based on the phytochemical profile requires detailed knowledge of the constituents of *Echinacea* species and their adulterants. Below

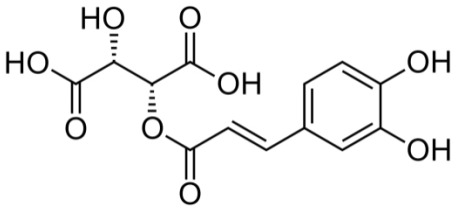
Table 3. Levels* of Major Constituents in *Echinacea* Species Used Medicinally[5]

Species	***E. purpurea***	***E. purpurea***	***E. angustifolia***	***E. pallida***
Plant Part	Root	Herb	Root	Root
Alkamides	0.12–2.8	0.2–3.9	0.19	<0.01
Echinacoside	<0.01	<0.01	0.83–1.55	0.07–1.7
Cichoric Acid	0.6–3.2	0.5–2.8	<0.1	0.01–0.22
Caftaric Acid	0.2–0.6	0.2–0.9	<0.01	<0.01
Cynarin	<0.01	<0.01	0.07–0.12	<0.01

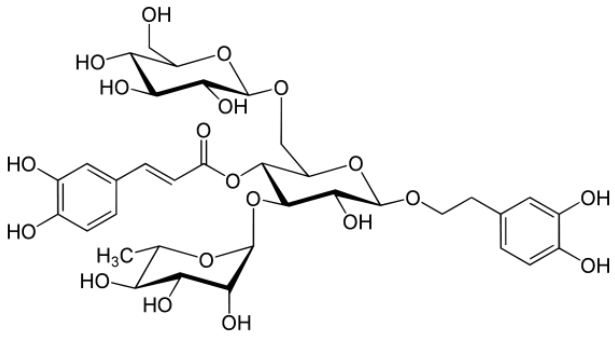
*All values are mean % w/w of dried plant material



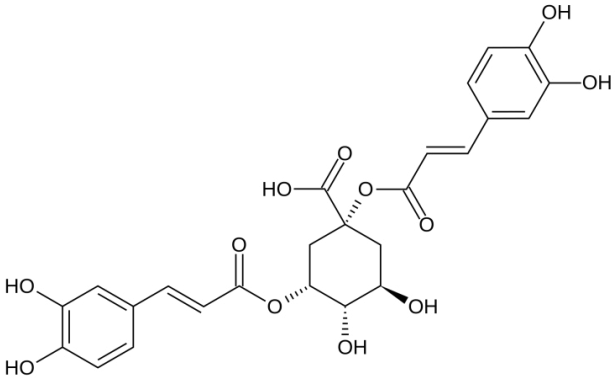
(2*R*,3*R*)-Cichoric acid



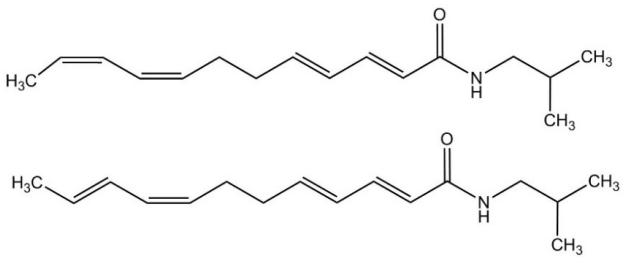
(2*R*,3*R*)-Caftaric acid



Echinacoside



Cynarin (1,3-dicaffeoylquinic acid)



Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides

Figure 1. Key constituents of *Echinacea purpurea*, *Echinacea angustifolia* and *Echinacea pallida*

is a summary of their phytochemical composition, including the chemical structures of their principal compounds (Figure 1). Additionally, the main secondary metabolites in *E. purpurea, E. angustifolia, E. pallida, E. atrorubens*, potential adulterants *C. deserticola, C. tubulosa*, and the historical adulterant *P. integrifolium* are discussed for comparison. When the distinction is based on chromatographic or spectral patterns, identification of specific constituents may not be necessary.

10.1 Chemistry of *Echinacea* and Potential Adulterants

Echinacea species contain a wide variety of chemical components, including high molecular-weight polysaccharides, polyacetylenes, alkamides, caffeic acid derivatives (CADs), flavonoids and the terpenoids found in the essential oil. Some of these constituents are unique to a single species, while others are present in two or more species (Table 3). This section first presents the chemical compositions of *E. purpurea*, followed by comparative data on other commercial *Echinacea* species and their potential adulterants.

Echinacea purpurea

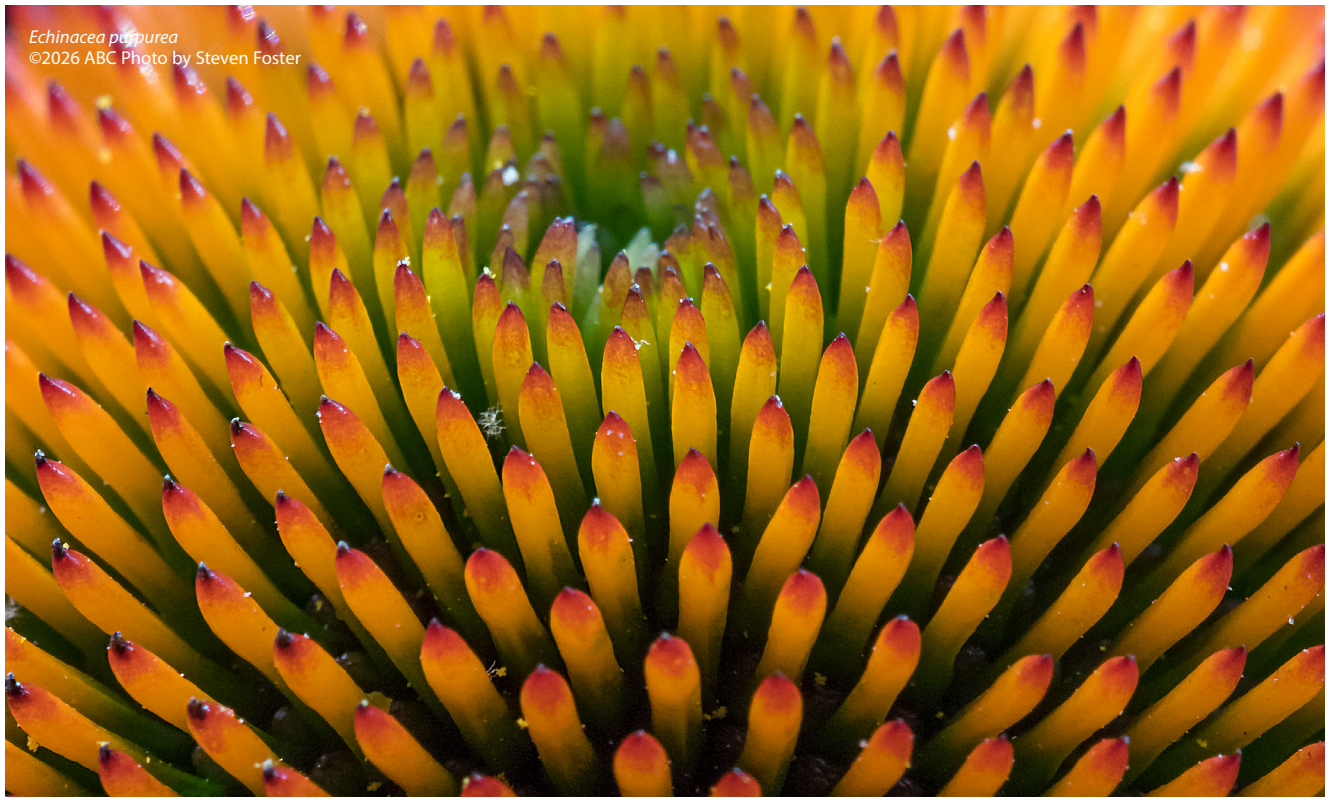
Cichoric acid (2,3-*O*-dicaffeoyltartaric acid) is the most prominent CAD found in the roots and aerial parts of *E. purpurea* with a concentration range of 0.6–3.2% and 0.5–2.8% of dry weight, respectively.[5] Caftaric acid (2-*O*-caffeoyltartaric acid) and chlorogenic acid are also commonly found in *E. purpurea*. Echinacoside is either absent or present only in trace amounts in both aerial parts and roots of *E. purpurea*.[50-52] The major flavonoids in *E. purpurea* include nicotiflorin (kaempferol 3-*O*-β-rutinoside), rutin (quercetin-3-*O*-rutinoside), and patuletin 3-*O*-rutinoside, particularly in their flowers and leaves.[53,54] In addition, the following flavonoids have been reported and occur as both the aglycones and as conjugates with various sugars: luteolin, kaempferol, quercetin, apigenin, isorhamnetin, and robinetin.[54-56] The main anthocyanins in the flowers are cyanidin 3-*O*-glucoside and cyanidin 3-*O*-(6′′-*O*-malonylglucoside).[57]

Alkamides (or alkylamides) are the principal lipophilic constituents of *Echinacea*, with many occurring E/Z isomeric pairs. These compounds are mainly derived from undecanoic and dodecanoic acid and differ in the degree of unsaturation

and the configuration of the double bonds. The alkamide content of *E. purpurea* ranges from 0.12–2.8% (w/w) in the dried roots and from 0.2–3.9% (w/w) in the dried aerial parts.[5] Isolated alkamides in *E. purpurea* are mainly isobutylamides (although 2-methylbutylamide derivatives are also observed) with 2,4-dienoic units in their structures.[58-61] Compared to *E. angustifolia*, *E. purpurea* roots have higher amounts of undeca-2*E*,4*Z*-diene-8,10-diynoic acid isobutylamide, undeca-2*Z*,4*E*-diene-8,10-diynoic acid isobutylamide, and dodeca-2*E*,4*Z*-diene-8,10-diynoic acid isobutylamide.[62,63] In contrast to the roots, the isomeric pair of dodeca-2*E*,4*E*,8Z,10*E/Z*-tetraenoic acid isobutylamides (Alkamide 8/9) become the most abundant alkamides in the aerial parts and they are concentrated mainly in the flower heads.[63-65]

Additional lipophilic components are found in the essential oil of *E. purpurea*, chiefly sesquiterpene hydrocarbons.[66] Fresh flowering parts of *E. purpurea* contain an average of 0.13% essential oil, which mainly consists of germacrene D, α-phellandrene, β-caryophyllene, γ-curcumene, α-pinene, δ-cadinene, and β-pinene.[67,68] The average yield of essential oil from the dried leaf and root of the plant was 0.24 and 0.29% w/w, respectively.[69] The leaf and root oils of *E. purpurea* were reported to contain mainly germacrene D, naphthalene, α-phellandrene, β-caryophyllene, α-cadinol, cedrol, and caryophyllene oxide. Germacrene D has frequently been reported as a typical, and most often as the most abundant, constituent of *E. purpurea* oil.[66,69] Contrarily, Mazza et al analyzed volatiles of *Echinacea* species using purge-and-trap headspace gas chromatography-mass spectrometry (GC-MS) and reported that the main constituents of root tissue are α-phellandrene, dimethyl sulfide, 2-methylbutanal, 3-methylbutanal, 2-methylpropanal, acetaldehyde, camphene, 2-propanal, and limonene. The major constituents of the aerial parts are β-myrcene, α and β-pinene, limonene, camphene, trans-β-ocimene, 3-hexen-1-ol, and 2-methyl-4-pentenal.[70]

Various polysaccharides have been isolated from the juice of *E. purpurea,* including an inulin-type fructan, xyloglucan, and an arabinorhamnogalactan. Both pressed juice and hot water extracts of *E. purpurea* roots were characterized by a high total fructan content, in which inulin predominates, representing over 88% of the total fructan.


Echinacea purpurea
©2026 ABC Photo by Steven Foster

The linear inulin-type fructan content in the aerial parts was found to be about 10 times lower than in the roots.[71,72]

Bergeron and Gafner (2007) reported the polysaccharide and glycoprotein content of *E. purpurea* and *E. angustifolia* roots, expressed as arabinogalactan equivalent. Their study further demonstrated that the composition of polysaccharides and glycoproteins varies among *Echinacea* species, between different organs of the same species, across geographical origins, and depending on the extraction solvent.[73] A heteroxylan (35 kDa) and an arabinorhamnogalactan (50 kDa) were isolated from the aerial parts of *E. purpurea* and identified as 4-*O*-methylglucuroarabinoxylan and an acidic arabinorhamnogalactan, respectively.[74-76] Xyloglucan (79 kDa) was also isolated from the leaves and stems.[50,60] Hou et al isolated three polysaccharides, EPPS-1 (21.5 kDa), EPPS-2 (12.0 kDa), and EPPS-3 (13.0 kDa), and tested their various biological activities.[77] In addition, two homogeneous polysaccharides, a neutral fucogalactoxyloglucan (25 kDa) and an acidic arabinogalactan (75 kDa) were isolated from the growth medium of leaf tissue cultures.[76,78,79] Classen et al reported the isolation of an arabinogalactan protein (AGP) from the high molecular weight fraction of the pressed juice of *E. purpurea* aerial parts. They characterized 83% polysaccharides, 4–5% uronic acids and 7% proteins in this fraction.[80,81] Glycoproteins with different molecular weights (17–40 kDa) have also been reported in the roots of *E. purpurea*.[1,82] The major polysaccharides present in *Echinacea* are summarized in Table 4.

Echinacea angustifolia

The chemical composition of *E. angustifolia* is generally similar to *E. purpurea* but with several notable distinguishing features. The main caffeic acid derivatives found in *E. angustifolia* roots include echinacoside (0.83–1.55%) and cynarin (1,3-*O*-dicaffeoylquinic acid; 0.07–0.12%) in addition to cichoric acid, chlorogenic acid, caffeic acid, ferulic acid, and verbascoside (acteoside).[5,86,87] Echinacoside is considered a key marker for *E. angustifolia* roots, for which the Ph. Eur. sets a minimum content of 0.5% in the dried root.[88] Cynarin is present in *E. angustifolia* root, but not in the roots of the other two species. Kabganian et al[89] detected cynarin in various plant parts at concentrations ranging from 0.1 mg/g to 0.9 mg/g dry weight. In the aerial parts of *E.*

Table 4. Summary of Polysaccharides and Glycoproteins in *Echinacea* Species

Polysaccharides	MW (kDa)	Species	Plant part
Inulin-type fructan[71,83]	4–6	*E. purpurea*	Root/herb
Heteroxylan (4-*O*-methylglucuroarabinoxylan)[74]	35	*E. purpurea*	Herb
Arabinorhamnogalactan (acidic arabinorhamnogalactan)[74,76]	50	*E. purpurea*	Herb
Xyloglucan[60]	79.5	*E. purpurea*	Herb
Neutral fucogalactoxyloglucan[76,79]	25	*E. purpurea*	Leaf (tissue culture)
Acidic arabinogalactan[76,78]	75	*E. purpurea*	Leaf (tissue culture)
Arabinogalactan-protein[80]	1200	*E. purpurea*	Herb
Arabinan[84]	970	*E. pallida*	Root
Arabinogalactan-protein[84]	1100	*E. pallida*	Root
Inulin[85]	4.5	*E. angustifolia*	Root
Highly methoxylated pectin[85]	128	*E. angustifolia*	Root

angustifolia, the major flavonoid is patuletin-3-*O*-rutinoside, which occurs at higher concentrations (0.11–0.24%) than in *E. purpurea* or *E. pallida*. Rutin is also present, though in lower amounts (0.019–0.032%).[53] The alkamide profile of *E. angustifolia* differs from that of *E. purpurea*. While diene alkamides are predominant in *E. purpurea*, *E. angustifolia* is characterized by the presence of significant levels of monoene alkamides and higher concentrations of tetraene alkamides.[90] For example, *E. angustifolia* is distinguished by the unique presence of specific monoene alkamides that are absent in *E. purpurea*, such as dodeca-2*E*-ene-8,10-diynoic acid isobutylamide and undeca-2*Z*-ene-8,10-diynoic acid isobutylamide. The relatively high concentrations of pentadeca-2*E*,9*Z*-diene-12,14-diynoic acid isobutylamide and dodeca-2*E*,4*E*-dienoic acid isobutylamide can be used to distinguish it from *E. purpurea*. However, the isomeric pair of dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides represents the most abundant two alkamides with their concentrations higher than those found in *E. purpurea*.[59,90,91]

The *E. angustifolia* essential oil is almost identical to that of *E. purpurea*. Although the essential oil can be obtained from several parts of the plant, the most widely investigated is the hydrodistillation of the flowerheads. Germacrene-D, β-caryophyllene, α-humulene, β-bisabolene, δ-cadinene, spathulenol, α-cadinol, and the oxygenated monoterpene bornyl acetate are the major chemical constituents in the essential oil from *E. angustifolia* flowerheads.[66]

The polysaccharide fraction of *E. angustifolia* root (Table 4) consists of two main components: a low molecular weight inulin-type fructan (4.5 kDa) and a high molecular weight pectin (128 kDa).[85] *E. angustifolia* root extract reportedly contains the highest proportion of low molecular weight compounds (5–48.6 kDa), and the total polysaccharide/glycoprotein content in the roots ranges between 0.12–2.98%.[73]

Echinacea pallida

The roots of *E. pallida* are characterized by a high content of echinacoside, typically ranging from 0.5–1.7%, making it a key chemical marker.[5] Other caffeic acid derivatives such as 6-*O*-caffeoyl-echinacoside, verbascoside, desrhamnosylverbascoside, caftaric acid, cichoric acid, chlorogenic acid, 3,5-*O*-dicaffeoylquinic acid, and 4,5-*O*-dicaffeoylquinic acid are also identified in *E. pallida*, although generally in trace amounts compared to *E. purpurea*.[92-95]

Unlike other species, *E. pallida* roots are low in alkamides but rich in lipophilic polyacetylenes and polyenes. These compounds are primarily simple aliphatic structures containing a carbonyl (keto) group at position 2. Polyacetylene-derived ketoalkenes/ynes have been detected only in traces in *E. angustifolia* and *E. purpurea,* making them potentially useful markers for *E. pallida* products. However, these compounds are very susceptible to auto-oxidation, therefore their presence in the roots is highly dependent on processing and storage conditions.[61,90,96,97] Polyacetylenic compounds are important constituents of essential oil from *E. pallida* root. 8-Pentadecene-2-one and cyclopentadecanone are the major compounds, and they make up approximately 45% of the essential oil.[98]

Regarding the polysaccharide composition of *E. pallida*, Thude et al isolated an AGP (1100 kDa) and an arabinan from the roots of *E. pallida* (Table 4). Their structural comparisons with AGP from *E. purpurea* show similarities, although the arabinoside/galactoside ratio differs, mainly due to a higher proportion of 6-linked galactose residues in *E. purpurea* AGP.[80,84,91]

Echinacea atrorubens

Unlike other *Echinacea* species, echinacoside, cynarin, cichoric acid, and caftaric acid are either absent or only present in trace amounts in both roots and aerial parts of *E. atrorubens*. However, chlorogenic acid, rutin, and narcissin have been identified in the aerial parts, contributing to a distinct phytochemical profile of *E. atrorubens.*[32,56] The roots of *E. atrorubens* contain a complex mixture of alkamides, predominantly conjugated 2,4-dienoic acid amides. Among these, the tetraene isomers are the major components and are present in higher quantities than in *E. purpurea* but in similar amounts to those reported for *E. angustifolia*. Dodeca-2*E*,4*Z*,10*Z*-trien-8-ynoic acid isobutylamide is identified as the second major isobutylamide in *E. atrorubens* roots. Monoenoic acid amides are present in smaller amounts, but polyacetylenes are

not detected in this species. In the aerial parts, the same tetraene alkamides are present but at significantly lower concentrations than in the roots. The essential oil composition of *E. atrorubens* roots does not differ much from that of *E. pallida*.[98]

Parthenium integrifolium

Parthenium integrifolium has been a common adulterant in commercial *Echinacea* products for much of the 20th century.[29,99,100] It is rich in sesquiterpene lactones, particularly C14 and C15 oxygenated pseudoguaianolides.[101] Cinnamoyl esters of sesquiterpenes such as cinnamoyl echinadiol and cinnamoyl echinaxanthol and their derivatives have also been reported from *P. integrifolium*.[67] Although it is commonly referred to as wild quinine, it does not contain quinine, but does contain anthraquinones.[102] Only trace amounts of dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides have been detected, highlighting a major chemical difference from *E. purpurea* and *E. angustifolia*, which typically contain a complex alkamide profile.[99] Similarly, it does not contain echinacoside, cichoric acid, caftaric acid, or cynarin, making its phytochemical profile distinct from that of *Echinacea*.

Cistanche deserticola and *C. tubulosa*

Various classes of compounds have been identified from *Cistanche* species, including phenylethanoid glycosides, benzyl glycosides, lignans, iridoids, monoterpenes, sterols, polysaccharides and alkaloids. Polysaccharides in *C. deserticola* have recently drawn attention for their immunomodulatory and anti-aging activities. Phenylethanoid glycosides represent the largest proportion relative to the other types of compounds.[45,77] The echinacoside content of *Cistanche* species is important in the context of adulteration, as this compound is also found in *E. angustifolia* and *E. pallida*. However, the overall phenylethanoid profile of *Cistanche* differs markedly from that of *Echinacea*. More than 85 phenylethanoid glycosides have been identified in *Cistanche*, consisting mainly of diglycosides and triglycosides, along with some monoglycosides.[103] In *C. deserticola*, the major constituents among these are verbascoside (the most abundant), echinacoside, 2′-acetylacteoside, tubuloside B, isoacteoside, cistanoside A, cistanoside C, and isocistanoside C. The levels of verbascoside and echinacoside are relatively similar in this species.[104,105] According to the *Pharmacopoeia of the People's Republic of China*, the contents of echinacoside and verbascoside in *C. deserticola*





Left photo: *Cistanche tubulosa* growing in the West Bank.
Right photo: *Cistanche* spp.
Photos ©2026 Chris Thorogood

should be higher than 0.3% (w/w), and those in *C. tubulosa* should be higher than 1.5% (w/w).[105,106] While the concentration of echinacoside in *C. deserticola* extracts ranges from 0.54% to 4.28%, it can reach up to 41.65% in *C. tubulosa* extracts.[107] Although the concentration of echinacoside is generally significantly higher in *Cistanche* than *E. angustifolia* and *E. pallida,* some *Cistanche* species may exhibit similar levels. Detailed descriptions of the phytochemical profiles of *C. deserticola* and *C. tubulosa* are presented in the published literature.[44,77,103,108]

Other sources of cichoric acid

Cichoric acid (also known as chicoric acid) is not unique to *Echinacea* species, so there is a possibility that other sources of the phenolic compound could be used as adulterants. A review on the natural occurrence, biosynthesis, and chemical synthesis of cichoric acid reports that at least 63 species from 25 genera contain the compounds, including many dandelions (*Taraxacum* spp., Asteraceae).[109] Two species, *Pterocypsela laciniata* (Asteraceae) and *Sonchus asper* (Asteraceae), contain amounts of cichoric acid that are comparable to *E. purpurea* herb. Due to the large-scale cultivation of *E. purpurea* and its relatively low raw material costs, it is not clear if the sale of extracts of other cichoric acid-containing plants, falsely labeled as *Echinacea purpurea* extract, would make economic sense.

Cichoric acid can also be obtained by isolation from *E. purpurea* or by chemical synthesis.[110] However, the reported purification methods suffer from a lack of purity or are not cost-effective enough to be considered.[109] So far, there is no information suggesting that other cichoric acid-rich plant species or synthetic cichoric acid are used as adulterants.

Other sources of echinacoside

Echinacoside was first isolated from *E. angustifolia* in 1950 and subsequently identified in other sources including the genus *Cistanche*, the aerial parts of *Penstemon crandallii* (Plantaginaceae), and the whole plants of *Pedicularis striata* (Orobanchaceae). To date, it has been found in 40 plant species belonging to 18 genera and 10 families including *Echinacea* spp., *Cistanche* spp., *Callicarpa* spp. (Lamiaceae), *Marrubium* spp. (Lamiaceae), *Phlomis* spp. (Lamiaceae), *Cymbaria* spp. (Orobanchaceae), *Plantago* spp. (Plantaginaceae), *Rosa* spp. (Rosaceae), *Buddleja* spp. (Scrophulariaceae), *Rehmannia* spp. (Orobanchaceae), and *Verbascum* spp. (Scrophulariaceae). Among these, *Echinacea* and *Cistanche* species are the main natural plant sources for echinacoside.[111,112]

Due to their high echinacoside content, *C. deserticola* and *C. tubulosa* are valuable resources for the isolation of pure echinacoside. Chemical synthesis of echinacoside is possible but challenging and results in a low yield due to its structural complexity. Its microbial production is also possible in the yeast *Saccharomyces cerevisiae*.[113] Currently, there is no evidence to suggest that synthetic or *de novo* echinacoside are used as adulterants.

Comments: Caftaric acid, cichoric acid, chlorogenic acid, caffeic acid, cynarin, and echinacoside are the most frequently reported caffeic acid derivatives in *Echinacea* species (Figure 1). However, their abundance varies depending on the species and the plant organ. Chlorogenic acid is found in low concentrations across all *Echinacea* species, while cichoric acid is the main caffeic acid derivative of *E. purpurea,* along with caftaric acid; cynarin is instead specific to *E. angustifolia* roots. Echinacoside is a key phytochemical marker for *E. pallida* and *E. angustifolia*, but it is either absent or present only in trace amounts in both aerial and underground parts of *E. purpurea* and *E. atrorubens*. Since the composition of caffeic acid derivatives is species or organ specific, these compounds are widely used as markers for quality control. Most analytical methods rely on qualitative and quantitative profiling of caffeic acid derivatives to confirm the authenticity and detect potential adulteration.

Alkamides are among the most studied bioactive compounds in *Echinacea* species. To date, more than 25 alkamides have been identified, many of which are isomeric pairs. Approximately two thirds of the alkamides found in *Echinacea* species are isobutylamides derived from C11-C16 long-chain unsaturated fatty acids, while the rest are 2-methylbutylamides. The alkamide profiles are similar in the roots of *E. purpurea, E. angustifolia,* and *E. atrorubens*. Significantly lower levels of alkamides

are observed in the aerial parts of these species and *E. pallida* roots. Although *E. pallida* roots contain relatively low levels of alkamides, they are rich in highly lipophilic ketoalkenes and ketoalkynes, which are not prominent in other *Echinacea* species.

The phytochemical profile of *Parthenium integrifolium* differs markedly from that of *Echinacea*. Its historical presence as an adulterant in *Echinacea* products is probably due to its similar root morphology, significant geographical overlap in the United States, and shared common name as "snakeroots."[40] In the case of *Cistanche* species, the phytochemical profile is very complex, including dozens of structurally diverse compounds that are not found in *Echinacea*. Although echinacoside is one of the major phenylethanoid glycosides present in both *Cistanche* and *Echinacea* species, the overall chemical composition of *Cistanche* is distinctly different. Furthermore, the concentration of echinacoside is typically higher in *Cistanche* species. In addition, *C. deserticola* and *C. tubulosa* are rich in phenylethanoid glycosides including a wide range of unique compounds such as cistanosides A–N and tubulosides A–E. These compounds contribute to a more complex phenylethanoid profile compared to that of *Echinacea*. Therefore, while the presence of shared compounds like echinacoside and verbascoside alone may motivate the fraudulent use of *Cistanche* extracts for adulteration, comprehensive chemical profiling enables a clear distinction between the two genera.

10.2 Laboratory methods

Many analytical methods have been developed with the goal of authenticating commercial *Echinacea* species, assessing their quality, and/or determining evidence of adulteration. However, the reliability of these techniques depends on the use of authenticated botanical reference materials (BRMs).

10.2.1 Thin-layer chromatography (TLC)/ High-performance thin-layer chromatography (HPTLC)

This review evaluated methods from Ph. Eur. 11.8,[88,114-116] USP41-NF36,[117-129] AHP,[23-25] HPTLC Association,[130-133] Agatonovic-Kustrin et al,[134,135] Bauer et al,[58,59,91] Classen et al,[80] Frommenwiler et al,[136] Gilroy et al,[137] Glavac et al,[74] Reich et al,[138,139] and Waidyanatha et al.[30]

Comments: TLC and HPTLC are mainly used for the qualitative identification of *Echinacea* species and the detection of potential adulterants, with a focus on fingerprints of phenolic compounds and alkamides. Most TLC studies have used normal phase silica gel plates for *Echinacea* analysis, employing UV detection (254/366 nm), video densitometry, and derivatization with reagents such as anisaldehyde-sulfuric acid or Natural Products Reagent/Polyethylene Glycol (NP/PEG) to evaluate chromatograms.[58,59,91,117]

Bauer et al applied TLC and HPLC for the fingerprinting of *E. pallida* and *E. angustifolia* root extracts.[91] They performed TLC on silica gel plates by using toluene:ethyl acetate (7:3) and n-hexane:ethyl acetate (2:1) as a solvent system for the lipophilic constituents, and toluene:ethyl formate:formic acid:water (5:100:10:10) for the phenolic constituents. The method allowed the observation of differences between *E. pallida* and *E. angustifolia*.[58,91]

TLC and HPTLC identification is a key test used in the USP *Echinacea* monograph series for distinguishing among the *Echinacea* species based on the presence or absence of characteristic bands corresponding to phenolics and alkamides.[117-129] Gilroy et al tested 59 commercially sold *Echinacea* preparations by TLC to confirm their labeling compliance. These authors used ethyl acetate:formic acid:acetic acid:water (100:11:11:27) as a mobile phase. Their quantitative analysis measured reflective absorbance from TLC plates, comparing it to standard compounds (cichoric acid and echinacoside).[137] Agatonovic-Kustrin et al combined TLC with video densitometry and multivariate statistics based on an artificial neural network (ANN) for data modelling as a method to estimate the concentrations of three phenylpropanoid markers (cichoric acid, chlorogenic acid, and echinacoside) using the same solvent system as Gilroy et al.[135,137]

HPTLC is recommended by several pharmacopeial monographs as a technique for fingerprint analysis of *Echinacea* products. The methods in

the AHP,[25] USP41-NF36,[117-129] Ph. Eur. 11.8,[88] HPTLC Association,[130-133] Reich, et al[139] and Frommenwiler et al[136] are almost identical with only minor modifications for the determination of phenolics and alkamides. These methods provide reliable data for distinguishing among *Echinacea* species (*E. purpurea*, *E. angustifolia*, *E. pallida*, *E. atrorubens*) and and potential adulterants (*P. integrifolium*). Using these methods, HPTLC allows for the detection of adulterants such as *P. integrifolium* or *Cistanche* species through the appearance of characteristic foreign bands that visually alter the fingerprint.[25,130-133]

Ethanol or methanol are typically used as an extraction solvent for phenolic compounds, while dichloromethane and n-hexane are commonly used for alkamides. Extraction is usually performed using an ultrasonic bath, sonicator, or shaker. In many studies, the mobile phase for phenolics consists of ethyl acetate:ethyl methyl ketone:formic acid:water (15:9:3:3),while toluene:ethyl acetate:cyclohexane:formic acid (24:6:3:0.9) is frequently employed for alkamides.[136,138] While caftaric, chlorogenic, and cichoric acids are used as reference standards for phenolic compounds, β-sitosterol is used for alkamides and ketoalkene/ynes. The detection of phenolic compounds is carried out using NP/PEG reagent, or NP reagent alone, under UV light at 366 nm, while alkamides are detected after derivatization with anisaldehyde-sulfuric acid in daylight and at 366 nm.[25,88,130,136] These HPTLC methods were peer-verified in an AOAC study and shown to reliably distinguish *E. purpurea*, *E.*

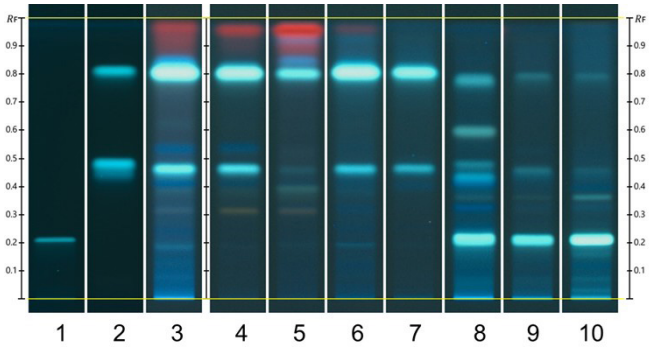


Figure 2: HPTLC fingerprints of phenolic constituents in echinacea-derived ingredients under UV 366 nm after derivatization with natural product reagent.[132] Lane 1: USP Echinacoside RS; Lane 2: USP Chlorogenic acid RS, USP Caftaric acid RS, and USP Cichoric acid RS (with increasing Rf); Lane 3: Powdered *E. purpurea* aerial parts (USP); Lane 4: Powdered *E. purpurea* aerial parts; Lane 5: Powdered *E. purpurea* root, not compliant (similar to *E. purpurea* aerial parts); Lanes 6–7: Powdered *E. purpurea* root; Lane 8: Powdered *E. angustifolia* root; Lane 9–10: Powdered *E. pallida* root. Conditions according to HPTLC Association. Image provided by CAMAG (Muttenz, Switzerland)

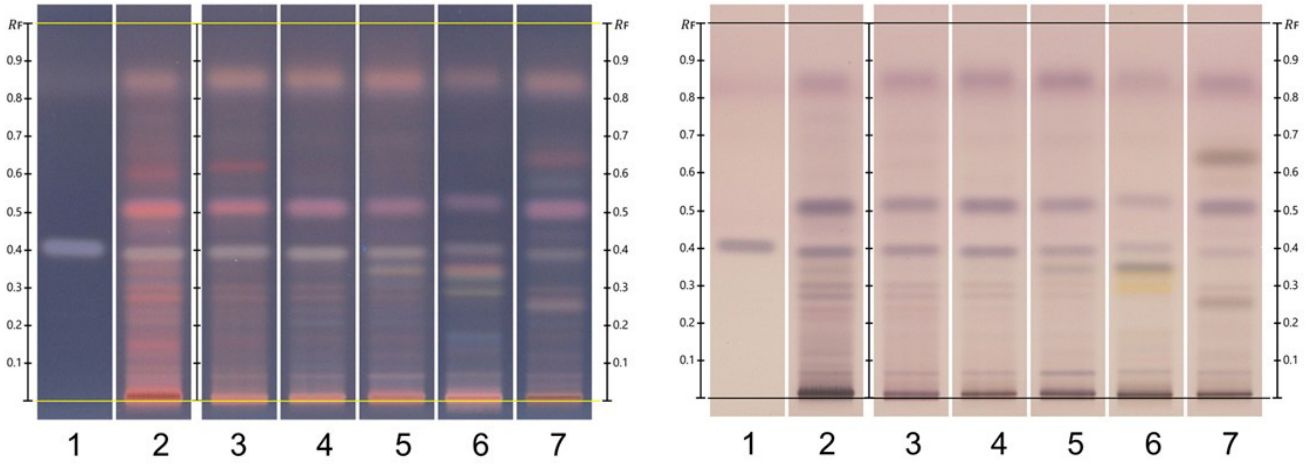


Figure 3. **HPTLC fingerprints of lipophilic constituents in echinacea-derived ingredients under UV 366 (A) and white light (B) after derivatization with anisaldehyde reagent.**[133] Lane 1: USP β-sitosterol RS; Lane 2: Powdered *E. purpurea* aerial parts (USP); Lanes 3–4: Powdered *E. purpurea* aerial parts; Lane 5: Powdered *E. purpurea* root; Lane 6: Powdered *E. angustifolia* root; Lane 7: Powdered *E. pallida* root. Conditions according to HPTLC Association. Image provided by CAMAG (Muttenz, Switzerland)

angustifolia, and *E. pallida* from common adulterants. The results of this study supported their inclusion in the AHP and Ph. Eur. with slight modification such as change in application volume or developing distance.[24,138]

The combination of HPTLC with DNA-based methods offers a more comprehensive approach, where HPTLC confirms the *Echinacea* chemical fingerprint and DNA barcoding/metabarcoding may help to identify unknown plant species present in the product inadvertently or on purpose. Details of the genetic studies are given in Section 9. For quantitative analysis of *Echinacea* phenolics, Agatonovic-Kustrin et al developed an HPTLC-video densitometry method.[134] This validated approach successfully quantified echinacoside, chlorogenic acid, and cichoric acid in commercial products, demonstrating its suitability for the analysis of these markers.

A recent investigation identified adulteration of *E. angustifolia* extract with *Cistanche* species (Figure 4). This adulteration was further confirmed by HPLC-MS analysis.[34,88]

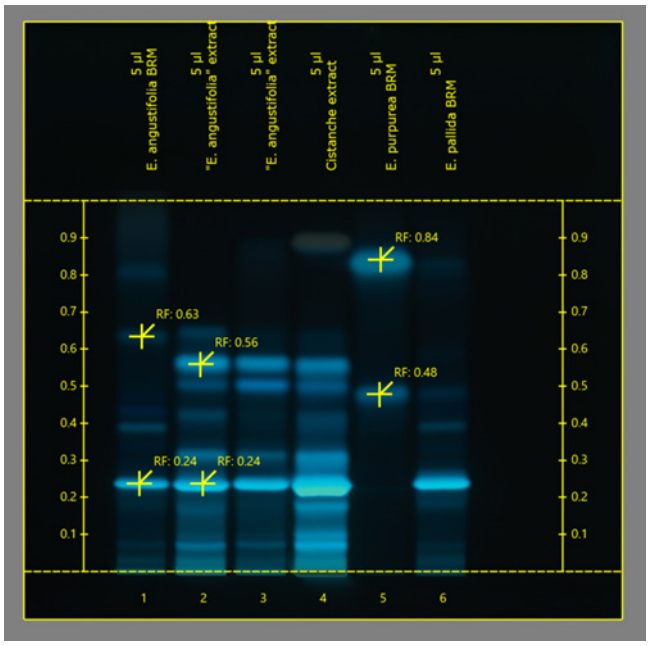


Figure 4. Comparison of HPTLC fingerprints of commercial samples labeled as *E. angustifolia* (lanes 2–3) with authentic *E. angustifolia* (lane 1) root extract, *Cistanche deserticola* herb extract (lane 4), *E. purpurea* root extract (lane 5), and *E. pallida* root extract (lane 6). Cichoric acid, Rf = 0.84; cynarin, Rf = 0.63; verbascoside, Rf = 0.56; caftaric acid, Rf = 0.48; echinacoside, Rf = 0.24. Conditions according to the Ph. Eur. monograph for *E. angustifolia* root. Image provided by NOW Foods

10.2.2 High-performance liquid chromatography (HPLC) and Ultrahigh-performance liquid chromatography (UHPLC)

This review evaluated methods from AHP,[25] Ph. Eur. 11.8,[88] USP41-NF36,[117-119] Aiello et al,[86] Bergeron & Gafner,[73] Bergeron et al,[140] Brown et al,[141,142] Handy et al,[4] Karadağ et al,[143] Laasonen et al,[99] Lin et al,[52] Mølgaard et al,[62] Mudge et al,[144] Petrova et al,[72] Russo et al,[87] Thomsen et al,[61] Thude & Classen,[84] and Waidyanatha et al.[30] HPLC and UHPLC are widely used for the analysis of *Echinacea* species and their products. Methods poorly explained or focused on the analysis of just one compound without applicability to quality control or adulteration assessment are not discussed in detail here. A comparison among the various HPLC methods for quality evaluation is given in Table 5.

Comments:

Analysis of Phenolic Compounds (caffeic acid derivatives): A variety of HPLC methods with different analytical conditions are used to analyze phenolic compounds for the quality control of *Echinacea* products.[4,62,64,94,143,145] Separation of phenolic compounds is commonly achieved on reversed phase C18 columns using gradient elution. Mobile phases usually consist of acidified aqueous solutions such as 0.1% (v/v) phosphoric acid or formic acid, adjusted to pH 2.3 ~ 3.0, and acetonitrile or methanol, sometimes with 0.1–1% (v/v) formic acid for MS compatibility as an organic modifier. The critical importance of mobile phase pH control was highlighted by Bergeron et al for the effective resolution of cichoric acid from cynarin, particularly in *E. angustifolia* samples, in addition to avoiding peak tailing.[140] Detection using a UV/Vis instrument at a wavelength of around 320–330 nm is standard for quantification.[25,117,140-143] A partially validated quantitative method described by Bergeron et al was applied for the analysis of commercial *Echinacea* products and for the evaluation of phytochemical variation within *Echinacea* populations.[63,90,140,147] *Echinacea purpurea* samples from different origins were evaluated using a

Table 5. Comparison of HPLC/UHPLC Methods for the Assessment of Adulteration in *Echinacea* products*

Source	Sample set	Analyte(s)	Run time	Detection	Comments
USP41-NF36[120,123,124]	*E. angustifolia* dried rhizome and roots, their powder and extract	Phenolics: Echinacoside, cynarin, chlorogenic acid Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	25 min	330 nm 254 nm	Validated method for phenolics and alkamides. Used gradient elution for phenolics, isocratic for alkamides. Good resolution and peak shape.
USP41-NF36[121,128]	*E. purpurea* dried rhizome and roots, their powder and extracts	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid, echinacoside 10 major alkamides	30 min	330 nm 254 nm	Validated method for phenolics and alkamides. Used gradient elution for phenolics, isocratic for alkamides. Good resolution and peak shape.
USP41-NF36[121,129]	*E. purpurea* aerial parts, their powder and extracts	Phenolics: Cichoric acid, caftaric acid, echinacoside Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	30 min	330 nm 254 nm	Validated method for phenolics and alkamides. Used gradient elution for phenolics, isocratic for alkamides. Good resolution and peak shape.
USP41-NF36[122,125,126]	*E. pallida* dried rhizome and roots, their powder and extract	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid, echinacoside	25 min	330 nm	Validated method for phenolics. Good resolution and peak shape.
Ph. Eur.11.8[88]	*E. angustifoliae* radix	Phenolics: Cichoric acid, caftaric acid, caffeic acid, chlorogenic acid, cynarin, echinacoside	20 min	330 nm	Validated method for phenolics. The method focuses on quantifying echinacoside. Good resolution and peak shape.
Ph. Eur.11.8[115,116]	*E. purpureae* herbae, radix	Phenolics: Cichoric acid, caftaric acid, caffeic acid, chlorogenic acid	20 min	330 nm	Validated method for phenolics. The method focuses on quantifying cichoric acid and caftaric acid.
Ph. Eur.11.8[114]	*E. pallidae* radix	Phenolics: Cichoric acid, caftaric acid, caffeic acid, chlorogenic acid, cynarin, echinacoside	20 min	330 nm	Validated method for phenolics. The method focuses on quantifying echinacoside. Good resolution and peak shape.
AHP[25]	*E. angustifoliae* radix	Alkamides: Undeca-2-ene-8,10-diynoic acid isobutylamide, dodeca-2-ene-8,10-diynoic acid isobutylamide, dodeca-2*E*,4*E*-dienoic acid isobutylamide, dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	40 min	210/259 nm	Validated method for alkamides. Good separation. The procedure does not differentiate dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides in quantitation, although they are clearly separated in the chromatogram. One of the few alkamide methods that includes multiple constituents including the two major alkamides.
AHP[25]	*E. angustifoliae* radix	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid, echinacoside, cynarin	14.5 min	330 nm	Validated method for phenolics. Conditions similar to USP method, but shorter run time. Good separation and peak shape (slight overlap with cichoric acid).
AHP[23]	*E. purpureae* radix	Alkamides	25 min	254 nm	Corresponds to USP method for alkamides in *E. purpurea* roots.
AHP[23]	*E. purpureae* radix	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid	30 min	330 nm	Validated method for phenolics. Good separation and peak shape. Conditions correspond to USP method, although column wash is much longer. System suitability parameters for this method can be applied to other AHP echinacea methods for phenolics.
AHP[24]	*E. pallidae* radix	Phenolics: Cichoric acid, caftaric acid, caffeic acid, chlorogenic acid, cynarin, echinacoside	14.5 min	330 nm	Validated method for phenolics. Short run time. Conditions similar to USP method. The method focuses on quantifying echinacoside. Good separation and peak shape.
Bauer et al (1999)[64]	6 commercial preparations	Phenolics: Cichoric acid Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	30 min 20 min	330 nm 254 nm	Not a validated method. Limited to main alkamide isomers and cichoric acid. Cichoric acid peak is quite broad.
Bergeron et al (2000)[140]	7 samples of *E. purpurea* roots, 20 samples of *E. purpurea* aerial parts, 9 samples of *E. angustifolia* roots	Phenolics: Cichoric acid, echinacoside, chlorogenic acid Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	9 min 15 min	320 nm 210/260 nm	Partially validated quantitative method. Limited to main alkamide isomers and three phenolic compounds. Short run time and excellent separation of the phenolic compounds. Some overlapping peaks may hamper quantification of the alkamides in the method for lipophilic compounds. The use of sodium dihydrogen phosphate requires extensive cleaning after analysis to avoid pump damage.
Laasonen et al (2002)[99]	18 samples from *E. purpurea,* 23 samples of *E. angustifolia,* 10 samples of *E. pallida,* and 2 samples of *P. integrifolium*	Phenolics: Cichoric acid, chlorogenic acid, cynarin, echinacoside Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides	15 min	255 nm	Not a validated method. It is for simultaneous analysis of phenolics and alkamides. Short run time.
Mølgaard et al (2003)[62]	19 commercial preparations	Phenolics: Cichoric acid Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic acid isobutylamides, undeca-2*Z*,4*E*-diene-8,10-diynoic acid isobutylamide	55 min	290 nm 260 nm	Validated method for simultaneous analysis of phenolics and alkamides. Limited to main alkamide isomers and cichoric acid. Good separation but very long run time.
Bergeron and Gafner (2007)[73]	*E. purpurea* herb and root, *E. angustifolia* root	The results are expressed as arabinogalactan equivalents	25 min	ELSD	Validated method for the analysis of polysaccharide/glycoprotein fraction of *Echinacea* spp. Sample preparation time is reasonable (~2 h). The main limitation is that it does not distinguish types of polysaccharides or glycoproteins.
Brown et al (2010)[141]	Root and aerial samples of *E. angustifolia, E. pallida*, and *E. purpurea*	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid, cynarin, echinacoside	14.5 min	330 nm	Validated method as per AOAC guidelines for the analysis of phenolics. Short run time. Suitable for determination of the major phenolics. A subsequent collaborative study (Brown et al, 2016)[142] found that the method has limitations in accurately quantifying individual phenolic compounds.
Mudge et al (2011)[144]	9 commercial preparations	Alkamides	15 min	254 nm MS/MS	Not a validated method. 24 alkamides identified in 15 min. Short run time, good separation although some minor peak overlap. Products made from root and aerial parts were differentiated based on their alkamide profiles. MS equipment is expensive.
Ferencz et al (2020)[145]	12 commercial preparations	Phenolics: Cichoric acid, caftaric acid, chlorogenic acids, caffeic acid, echinacoside	20 min	330 nm	Method only for phenolics and not validated. Short run time, but no resolution between caftaric acid and chlorogenic acid.
Aiello et al (2020)[86]	65 *E. angustifolia* accessions, roots	Phenolics: Echinacoside, cynarin Alkamides: Dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic isobutylamides	34 min	325 nm 254 nm MS/MS	Validated method for simultaneous analysis of phenolics and alkamides. Combined with principal component analysis (PCA), the method successfully identified distinct groups of accessions. Limited with three compounds. MS equipment is expensive.
Handy et al (2021)[4]	20 commercial preparations	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid, cynarin, echinacoside	40 min	330 nm 380 nm	Method only for phenolics and not validated. Relatively short run time and good peak shape. Analytes of interest are well resolved.
Lv et al (2022)[146]	Five batches of *E. purpurea*	Phenolics: Cichoric acid, caftaric acid, chlorogenic acid	70 min	330 nm	Validated method for phenolics. Good separation and resolution of the 15 common peaks, the combination with chemometrics (PCA/HCA) allows successful differentiation of samples from different origins. Very long run time. The combined method with multivariate statistics requires specialized software.
Vlasheva et al (2024)[94]	9 commercial preparations	Phenolics: Cichoric acid, caftaric acid, caffeic acids, cynarin, echinacoside, quercetin, apigenin	17 min	330 nm	Validated method for phenolics. Short run time, but substantial overlapping peaks and some tailing observed in commercial products.

validated HPLC fingerprint combined with chemical pattern recognition and multi-component determination. The study successfully demonstrated that this integrated method with principal component analysis (PCA) and hierarchical cluster analysis (HCA) has high discriminatory power and can clearly distinguish samples based on their geographical cultivation area.[146]

Waidyanatha et al[30] compared HPLC coupled to a charged aerosol detector (CAD) and HPLC with tandem mass spectrometry (HPLC-MS/MS) for phenolic quantitation in *E. purpurea* root extract. Although the pattern of constituent distribution was similar between the two methods, the concentration of phenolic compounds was 2- to 3-fold higher using CAD than those using MS detection. The differences in the quantitative data between the CAD and the MS detector are difficult to explain as another study comparing the two detectors for the determination of phenolic compounds in agrimony (*Agrimonia eupatoria*, Rosaceae) showed that both instruments provide similar results.[148] Russo et al[87] conducted a detailed study of an *E. angustifolia* root hydroalcoholic extract. These studies show the value of MS techniques for robust identification and accurate quantification.


Echinacea pallida
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A validated method initially developed by the Institute for Nutraceutical Advancement (INA) was optimized by Brown et al and subjected to a collaborative validation study in 11 laboratories.[141,142] This method was later adopted by the AHP, the Ph. Eur., and the USP, although there are differences in the sample preparation methods among the three standards. These pharmacopeial monographs provide detailed HPLC conditions and acceptance criteria for the phenolic markers in *Echinacea* species.

Analysis of Alkamides: The most frequently used marker compounds are the dodeca-2*E*,4*E*,8*Z*,10*E*-tetraenoic acid and dodeca-2*E*,4*E*,8*Z*,10*Z*-tetraenoic acid isobutylamides, which are used in USP41-NF36 as a standard compound together with 2*E*,4*E*-hexadienoic acid. Additional alkamides such as undeca-2-ene-8,10-diynoic acid isobutylamide, dodeca-2-ene-8,10-diynoic acid isobutylamide, and dodeca-2*E*,4*E*-dienoic acid isobutylamide are also used as marker compounds to increase reliability and accuracy of the analysis.[25,62,99,140] Mobile phases are typically gradient systems of water and acetonitrile, often with formic acid (0.1%, v/v). While UV/DAD detection at lower wavelengths (210 nm, or 254–260 nm) is a very popular tool for detecting alkamides, the addition of tandem mass spectrometric (MS/MS) detection is advantageous for both identification and quantification. Positive ion mode is particularly suitable for the mass spectrometric detection of alkamides due to the presence of a nitrogen atom in the alkamides. Mudge et al profiled 25 alkamides with an ultrafast liquid chromatography (UFLC)-MS/MS method within a 15-minute run time.[144] Thomsen et al used HPLC-DAD-APCI-MS/MS to identify and quantify 16 alkamides, two ketoalkenes, and three ketoalkynes in *E. purpurea* and *E. pallida* roots.[61] These studies highlight the utility of MS/MS for the accurate identification of alkamides. A key advantage of the MS/MS approach is its ability to distinguish isobutylamides and 2-methylbutylamides.

Simultaneous Analysis of Phenolics and Alkamides: For efficiency, some methods have been developed for the simultaneous determination of both hydrophilic phenolics and lipophilic alkamides. Mølgaard et al described a validated HPLC-UV method achieving this with a ternary

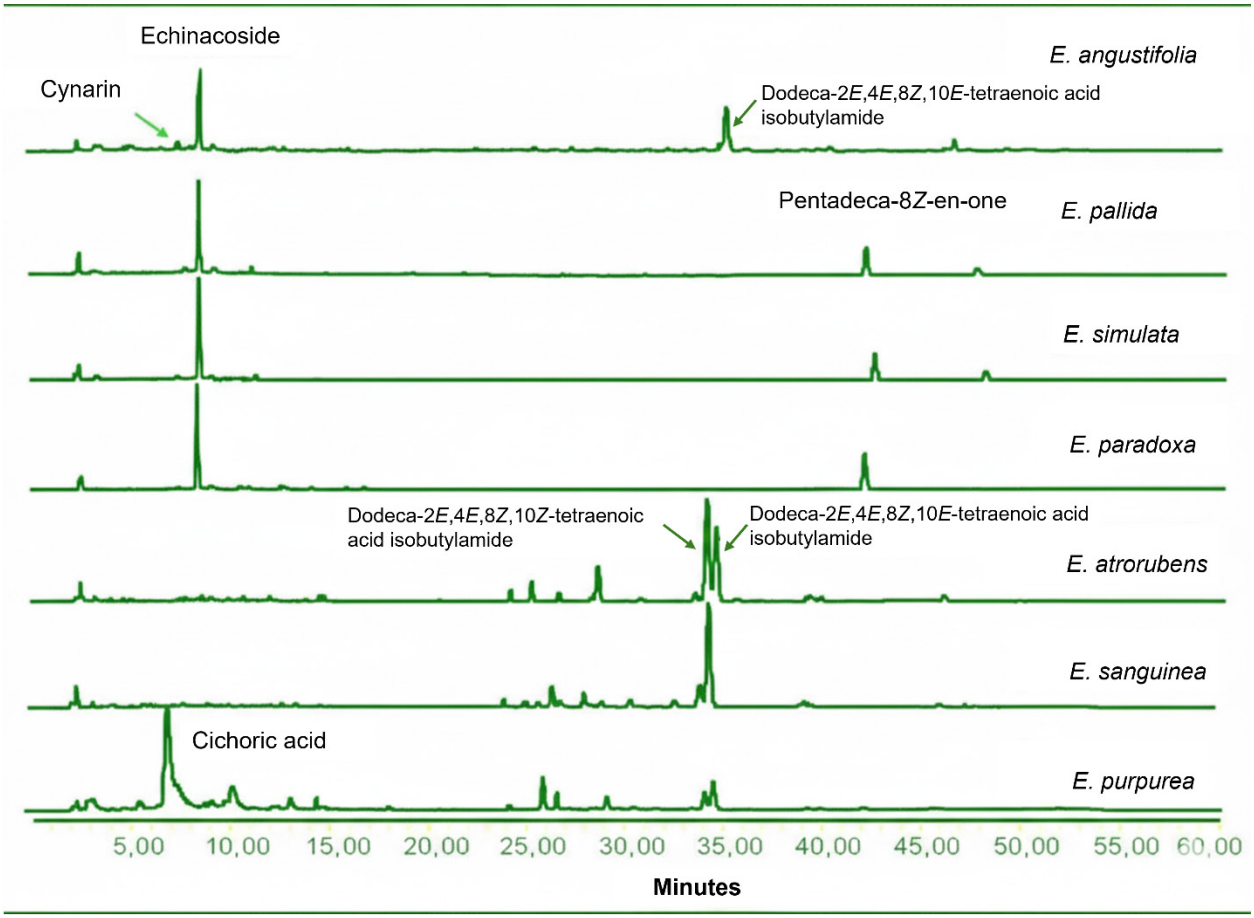


Figure 5. Comparative HPLC fingerprints of seven *Echinacea* species illustrating distinct phytochemical profiles*. Image provided by Indena S.p.A. (Milano, Italy).

*Chromatographic conditions: Column: Zorbax SB C 18 (250 x 6 mm), 5 µm; Mobile phase: Water (solvent A) and 0.01% trifluoroacetic acid in acetonitrile (Solvent B), linear gradient: 10-55% B in 20 min, 55% B for 10 min, 55-80% B in 20 min, 80-10% B in 2 min and 10% B for 8 min.; Flow rate: 1.0 ml/min.; Detection: UV at 235 nm.

gradient system over approximately 55 minutes.[62] Laasonen et al also used a single HPLC run (15 min, UV 255 nm) for identifying both classes of compounds, mainly for authentication.[99] The phytochemical diversity of *Echinacea* is given in Figure 5, which shows comparative HPLC fingerprints for seven *Echinacea* species. Each species exhibits a unique chemical profile based on the distribution of caffeic acid derivatives and lipophilic constituents such as cichoric acid (major in *E. purpurea*), echinacoside, and cynarin (characteristic of *E. angustifolia*) and various alkylamides or ketones that differentiate the remaining species. Cech et al developed an HPLC-ESI-MS/MS method specifically for the simultaneous analysis of caffeic acid derivatives and alkamides in *E. purpurea* extracts. It started in negative ion mode for the earlier-eluting caffeic acid derivatives, then switched to positive ion mode for the alkamides.[149] Similarly, Aiello et al (2020) also quantified key phenolics (echinacoside, cynarin) and an alkamide (dodeca-2*E*,4*E*,8*Z*,10*E/Z*-tetraenoic isobutylamide) together in *E. angustifolia* roots using an HPLC-PDA-MS/MS system. For their qualitative MS identification, they acquired spectra in both positive and negative ion modes to best characterize all target compounds, while quantification relied on UV/Vis detection.[86] These simultaneous analysis methods are particularly valuable since they allow for detection of a

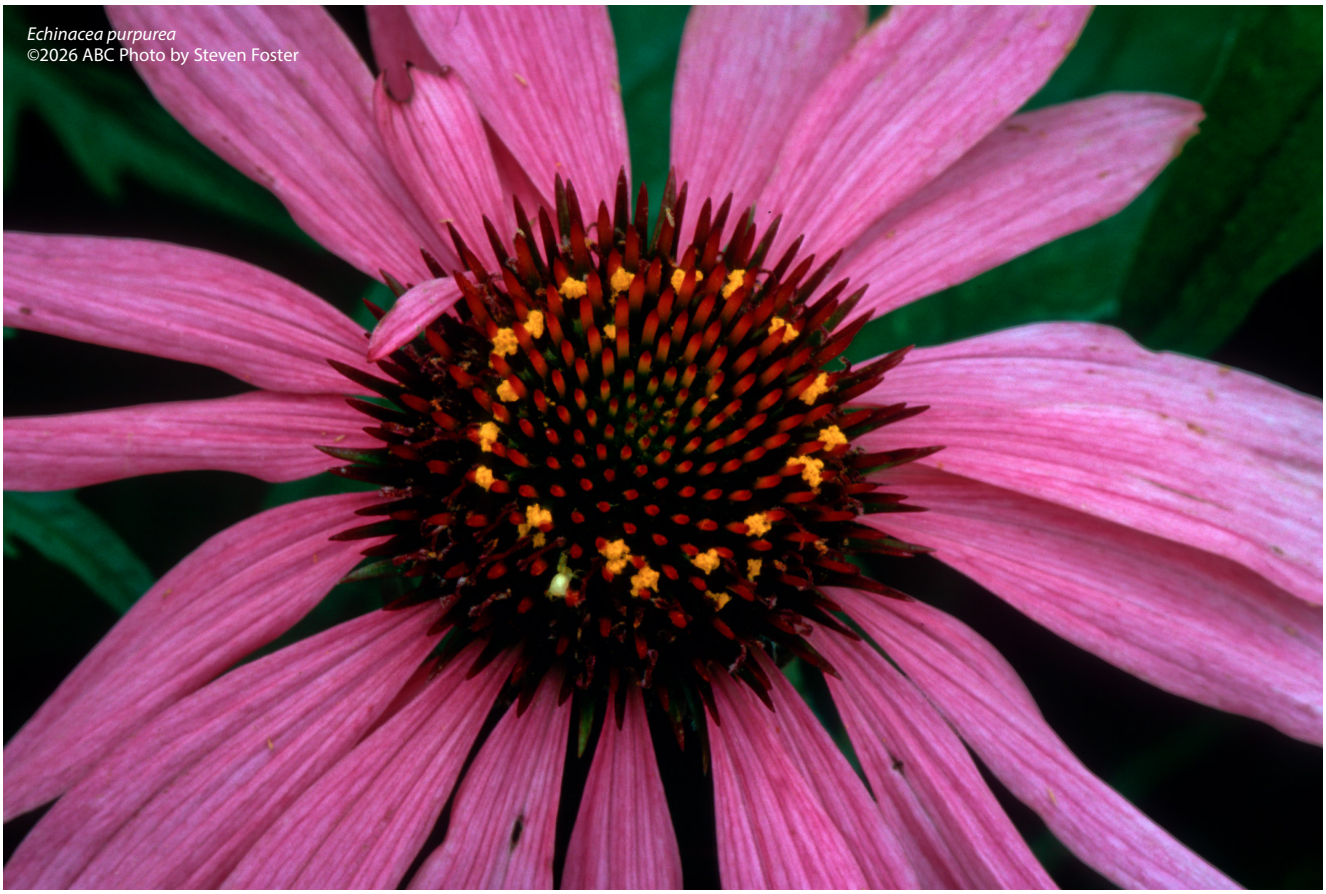
broader range of adulterants.

While the primary focus of adulteration detection in *Echinacea* often targets phenolics and alkamides, the analysis of polysaccharide and sugar profiles can provide valuable additional information. Significant deviations from an expected polysaccharide or sugar profile, or the detection of unusual sugars, may indicate the presence of undeclared fillers or excipients.[4] For the separation of polysaccharides, HPLC is the primary technique. Bergeron and Gafner used HPLC with evaporative light scattering detection (ELSD) to quantify high molecular weight polysaccharide and glycoprotein (PS/GP) fractions, expressed as arabinogalactan equivalent.[73] Thude and Classen also investigated the amino acid composition of AGPs from *E. pallida* roots by HPLC with post column ninhydrin derivatization.[84] For specific fructans like inulin and for simple sugars, HPLC coupled with refractive index detection (RID) and specialized HPLC columns for the separation of polysaccharides is typically used.[72]

Overall, most HPLC methods that measure the phenolic or alkamide fingerprints are suitable to detect substitution or admixture of *Echinacea* with other plant materials. The relatively short run time, robust validation, and universal acceptance make the compendial method for phenolics in the AHP, Ph. Eur., and USP particularly appealing. In addition, screening for specific negative markers such as iridoids or anthraquinones is essential to explicitly exclude the presence of adulterants like *Cistanche* or *Parthenium*. For the detection of undeclared fillers, a combination of a chromatographic method (HPTLC, HPLC-UV/Vis, HPLC-MS) with microscopy is warranted.

10.2.3. Size-Exclusion Chromatography

Size-exclusion chromatography (SEC), also known as gel permeation chromatography or gel filtration, is employed for the characterization of high molecular weight polysaccharides from *Echinacea* species. This review evaluated methods for SEC analysis of *Echinacea* polysaccharides from Bergeron and Gafner,[73] Classen et al,[80] Cozzolino et al,[85] Thude and Classen,[84] and Volk and Classen.[81]



Echinacea purpurea
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Comments: The methods described in these papers use SEC primarily to isolate and determine the molecular weight of polysaccharides as well as to quantify total polysaccharide/glycoprotein (PS/GP) fractions. Hence, the usefulness of these methods to distinguish between *Echinacea* species has, in most cases, not been assessed. An exception is the paper by Bergeron and Gafner,[73] where clear differences in the polysaccharide composition of *E. purpurea* herb, root, and *E. angustifolia* root were reported. However, no other *Echinacea* species nor any other potential adulterants were included. Polysaccharide concentration can be determined by the phenol-sulfuric method. However, the low reproducibility of the results and the lack of specificity make this method unsuitable for identity determination.[73,74]

The primary advantage of SEC is its ability to separate based on size and provide direct information on molecular weight distribution, which is a key characteristic of polysaccharides. Common SEC systems use columns like Sepharose, Sephacryl, or specialized SEC columns with aqueous buffers (often containing salts like NaCl) as the mobile phase. Detection is typically performed by refractive index (RI) or ELSD, which is mass-sensitive and often preferred for quantifying total polysaccharides.[73] Advanced detectors like multi-angle laser light scattering (MALLS) can provide absolute molecular weight data. Pullulans with known molecular weights are commonly used for column calibration when determining relative molecular weights.[81]

SEC for *Echinacea* quality control does not provide direct structural information about the polysaccharides. For detailed structural elucidation (e.g., monomer composition, linkage analysis) after the SEC fractionation or purification step, the collected fractions can be analyzed by other techniques. For example, Cozzolino et al performed enzymatic digestions on pectin fractions obtained after SEC characterization and then analyzed the resulting oligosaccharides with matrix-assisted desorption/ionization-time of flight mass spectrometry (MALDI-TOF MS) to get insights into the structure of the pectin.[85]

In the context of adulteration detection, SEC could play a role as an additional screening tool for distinguishing *Echinacea* species based on their polysaccharide composition. However, the availability of shorter, more user-friendly, and more specific authentication methods like HPTLC or HPLC-UV/Vis analysis of phenolics or alkamides make the polysaccharide analysis a less compelling approach for authenticating *Echinacea.*

10.2.4. Gas Chromatography (GC)

This review evaluated GC methods from Bruni et al,[1] Dosoky et al,[68] Hudaib et al,[150] Mazza et al,[70] Kabganian et al,[89] Petkova et al[83] and Vaverkova et al.[98].

Comments: GC-MS is a useful technique for the analysis of the alkamides and other lipophilic constituents. Hudaib et al developed a GC-MS method on a nonpolar fused silica capillary column to analyze alkamides, alkenes, and sesquiterpenoids from *E. purpurea* root extracts. The lipophilic compounds were recovered by subjecting a 70% aqueous methanol extract to liquid-liquid extraction with n-hexane-ethyl acetate.[150] GC-MS is the primary analytical technique for analyzing echinacea essential oils. While the essential oils of *E. purpurea* and *E. angustifolia* flowerheads are dominated by sesquiterpenes like germacrene D and β-caryophyllene, essential oils of *E. pallida* and *E. atrorubens* roots have a different composition (e.g., the presence of ketoalkenes).[1,70,98] Furthermore, chiral GC-MS was employed to determine enantiomeric distributions of chiral compounds present in essential oils of *E. purpurea*.[68] The determination of enantiomeric ratios of volatile compounds can be very useful in the detection of adulteration.

10.2.5. Near Infrared Spectroscopy (NIR)

This review evaluated NIR methods from Laasonen et al[151] and Schulz et al.[152]

Comments: Near-infrared spectroscopy (NIR) is a fast and non-destructive analytical technique that requires very little or no sample preparation. Both quantitative and qualitative analysis can be directly performed on whole, cut, or powdered samples.[99,153] Laasonen et al developed a fast NIR method to confirm the identity of *E. purpurea* roots and to detect adulteration.[99,151] The authors created a library of NIR spectra for

authentic *Echinacea* samples (*E. purpurea, E. angustifolia, E. pallida*) and *Parthenium integrifolium*. The partial least-squares (PLS) algorithm was used for data analysis and sample classification. The method demonstrated excellent specificity and classified all the adulterated test samples correctly. Presence of other species in *E. purpurea* samples could be detected at concentrations of 10% or higher. However, one authentic *E. purpurea* sample was described as "misidentified" due to the differences in the particle size distribution. This result indicates that samples have to be prepared (milled) with exactly the same procedure to avoid errors using the NIR method.[151,99] The work by Schultz et al focused on the quantification of echinacoside content in the roots of *E. angustifolia* and *E. pallida* by NIR.[152] A calibration model was created using multivariate statistics with PLS as the algorithm. In parallel, echinacoside content was measured by an HPLC method. The quantitative results of the NIR method showed a very good correlation with the HPLC results with an analysis time of about one minute per sample. However, since this method relies on echinacoside as a marker compound, other plants containing echinacoside, such as *Cistanche deserticola*, might go undetected.

While NIR can be used successfully to detect adulteration of cut or powdered *Echinacea* roots, it is not clear if the method performs as well with echinacea extracts, especially since the manufacturing process (e.g., extraction solvent, additional purification steps, excipients) has a substantial impact on the composition and, hence, the NIR spectrum of the ingredient. The libraries of NIR spectra created and used are critical to successful application of the NIR technique.

10.2.6. Hyperspectral Imaging (HSI)

This review evaluated the method by Sandasi et al.[154]

Comments: This study introduces hyperspectral imaging (HSI) with chemometric evaluation for quality control of *Echinacea*. HSI combines conventional spectroscopy and imaging to get both spectral and spatial information from a sample. HSI captures a spectral fingerprint from every pixel of the sample image which represents the entire chemical composition at once. This


Echinacea purpurea
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non-destructive technique allows rapid quality assessment with the aid of multivariate data analysis like PCA and partial least squares discriminant analysis (PLS-DA). PCA plots showed a clear distinction between the root and leaf samples of each of the three *Echinacea* species and further differentiated the roots of the species. They applied their model to 20 commercial products and the majority (12 out of 20) were predicted to contain *E. purpurea, E. angustifolia,* or both. They confirmed their results by using UPLC-MS analysis, providing very strong evidence of mislabeling of some of the commercial samples. The study authors concluded that HSI is suitable for the quality control of *Echinacea*. Advantages are that HSI is a rapid and non-destructive method with high prediction ability, which considers a large part of the phytochemical metabolome. However, the technique involves relatively high costs and requires large instrumentation, which may limit its routine use in smaller laboratories. Moreover, this method is clearly more suitable for identification of cut or powdered root rather than

extracts, and its prediction ability is limited in the presence of polyherbal formulations or for products containing high levels of excipients.

10.2.7. Flow Injection Mass Spectrometry (FIMS)

This review evaluated the method by Harnly et al.[155]

Comments: FIMS generates a rapid chemical fingerprint without chromatographic separation for the authentication of plant extracts. In this study, its primary application is to verify the presence of authentic *E. purpurea* aerial parts in commercial supplements by using a correlation spectrum to match their chemical profiles. Then, PCA is used as a critical tool for data interpretation. By applying this combined method, the study verified the presence of *E. purpurea* aerial parts in five out of six single ingredient supplements and seven out of 13 mixed ingredient supplements. The authors conclude that FIMS is a powerful and rapid screening tool for qualitative authentication. Although FIMS requires expensive instrumentation and is not suitable for accurate quantification of individual compounds in *Echinacea* extracts, it is an effective method as a first line screening for comparison of botanical ingredients and commercial botanical supplements.

10.2.8. Nuclear Magnetic Resonance (NMR)

This review evaluated methods from Frédérich et al,[156] Hussin,[157] Politi et al,[158] Ramasahayam et al,[159] and Nagumalli et al.[160]

Comments: Metabolomics, metabolite profiling, or chemical fingerprinting of species and plant parts are increasingly used in quality control of plant extracts as reflected by the growing number of studies. NMR-based methods generate a rapid chemical fingerprint of *Echinacea* extracts without chromatographic separation or evaporation. This direct analysis provides several advantages such as a short sample preparation time, non-destructive workflow, reliable quantitative data without multiple reference standards, and the ability to determine molecular structures of individual compounds, even in mixtures. Classic HPLC or HPTLC analysis often focuses on a group of marker compounds. This can cause an analyst to miss adulterants in the extracts. In contrast, direct ^{1}H-NMR detects all protons present in an extract, providing a more comprehensive fingerprint of the ingredient.[110] Politi et al[158] evaluated the batch-to-batch homogeneity and degradation of a batch in different *Echinacea* tinctures using one-dimensional diffusion-oriented NMR spectroscopy (DOSY) and regular ^{1}H-NMR spectroscopy with suppression of the water and ethanol signals. A DOSY experiment helps distinguish compounds based on their size or aggregation. These methods were able to distinguish the *Echinacea* tinctures from ginkgo (*Ginkgo biloba*, Ginkgoaceae) and valerian (*Valeriana officinalis*, Valerianaceae) tinctures but found no major differences among *Echinacea* batches from the same manufacturer.

Frédérich et al[156] used ^{1}H-NMR fingerprinting and multivariate analysis PCA to discriminate among *E. purpurea*, *E. angustifolia*, *E. pallida*, and *E. simulata*. Among the commercial samples analyzed, dry extracts labelled as *E. angustifolia* roots were identified as *E. pallida* roots. Similarly, a crude plant sample labelled as *E. pallida* was in fact *E. purpurea*, confirming mislabeling among the three officinal *Echinacea* species sold in the Belgian phytomedicine market. Several of the papers evaluated the benefits of correlating NMR fingerprint and specific biological effects.[157,159,160] For example, Nagumalli et al analyzed 11 different *Echinacea* samples for their myeloid progenitor-stimulating activity and correlated specific regions in the NMR spectrum to the activity.[160]

While the available published information does not permit determination of the usefulness of NMR spectroscopy to detect *Echinacea* adulteration, the amount of information that can be obtained suggests that it is a suitable method to distinguish *Echinacea* species from potential adulterants. It can also help detect undeclared excipients and fillers present in larger concentrations (if the excipients/fillers are soluble in the NMR solvent). Drawbacks are the relatively low sensitivity and the high equipment costs.

11. Conclusion

Echinacea preparations are primarily derived from three species including the aerial parts of *E. purpurea* and the roots of *E. purpurea, E. angustifolia*, and *E. pallida*. Despite substantial

fluctuations in global sales, *Echinacea* products consistently rank among the most popular herbal supplements worldwide. However, their quality remains a concern due to species mix-ups, adulteration with botanicals like *Cistanche* species, and excessive dilution with undeclared excipients or carriers. Authentication of *Echinacea* products can be challenging, especially when other *Echinacea* species or plant parts are added at low concentrations.

Macroscopic, microscopic, and organoleptic analysis are the first indication of identity and potential adulteration. For whole or semi-whole materials, macroscopic and organoleptic assessment when performed by trained personnel using authenticated BRMs is often considered the most definitive method of identification. Even for processed *Echinacea* extracts, organoleptic evaluation serves as a crucial first step; adulterated or diluted extracts often fail to conform to the characteristic color, aroma, or flavor of authentic material. Microscopy is the most cost-effective tool for detecting undeclared fillers (e.g., various types of starch, maltodextrin, etc.) or foreign plant fibers. For materials where DNA is sufficiently intact, some DNA-based technologies may offer accurate species level identification. DNA metabarcoding or genome skimming can not only confirm the presence of the declared species but also detect undeclared botanical ingredients, giving a comprehensive view of a product's composition.

Chemical fingerprinting methods, when used properly, are suitable for authenticating extracts and assessing their quality, though they may be less definitive for identifying complex mixtures or dilutions. While adulterants can readily be detected chemically, relying on the presence or absence of a single marker compound is insufficient for the authentication of *Echinacea*. For example, while echinacoside is a good indicator for *E. angustifolia* or *E. pallida,* its presence does not exclude admixture of *E. purpurea* or adulteration with *Cistanche* species. Therefore, a valid chemical authentication should be based on a fingerprint of characteristic compounds, including both caffeic acid derivatives and alkamides. HPTLC is strongly recommended by several pharmacopeial monographs for this purpose. The methods in AHP, USP41-NF36, Ph. Eur. 11.8, and the HPTLC Association are largely identical for the determination of phenolics and alkamides. This



Echinacea purpurea
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means that a widely accepted HPTLC method can be used for routine quality control and to help detect adulteration and mislabeling. HPLC and UHPLC methods are essential for quantitative assessment to detect low quality *Echinacea* material. These techniques provide a detailed chemical profile that is crucial for detecting adulteration. By analyzing the specific ratios of caffeic acid derivatives (e.g., cichoric acid, caftaric acid, cynarin) and alkamides, the three medicinal *Echinacea* species can be distinguished, and the presence of adulterants like *P. integrifolium* or *Cistanche* species, which exhibit distinct chromatographic fingerprints, can be detected. It is important to note that standard fingerprint methods are not designed for compounds unique to adulterants. They do not routinely search for negative markers, such as the iridoids or other phenylethanoids in *Cistanche* or anthraquinones in *Parthenium*, to rule them out. Instead, detection often relies on observing unusual constituent ratios in HPLC or using HPTLC for visual confirmation. So, screening for specific negative markers such as iridoids or anthraquinones is essential to explicitly exclude the presence of adulterants like *Cistanche* or *Parthenium*. For ingredients in cut or powdered form, the combination of chemical profiling (HPTLC or HPLC-UV/Vis) with DNA-based methods offers a more comprehensive approach, where HPTLC/HPLC-UV/Vis confirms the chemical consistency, and DNA barcoding or genome skimming can identify other plant species present in the product.

Other methods proposed for *Echinacea* quality control include NMR, NIR, HSI, or analysis of the *Echinacea* polysaccharides by various means. NMR, HSI, and NIR all require less time for the sample preparation than chromatographic methods, which saves time for the quality control personnel. Although these are very useful orthogonal methods to detect adulteration, they may be less appealing in a quality control setting due to higher instrument costs, lower selectivity, or a more limited applicability. A comparison of advantages and disadvantages of the more commonly used test methods for authentication of *Echinacea* species and their extracts are provided in Table 6.

12. References

1. Bruni R, Brighenti V, Caesar LK, Bertelli D, Cech NB, Pellati F. Analytical methods for the study of bioactive compounds from medicinally used *Echinacea* species. *J Pharm Biomed Anal*. 2018;160:443-477.
2. Foster S. A Brief history of adulteration of herbs, spices and botanical drugs. *HerbalGram*. 2011;92:42-58.
3. Orhan N, Gafner S, Blumenthal M. Estimating the extent of adulteration of the popular herbs black cohosh, echinacea, elder berry, ginkgo, and turmeric — Its challenges and limitations. *Nat Prod Rep*. 2024;41(10):1604-1621.
4. Handy SM, Pawar RS, Ottesen AR, et al. HPLC-UV, metabarcoding and genome skims of botanical dietary supplements: A case study in *Echinacea*. *Planta Med*. 2021;87(4):314-324.
5. Harput Döner Ü, Gafner S. Botanical Adulterants Prevention Bulletin on Echinacea (*Echinacea purpurea, Echinacea angustifolia,* and *Echinacea pallida*). Austin, TX: ABC-AHP-NCNPR Botanical Adulterants Prevention Program; 2025.
6. *Echinacea purpurea* (L.) Moench. USDA Natural Resources Conservation Service website. Available at: https://plants.usda.gov/plant-profile/ECPU. Accessed October 10, 2024.
7. *Echinacea angustifolia* DC. USDA Natural Resources Conservation Service website. Available at: https://plants.usda.gov/plant-profile/ECAN2. Accessed October 10, 2024.
8. *Echinacea pallida* (Nutt.) Nutt. The World Flora Online website. Available at: www.worldfloraonline.org/taxon/wfo-0000020152. Accessed October 02, 2024.
9. *Echinacea purpurea* (L.) Moench. International Plant Names Index website. Available at: www.ipni.org/n/1174497-2. Accessed October 18, 2024.
10. *Echinacea angustifolia* DC. International Plant Names Index website. Available at: www.ipni.org/n/87143-2. Accessed October 18, 2024.
11. *Echinacea pallida* (Nutt.) Nutt. International Plant Names Index website. Available at: www.ipni.org/n/202374-1. Accessed October 18, 2024.
12. *Echinacea purpurea* (L.) Moench. The World Flora Online website. Available at: www.worldfloraonline.org/taxon/wfo-0000036347. Accessed October 2, 2024.
13. *Echinacea purpurea* whole. National Library of Medicine website. Available at: https://pubchem.ncbi.nlm.nih.gov/substance/482034713. Accessed March 16, 2025.
14. *Echinacea angustifolia* DC. The World Flora Online website. Available at: www.worldfloraonline.org/taxon/wfo-0000041434. Accessed October 2, 2024.
15. *Echinacea angustifolia* (Kansas snakeroot). National Library of Medicine website. Available at: https://pubchem.ncbi.nlm.nih.gov/taxonomy/308558. Accessed December 17, 2024.
16. Medicinal Plant Names Services. Royal Botanic Gardens, Kew website. Available at: https://mpns.science.kew.org/mpns-portal. Accessed May 1, 2025.
17. Applequist W. *The Identification of Medicinal Plants: A Handbook of the Morphology of Botanicals in Commerce*. Austin, TX, and St. Louis, MO: American Botanical Council and Missouri Botanical Garden; 2006.
18. Urbatsch L, Neubig KM, Cox PB. *Echinacea purpurea*. Flora of North America website. July 17, 2020. Available at: http://floranorthamerica.org/Echinacea_purpurea. Accessed February 10, 2025.
19. Kindscher K, Riggs M. Cultivation of *Echinacea angustifolia* and *Echinacea purpurea*. In: Kindscher K, ed. *Echinacea*. Cham, Switzerland: Springer; 2016:21-33.
20. Mistrikova I, Vaverkova S. Morphology and anatomy of *Echinacea purpurea, E. angustifolia, E. pallida* and *Parthenium integrifolium*. *Biologia*. 2007;62(1):2-5.
21. McGregor RL. The taxonomy of the genus *Echinacea*

Table 6. Comparison Among the Different Analytical Methods to Authenticate *Echinacea* Species and Their Extracts

Method	Analyte	Advantage	Disadvantage
Macroscopic	Whole, broken, or cut plant part	Quick Low cost No solvents required Can detect filth, adulterants, diluents, and relative quality	No automation/statistics Difficult or impossible for finely cut and sifted materials
Microscopic	Whole, cut, or powdered plant material	Quick Low cost Can detect filth, adulterants, diluents, and relative quality No solvents required	No automation/statistics Challenging to distinguish *Echinacea* species due to their similar microanatomy
Organoleptic	Whole, cut, or powdered plant material	Quick Low cost Taste, aroma, and color may give an idea about adulteration (e.g., presence or lack of tingling sensation) No solvents required	Low specificity Cannot detect adulteration in mixture
Genetic			
RAPD	Whole, cut, or powdered plant material	Relatively simple, inexpensive method Needs only small amounts of plant material	Low reproducibility Low specificity Cannot discern plant parts Requires relatively undegraded DNA Work best on high quality DNA, such as from fresh plant material Not a quantitative method Older technology
DNA barcoding	Whole, cut, or powdered plant material, some extracts	Useful tool for authentication if good quality DNA is used Easy implementation Fast turnaround time	DNA degradation may prevent successful amplification Not a quantitative method Cannot discern plant parts It generally fails in a mixture containing multiple botanical species Low molecular divergence limits species-level resolution in *Echinacea*
DNA metabarcoding	Whole, cut, or powdered plant, multi-ingredient product, some extracts	Identify multiple botanical species in a mixture if the diagnostic regions are chosen Highly sensitive method even traces of DNA Good for detecting adulteration	Expensive equipment Lack of discriminatory resolution at the species level due to low genetic divergence of *Echinacea* Highly dependent on the selection of diagnostic regions Not a quantitative method DNA degradation may prevent successful amplification
Genome skimming	Whole, cut, or powdered plant, multi-ingredient product	Offers high genetic resolution for *Echinacea* authentication Can detect complex mixtures compared to traditional DNA metabarcoding More effective on fragmented DNA Can identify adulteration Semiquantitative	Requires expensive equipment Complex data analysis Requires bioinformatics information Lack of user-friendly tools DNA degradation may prevent successful amplification
Chromatographic			
TLC/HPTLC	Cut or powdered plant parts,* extracts	Quick Basic and affordable equipment Good for fingerprint analysis Well established pharmacopeial methods (AHP, Ph. Eur., USP) Can detect a small amount of adulteration Reliable differentiation of the three *Echinacea* species and detection of common adulterants (e.g., *Parthenium, Cistanche*).	No direct quantification Needs reference standard compounds and/or botanical reference materials (qualitative analysis)
TLC/HPTLC-video densitometry	Cut or powdered plant parts,* extracts	Allows quantitative estimation Offer more objective data interpretation Amenable to multivariate statistics	Requires specialized expertise and software Difficult to transfer analysis to routine quality control Needs reference standard compounds (quantification) and/or botanical reference materials (qualitative analysis)
HPLC-UV/Vis	Cut or powdered plant parts,* extracts	Standard equipment in many analytical labs Can detect and quantify key phenolics and alkamides Good for fingerprint analysis Enables detection of low-level adulterants by comparing the sample's fingerprint chromatogram against an authentic reference Well established in pharmacopeial monographs (AHP, Ph.Eur., USP) Suitable for routine analysis	Expensive equipment Resolution of minor alkamides can be challenging without MS detector Needs reference standard compounds (quantification) and/or botanical reference materials (qualitative analysis)
HPLC-MS and HPLC-MS/MS	Cut or powdered plant parts,* extracts	Can distinguish co-eluting alkamides High sensitivity Allows qualitative and quantitative analysis Ability to distinguish isobutylamides and 2-methylbutylamides Amenable to multivariate statistics	Expensive equipment Quality of data depends on ability to ionize analyte Needs reference standard compounds (quantification) and/or botanical reference materials (qualitative analysis)
HPLC-ELSD	Cut or powdered plant parts,* extracts	Universal detector (including *Echinacea* polysaccharides) Reasonable time for the preparation of the sample	No qualitative information constituents ELSD response depends on the volatility of the compound Limited dynamic range Lower sensitivity than other detectors Needs botanical reference materials
HPLC-CAD	Cut or powdered plant parts,* extracts	Universal detector (including *Echinacea* polysaccharides) Allows quantitative estimation	Potential overestimation of constituent levels Low specificity and selectivity in complex mixtures Needs botanical reference materials
HPLC-RID	Cut or powdered plant parts,* extracts	Universal detector for carbohydrates (simple sugars, inulin) Relatively simple and inexpensive detector	Low sensitivity Lower dynamic range than UV/Vis or MS Very susceptible to changes in ambient temperature, pressure, and flow rate Cannot be used for gradient elution Needs reference standard compounds and/or botanical reference materials
Spectroscopic			
NIR	Cut or powdered plant parts, extracts	Non-destructive and rapid sample preparation Works directly on solid, powdered samples without any need for solvents or extraction Short analysis time Its speed and simplicity make it ideal for high-throughput screening Low cost Mostly qualitative	Requires consistent sample preparation Less suitable for highly processed extracts Sensitive to particle size, cut, moisture, etc. Requires high level of specialized expertise Quantitative analysis for a limited number of compounds (e.g., echinacoside) feasible, but challenging Requires advanced statistical tools to interpret data Large number of plant samples needed to build reference library
HSI	Cut or powdered plant parts, extracts	Non-destructive and rapid sample preparation Short analysis time High prediction ability in raw material	Expensive and large equipment Requires multivariate statistical methods (e.g., PCA, PLS-DA) Less suitable for highly processed extracts Sensitivity is limited in the polyherbal formulations Less suitable for highly processed extracts Large number of plant samples needed to build reference library
^{1}H-NMR	Cut or powdered plant parts,* extracts	Non-destructive and rapid sample preparation Universal detector Short analysis time Qualitative and quantitative	Expensive and large equipment Relatively low sensitivity Severe signal overlap complicates quantitative analysis Requires advanced statistical tools to interpret data Large number of plant samples needed to build reference library

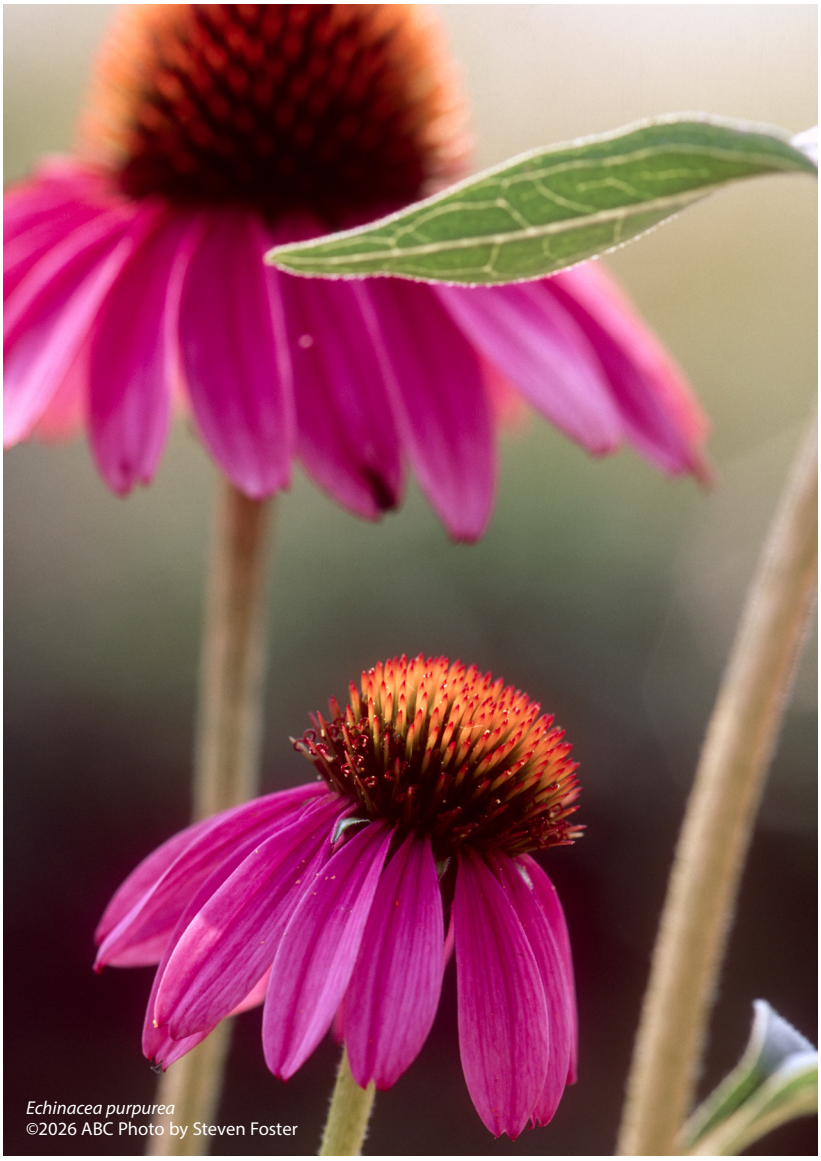
*Whole, cut, and powdered material is generally suitable for analysis after extraction

(Compositae). *Univ Kansas Sci Bull*. 1968;48:113-142.
22. Binns SE, Baum BR, Arnason JT. A taxonomic revision of *Echinacea* (Asteraceae: Heliantheae). *Syst Botany*. 2002;27(3):610-632.
23. Upton R, ed. *American Herbal Pharmacopoeia and Therapeutic Compendium:* Echinacea purpurea *Root*. Scotts Valley, CA: American Herbal Pharmacopoeia; 2004.
24. Upton R, ed. *American Herbal Pharmacopoeia and Therapeutic Compendium:* Echinacea pallida *Root*. Scotts Valley, CA: American Herbal Pharmacopoeia; 2010.
25. Upton R, ed. *American Herbal Pharmacopeia and Therapeutic Compendium:* Echinacea angustifolia *Root*. Scotts Valley, CA: American Herbal Pharmacopoeia; 2010.
26. Flagel LE, Rapp RA, Grover CE, et al. Phylogenetic, morphological, and chemotaxonomic incongruence in the North American endemic genus *Echinacea*. *Am J Bot*. 2008;95(6):756-765.
27. Colombo ML. Botanicals authentication in food, food supplements and herbal medicinal products. *Plant Biosyst*. 2016;150(1):22-26.
28. Raclariu AC, Tebrencu CE, Ichim MC, Ciuperca OT, Brysting AK, de Boer H. What's in the box? Authentication of echinacea herbal products using DNA metabarcoding and HPTLC. *Phytomedicine*. 2018;44:32-38.
29. Zhang N, Erickson DL, Ramachandran P, et al. An analysis of *Echinacea* chloroplast genomes: Implications for future botanical identification. *Sci Rep*. 2017;7(1):216.
30. Waidyanatha S, Pierfelice J, Cristy T, et al. A strategy for test article selection and phytochemical characterization of *Echinacea purpurea* extract for safety testing. *Food Chem Toxicol*. 2020;137:111125.
31. Länger R. Anatomy of the underground parts of four *Echinacea*-species and of *Parthenium integrifolium*. *Sci Pharm*. 2001;69(3):237-247.
32. Dietz B, Bauer R. The constituents of *Echinacea atrorubens* roots and aerial parts. *Pharm Biol*. 2001;39(1):11-15.
33. Gafner S, Blumenthal M, Foster S, Cardellina II JH, Khan IA, Upton R. Botanical ingredient forensics: Detection of attempts to deceive commonly used analytical methods for authenticating herbal dietary and food ingredients and supplements. *J Nat Prod*. 2023;86(2):460-472.
34. Adulteration of *Echinacea angustifolia* extract with *Cistanche* spp. extract documented. Botanical Adulterants Monitor. April 2022;25. Available at: www.herbalgram.org/resources/botanical-adulterants-prevention-program/botanical-adulterants-monitor/issues/issue-25/b25-industry-alerts/adulteration-echinacea-angustifolia-extract/. Accessed April 11, 2025.
35. *Cistanche deserticola* Ma. The World Flora Online website. Available at: www.worldfloraonline.org/taxon/wfo-0000607086. Accessed April 17, 2025.
36. Convention on International Trade in Endangered Species of Wild Fauna and Flora. CITES website. Available at: https://cites.org/eng/disc/text.php. Accessed March 26, 2026.
37. Chinese Medicinal Material Images Database. Hong Kong Baptist University website. Available at: https://sys01.lib.hkbu.edu.hk/cmed/mmid/detail.php?sort=name_cht&lang=eng&f_search=1&qry=Cistanche+&extension=all&pid=B00283. Accessed May 19, 2025.
38. Thorogood CJ, Leon CJ, Lei D, Aldughayman M, Huang L-f, Hawkins JA. Desert hyacinths: An obscure solution to a global problem? *Plants People Planet*. 2021;3(4):302-307.
39. Homepage. The World Flora Online website. Available at: www.worldfloraonline.org/. Accessed April 4, 2025.
40. Plants Database. US Department of Agriculture Natural Resources Conservation Service website. Available at: https://plants.usda.gov/. Accessed April 5, 2025.
41. Homepage. Flora of China website. Available at: www.efloras.org/. Accessed April 18, 2025.
42. Keller W. The genus *Echinacea* (Asteraceae): Floral, stem, and petiole morphology. *J Bot Res Inst Tex*. 2014;8(1):87-126.
43. Wang F, Zhuo B, Wang S, et al. *Atriplex canescens*: A new host for *Cistanche deserticola*. *Heliyon*. 2021;7(6):e07368.
44. Song Y, Zeng K, Jiang Y, Tu P. Cistanches herba, from an endangered species to a big brand of Chinese medicine. *Med Res Rev*. 2021;41(3):1539-1577.
45. Cheng N, Wang H, Hao H, Rahman FU, Zhang Y. Research progress on polysaccharide components of *Cistanche deserticola* as potential pharmaceutical agents. *Eur J Med Chem*. 2023;245(Pt 1):114892.
46. Williams JG, Kubelik AR, Livak KJ, Rafalski JA, Tingey SV. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Res*. 1990;18(22):6531-6535.
47. Wolf HT, Zundorf I, Winckler T, Bauer R, Dingermann T. Characterization of *Echinacea* species and detection of possible adulterations by RAPD analysis. *Planta Med*. 1999;65(8):773-774.
48. Kapteyn J, Simon JE. The use of RAPDs for assessment of identity, diversity, and quality of *Echinacea*. In: Janick J, Whipkey A, eds. *Trends in New Crops and New Uses*. Alexandria, VA: ASHS Press; 2002:509-514.
49. Raclariu AC, Heinrich M, Ichim MC, de Boer H. Benefits and limitations of DNA barcoding and metabarcoding in herbal product authentication. *Phytochem Anal*. 2017;29(2):123-128.
50. Mistrikova I, Vaverkova S. *Echinacea* — Chemical composition, immunostimulatory activities and uses. *Thaiszia — Journal of Botany*. 2006;16:11-26.
51. Manayi A, Vazirian M, Saeidnia S. *Echinacea purpurea*: Pharmacology, phytochemistry and analysis methods. *Pharmacogn Rev*. 2015;9(17):63-72.
52. Lin S, Sung J, Chen C. Effect of drying and storage conditions on caffeic acid derivatives and total phenolics of *Echinacea purpurea* grown in Taiwan. *Food Chem*. 2011;125:226-231.
53. Lin L, Qiu S, Lindenmaier M, He X, Featherstone T, Cordell GA. Patuletin-3-O-rutinoside from the aerial parts of *Echinacea angustifolia*. *Pharm Biol*. 2002;40(2):92-95.
54. Kurkin VA, Akushskaya AS, Avdeeva EV, Velmyaikina EI, Daeva ED, Kadentsev VI. Flavonoids from *Echinacea purpurea*. *Russ J Bioorg Chem*. 2011;37(7):905-906.
55. Sharif KOM, Tufekci EF, Ustaoglu B, et al. Anticancer and biological properties of leaf and flower extracts of *Echinacea purpurea* (L.) Moench. *Food Biosci*. 2021;41:101005.
56. Dietz B. *Untersuchungen zu den Inhaltsstoffen von Echinacea atrorubens sowie zur Wirkung und Bioverfügbarkeit von Alkamiden*. Düsseldorf, Germany: Heinrich Heine University; 2002.
57. Ahmadi F. Phytochemistry, mechanisms, and preclinical studies of *Echinacea* extracts in modulating immune responses to bacterial and viral infections: A comprehensive review. *Antibiotics (Basel)*. 2024;13(10):947-970.
58. Bauer R, Remiger P, Wagner H. Alkamides from the roots of *Echinacea purpurea*. *Phytochemistry*. 1988;27(7):2339-2342.
59. Bauer R, Remiger P, Wagner H. Alkamides from the roots of *Echinacea angustifolia*. *Phytochemistry*. 1989;28(2):505-508.
60. Bauer R, Wagner H. *Echinacea* species as potential immunostimulatory drugs. In: Wagner H, Farnsworth NR, eds. *Economic and Medicinal Plant Research*. San Diego, CA: Academic Press; 1991;5:253-321.
61. Thomsen MO, Frette XC, Christensen KB, Christensen LP, Grevsen K. Seasonal variations in the concentrations of lipophilic compounds and phenolic acids in the roots of *Echinacea purpurea* and *Echinacea pallida*. *J Agric Food*

Chem. 2012;60(49):12131-12141.
62. Molgaard P, Johnsen S, Christensen P, Cornett C. HPLC method validated for the simultaneous analysis of cichoric acid and alkamides in *Echinacea purpurea* plants and products. *J Agric Food Chem*. 2003;51(24):6922-6933.
63. Binns SE, Livesey JF, Arnason JT, Baum BR. Phytochemical variation in *Echinacea* from roots and flowerheads of wild and cultivated populations. *J Agric Food Chem*. 2002;50(13):3673-3687.
64. Bauer R. Standardization of *Echinacea purpurea* expressed juice with reference to cichoric acid and alkamides. *J Herbs Spices Med Plants*. 1999;6(3):51-62.
65. Bauer R, Remiger P. TLC and HPLC analysis of alkamides in *Echinacea* drugs. *Planta Med*. 1989;55:367-371.
66. Mirjalili MH, Salehi P, Badi HN, Sonboli A. Volatile constituents of the flowerheads of three *Echinacea* species cultivated in Iran. *Flavour Fragr J*. 2006;21(2):355-358.
67. Bauer R. *Echinacea*: Biological effects and active principles. In: Mazza G, Oomah BD, eds. *Herbs, Botanicals, and Teas*. Boca Raton, FL: CRC Press; 1998:45.
68. Dosoky NS, Kirpotina LN, Schepetkin IA, et al. Volatile composition, antimicrobial activity, and in vitro innate immunomodulatory activity of *Echinacea purpurea* (L.) Moench essential oils. *Molecules*. 2023;28(21):7330.
69. Nyalambisa M, Oyemitan IA, Matewu R, et al. Volatile constituents and biological activities of the leaf and root of *Echinacea* species from South Africa. *Saudi Pharm J*. 2017;25(3):381-386.
70. Mazza G, Cottrell T. Volatile components of roots, stems, leaves, and flowers of *Echinacea* species. *J Agric Food Chem*. 1999;47(8):3081-3085.
71. Wack M, Blaschek W. Determination of the structure and degree of polymerisation of fructans from *Echinacea purpurea* roots. *Carbohydr Res*. 2006;341(9):1147-1153.
72. Petrova A, Ognyanov M, Petkova N, Denev P. Phytochemical characterization of purple coneflower roots (*Echinacea purpurea* (L.) Moench.) and their extracts. *Molecules*. 2023;28(9):3956.
73. Bergeron C, Gafner S. Quantitative analysis of the polysaccharide and glycoprotein fractions in *Echinacea purpurea* and *Echinacea angustifolia* by HPLC-ELSD for quality control of raw material. *Pharm Biol*. 2007;45(2):98-105.
74. Glavač NK, Košir IJ, Rode J, Kreft S. Optimization and use of a spectrophotometric method for determining polysaccharides in *Echinacea purpurea*. *Cent Eur J Biol*. 2012;7(1):126-131.
75. Proksch A, Wagner H. Structural analysis of a 4-*O*-methyl-glucuronoarabinoxylan with immuno-stimulating activity from *Echinacea purpurea*. *Phytochemistry*. 1987;26(7):1989-1993.
76. Emmendörffer AC, Wagner H, Lohmann-Matthes M-L. Immunologically active polysaccharides from *Echinacea purpurea* plant and cell cultures. In: Wagner H, ed. *Immunomodulatory Agents from Plants*. Basel, Switzerland: Birkhäuser; 1999:89-104.
77. Lei H, Wang X, Zhang Y, et al. Herba cistanche (rou cong rong): A review of its phytochemistry and pharmacology. *Chem Pharm Bull (Tokyo)*. 2020;68(8):694-712.
78. Luettig B, Steinmüller C, Gifford GE, Wagner H, Lohmann-Matthes ML. Macrophage activation by the polysaccharide arabinogalactan isolated from plant cell cultures of *Echinacea purpurea*. *J Natl Cancer Inst*. 1989;81(9):669-675.
79. Wagner H, Stuppner H, Schäfer W, Zenk M. Immunologically active polysaccharides of *Echinacea purpurea* cell cultures. *Phytochemistry*. 1988;27(1):119-126.
80. Classen B, Witthohn K, Blaschek W. Characterization of an arabinogalactan-protein isolated from pressed juice of *Echinacea purpurea* by precipitation with the beta-glucosyl Yariv reagent. *Carbohydr Res*. 2000;327(4):497-504.
81. Volk R-B, Blaschek W, Classen B. Characterization of an arabinogalactan protein from the pressed juice of *Echinacea purpurea*: Investigations into the type of linkage between the protein and polysaccharide moieties. *J Nat Med*. 2007;61(4):397-401.
82. Balciunaite G, Juodsnukyte J, Savickas A, et al. Fractionation and evaluation of proteins in roots of *Echinacea purpurea* (L.) Moench. *Acta Pharm*. 2015;65(4):473-479.
83. Petkova N, Petrova A, Ivanov I, et al. Chemical composition of different extracts from *Echinacea purpurea* (L.) Moench roots and evaluation of their antimicrobial activity. *Chem Engineering*. 2023;7(5):94.
84. Thude S, Classen B. High molecular weight constituents from roots of *Echinacea pallida*: An arabinogalactan-protein and an arabinan. *Phytochemistry*. 2005;66(9):1026-1032.
85. Cozzolino R, Malvagna P, Spina E, et al. Structural analysis of the polysaccharides from *Echinacea angustifolia* radix. *Carbohydr Polym*. 2006;65(3):263-272.
86. Aiello N, Marengo A, Scartezzini F, et al. Evaluation of the farming potential of *Echinacea angustifolia* DC. accessions grown in Italy by root-marker compound content and morphological trait analyses. *Plants (Basel)*. 2020;9(7):873.
87. Russo D, Lela L, Benedetto N, et al. Phytochemical composition and wound healing properties of *Echinacea angustifolia* DC. root hydroalcoholic extract. *Int J Mol Sci*. 2025;26(6):2562.
88. *Echinaceae angustifoliae* radix. *European Pharmacopoeia*. 10th ed. Vol 1. Strasbourg, France: European Directorate for the Quality of Medicines & HealthCare; 2019:1548-1549.
89. Kabganian R, Carrier DJ, Rose PA, Abrams SR, Sokhansanj S. Localization of alkamides, echinacoside and cynarin with *Echinacea angustifolia*. *J Herbs Spices Med Plants*. 2003;10(2):73-81.
90. Binns SE, Arnason JT, Baum BR. Phytochemical variation within populations of *Echinacea angustifolia* (Asteraceae). *Biochem Syst Ecol*. 2002;30(9):837-854.
91. Bauer R, Khan IA, Wagner H. TLC and HPLC analysis of *Echinacea pallida* and *E. angustifolia* roots. *Planta Med*. 1988;54:426-430.
92. Pietta P, Mauri P, Bauer R. MEKC analysis of different *Echinacea* species. *Planta Med*. 1998;64(7):649-52.
93. Barnes J, Anderson LA, Gibbons S, Phillipson JD. *Echinacea* species (*Echinacea angustifolia* (DC.) Hell., *Echinacea pallida* (Nutt.) Nutt., *Echinacea purpurea* (L.) Moench): A review of their chemistry, pharmacology and clinical properties. *J Pharm Pharmacol*. 2005;57(8):929-954.
94. Vlasheva MK, Katsarova M, Dobreva A, Dzhurmanski A, Denev P, Dimitrova S. *Echinacea* species cultivated in Bulgaria as a source of chicoric and caftaric acids. *Agronomy*. 2024;14(9):2081-2094.
95. Cheminat A, Zawatzky R, Becker H, Brouillard R. Caffeoyl conjugates from *Echinacea* species: Structures and biological activity. *Phytochemistry*. 1988;27(9):2787-2794.
96. Feizlmayr E. *Phytochemical and Pharmacological Investigations of* Echinacea pallida *(NUTT.) NUTT. Roots Including New Insights into the Biological Activity of Polyacetylenes and Polyenes*. Graz, Austria: University of Graz; 2011.
97. Pellati F, Calò S, Benvenuti S, Adinolfi B, Nieri P, Melegari M. Isolation and structure elucidation of cytotoxic polyacetylenes and polyenes from *Echinacea pallida*. *Phytochemistry*. 2006;67(13):1359-64.
98. Vaverková S, Mikulásová M, Habán M, Tekel J, Hollá M, Otepka P. Variability of the essential oil from three sorts of *Echinacea* MOENCH genus during ontogenesis. *Ceska Slov Farm*. 2007;56(3):121-4.
99. Laasonen M, Wennberg T, Harmia-Pulkkinen T, Vuorela H. Simultaneous analysis of alkamides and caffeic acid

derivatives for the identification of *Echinacea purpurea, Echinacea angustifolia, Echinacea pallida* and *Parthenium integrifolium* roots. *Planta Med*. 2002;68(6):572-574.
100. Bauer RK, IA. Wagner, H. Echinacea: Proof of adulteration of *Echinacea purpurea* (L.) MOENCH with *Parthenium integrifolium* L. *Dtsch Apoth Ztg*. 1987;127(25):1325-1329.
101. Rodriguez E, Yoshioka H, Mabry TJ. The sesquiterpene lactone chemistry of the genus *Parthenium* (Compositae). *Phytochemistry*. 1971;10(5):1145-1154.
102. Hind N, King C. *Parthenium integrifolium* L. *Curtis's Botanical Magazine*. 2023;40:475-486.
103. Fu Z, Fan X, Wang X, Gao X. Cistanches herba: An overview of its chemistry, pharmacology, and pharmacokinetics property. *J Ethnopharmacol*. 2018;219:233-247.
104. Yang Z-Y, Lu D-Y, Yao S, Zhang R-R, Jiang Z-J, Ma Z-G. Chemical fingerprint and quantitative analysis of *Cistanche deserticola* by HPLC-DAD-ESI-MS. *J Food Drug Anal*. 2013;21(1):4.
105. Wang Y, Zhang L, Du Z, Pei J, Huang L. Chemical diversity and prediction of potential cultivation areas of *Cistanche* herbs. *Sci Rep*. 2019;9(1):19737.
106. Pharmacopoeia Committee of People's Republic of China. *Pharmacopoeia of People's Republic of China*. Beijing, China: China Medical Science and Technology Press; 2015.
107. Wang W, Jiang S, Zhao Y, Zhu G. Echinacoside: A promising active natural products and pharmacological agents. *Pharmacol Res*. 2023;197:106951.
108. Zhou S, Feng D, Zhou Y, Duan H, Jiang Y, Yan W. Analysis of the active ingredients and health applications of *Cistanche*. *Front Nutr*. 2023;10:1101182.
109. Yang M, Wu C, Zhang T, et al. Chicoric acid: Natural occurrence, chemical synthesis, biosynthesis, and their bioactive effects. *Front Chem*. 2022;10:888673.
110. Quesada-Espinoza J, Murillo-Masis R. Quality control of phytopharmaceuticals with the use of nuclear magnetic resonance (NMR) and the application of principal component analysis (PCA). *Tecnología en Marcha*. 2019;32(4):81-94.
111. Liu J, Yang L, Dong Y, Zhang B, Ma X. Echinacoside, an inestimable natural product in treatment of neurological and other disorders. *Molecules*. 2018;23(5)
112. Baidya R, Sarkar B. A systematic review of the traditional uses, chemistry, and curative aptitude of echinacoside-a phenylethanoid glycoside. *Naunyn Schmiedebergs Arch Pharmacol*. 2025;398(3):2071-2106.
113. Ban Y, Jiang J, Yang H, et al. The complete synthetic pathway of echinacoside from *Cistanche deserticola* and its de novo biosynthesis in yeast. *Plant Commun*. 2025;6(9)
114. *Echinaceae pallidae* radix. *European Pharmacopoeia*. 10th ed. Vol 1. Strasbourg, France: European Directorate for the Quality of Medicines & HealthCare; 2019:1568-1569.
115. *Echinaceae purpureae* herba. *European Pharmacopoeia*. 10th ed. Vol 1. Strasbourg, France: European Directorate for the Quality of Medicines & HealthCare; 2019:1589-1590.
116. *Echinaceae purpureae* radix. *European Pharmacopoeia*. 10th ed. Vol 1. Strasbourg, France: European Directorate for the Quality of Medicines & HealthCare; 2019:1591-1592.
117. *Echinacea* Species Dry Extract Capsules. *USP41-NF36*. Rockville, MD: United States Pharmacopeial Convention; 2018.
118. *Echinacea* Species Dry Extract Tablets. *USP41-NF36*. Rockville, MD: United States Pharmacopeial Convention; 2018.
119. *Echinacea* Species Powder Capsules. *USP41-NF36*. Rockville, MD: United States Pharmacopeial Convention; 2018.
120. Powdered *Echinacea angustifolia* Extract. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
121. Powdered *Echinacea purpurea* Extract. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
122. Powdered *Echinacea pallida* Extract. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
123. *Echinacea angustifolia*. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
124. Powdered *Echinacea angustifolia*. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
125. Powdered *Echinacea pallida*. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
126. *Echinacea pallida*. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
127. Powdered *Echinacea purpurea*. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
128. *Echinacea purpurea* root. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
129. *Echinacea purpurea* aerial parts. *USP41-NF36*. Vol. 2. Rockville, MD: United States Pharmacopeial Convention; 2018.
130. *Echinacea angustifolia* — Root and rhizome. HPTLC Association website. Available at: www.hptlc-association.org/methods.cfm. Accessed May 1, 2025.
131. *Echinacea pallida* — Root and rhizome. HPTLC Association website. Available at: www.hptlc-association.org/methods.cfm. Accessed May 1, 2025.
132. *Echinacea purpurea* — Aerial parts. HPTLC Association website. Available at: www.hptlc-association.org/methods.cfm. Accessed May 1, 2025.
133. *Echinacea purpurea* — Root and rhizome. HPTLC Association website. Available at: www.hptlc-association.org/methods.cfm. Accessed May 1, 2025.
134. Agatonovic-Kustrin S, Grace P, Morton DW. Evaluation of high-performance thin-layer chromatography for the quantification of phenylpropanoids in commercial *Echinacea* products. *JPC-J Planar Chromat*. 2014;27:260-266.
135. Agatonovic-Kustrin S, Loescher CM, Singh R. Quantification of phenylpropanoids in commercial *Echinacea* products using TLC with video densitometry as detection technique and ANN for data modelling. *Phytochem Anal*. 2012;24(4):303-308.
136. Frommenwiler DA, Reich E, Sharaf MHM, Cañigueral S, Etheridge CJ. Investigation of market herbal products regulated under different categories: How can HPTLC help to detect quality problems? *Front Pharmacol*. 2022;13:925298.
137. Gilroy CM, Steiner JF, Byers T, Shapiro H, Georgian W. *Echinacea* and truth in labeling. *Arch Intern Med*. 2003;163(6):699-704.
138. Reich E, Blatter A, Jorns R, Kreuter M, Thiekötter K. An AOAC peer-verified method for identification of *Echinacea* species by HPTLC. *J Planar Chromatogr*. 2002;15:244-253.
139. Reich E, Schibli A, DeBatt A. Validation of high-performance thin-layer chromatographic methods for the identification of botanicals in a cGMP environment. *J AOAC Int*. 2008;91(1):13-20.
140. Bergeron C, Livesey JF, Awang DVC, et al. A quantitative HPLC method for the quality assurance of *Echinacea* products on the North American market. *Phytochem Anal*. 2000;11:207-215.
141. Brown PN, Chan M, Betz JM. Optimization and single-laboratory validation study of a high-performance liquid chromatography (HPLC) method for the determination of phenolic *Echinacea* constituents. *Anal Bioanal Chem*. 2010;397(5):1883-1892.
142. Brown PN, Mudge EM, Paley L. Determination of

phenolic constituents in *Echinacea* raw materials and dietary supplements by HPLC-UV: Collaborative study. *J AOAC Int*. 2016;99(5):1197-203.
143. Karadağ AE, Baydar R, Kırcı D. Phytochemical quality analysis of commercial preparations containing *Echinacea purpurea*. *Eur J Life Sci*. 2024;3:45-54.
144. Mudge E, Lopes-Lutz D, Brown P, Schieber A. Analysis of alkylamides in *Echinacea* plant materials and dietary supplements by ultrafast liquid chromatography with diode array and mass spectrometric detection. *J Agric Food Chem*. 2011;59:8086-8094.
145. Ferencz E, Demeter E, Király R, Vancea S, Urkon M, Laczkó-Zöld E. Mapping of *Echinacea*-based food supplements on the Romania market and qualitative evaluation of the most commonly used products. *Bulletin of Medical Sciences*. 2020;93(2):111-123.
146. Lv X, Feng S, Zhang J, et al. Application of HPLC fingerprint combined with chemical pattern recognition and multi-component determination in quality evaluation of *Echinacea purpurea* (L.) Moench. *Molecules*. 2022;27(19):6463
147. Foster BC, Drouin C, Krantis A, et al. Chemical marker profile and biological effects of natural products containing echinacea. *J Comp Int Med*. 2005;2(1).
148. Granica S, Krupa K, Kłębowska A, Kiss AK. Development and validation of HPLC-DAD-CAD-MS3 method for qualitative and quantitative standardization of polyphenols in Agrimoniae eupatoriae herba (Ph. Eur). *J Pharm Biomed Anal*. 2013;86:112-122.
149. Cech NB, Eleazer MS, Shoffner LT, Crosswhite MR, Davis AC, Mortenson AM. High performance liquid chromatography/electrospray ionization mass spectrometry for simultaneous analysis of alkamides and caffeic acid derivatives from *Echinacea purpurea* extracts. *J Chromatogr A*. 2006;1103(2):219-28.
150. Hudaib M, Fiori J, Bellardi MG, Rubies-Autonell C, Cavrini V. GC-MS analysis of the lipophilic principles of *Echinacea purpurea* and evaluation of cucumber mosaic cucumovirus infection. *J Pharm Biomed Anal*. 2002;29(6):1053-60.
151. Laasonen M, Harmia-Pulkkinen T, Simard CL, Michiels E, Räsänen M, Vuorela H. Fast identification of *Echinacea purpurea* dried roots using near-infrared spectroscopy. *Anal Chem*. 2002;74(11):2493-9.
152. Schulz H, Pfeffer S, Quilitzsch R, Steuer B, Reif K. Rapid and nondestructive determination of the echinacoside content in *Echinacea* roots by ATR-IR and NIR spectroscopy. Planta Med. 2002; 68:926-929.
153. Zaushintsena AV, Milentyeva IS, Babich OO, et al. Quantitative and qualitative profile of biologically active substances extracted from purple echinacea (*Echinacea purpurea* L.) growing in the Kemerovo region: Functional foods application. *Foods Raw Mater*. 2019;7(1):84-92.
154. Sandasi M, Vermaak I, Chen W, Viljoen AM. Hyperspectral imaging and chemometric modeling of echinacea — A novel approach in the quality control of herbal medicines. *Molecules*. 2014;19(9):13104-13121.
155. Harnly J, Lu Y, Sun J, Chen P. Botanical supplements: Detecting the transition from ingredient to product. *J Food Comp Anal* . 2017;64:85-92.
156. Frédérich M, Jansen C, de Tullio P, Tits M, Demoulin V, Angenot L. Metabolomic analysis of *Echinacea* spp. by 1H nuclear magnetic resonance spectrometry and multivariate data analysis technique. *Phytochem Anal*. 2010;21(1):61-65.
157. Hussin HFA. *Comparison of 1H-NMR Fingerprints of* Echinacea purpurea *Extracts with Stimulation of Myelopoiesis in Rat to Identify Active Constituents*. Monroe, LA: University of Louisiana at Monroe; 2016.
158. Politi M, Zloh M, Pintado ME, Castro PM, Heinrich M, Prieto JM. Direct metabolic fingerprinting of commercial herbal tinctures by nuclear magnetic resonance spectroscopy and mass spectrometry. *Phytochem Anal*. 2009;20(4):328-334.
159. Ramasahayam S, Baraka HN, Abdel Bar FM, et al. Effects of chemically characterized fractions from aerial parts of *Echinacea purpurea* and *E. angustifolia* on myelopoiesis in rats. *Planta Med*. 2011;77(17):1883-1889.
160. Nagumalli SK, Salley JT, Carstens JD. Assessment of clinical chemistry and hematological parameters in female Sprague-Dawley rats following a 7-day oral exposure to three different species of *Echinacea*. *J Environ Sci Health C Toxicol Carcinog*. 2024;42(2):154-171.



Echinacea purpurea
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