Reprinted from: Trends in new crops and new uses. 2002. J. Janick and A. Whipkey (eds.). ASHS Press, Alexandria, VA.

Factors Affecting Echinacea Quality*

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Echinacea is a native of North America and traditionally used to combat cold, flu, cough, sore throats and many other ailments. Today, echinacea is among the most frequently utilized medicinal herbs around the world included in supplements and personal care formulations. The consumption of echinacea has significantly increased in Europe and North America, with a market share of about 10% of the herbal industry in the United States (Rawls 1996). In Russia, *E. purpurea* tops are mixed with animal feeds to improve the natural resistance of cattle to diseases, and improve milk production its quality. Numerous attempts have been underway in some non-traditional *Echinacea* growing countries, in Africa, Asia, Latin America, and the Middle East to introduce cultivation, processing, and marketing. Today, *E. purpurea* in the markets originates solely from cultivation, while *E. angustifolia*, *E. pallida*, *E. paradoxa*, *E. tenneseensis*, and *E. sanguinea* raw materials are sourced either from partial cultivation or totally collected from the wild.

Investigations of the pharmacological and biological activities of purported echinacea extracts have frequently shown them to be of widely differing character, with products obtained from either adulterated or misidentified species. With the evolution of botanical products, there has been an increasing demand for correctly identified herbal products that originate from cultivation. However, there has been little information on the influence of selected cultivars, various agronomic practices, and the geographical origin of the raw material. The objective of this study was to examine and demonstrate how factors such as growing conditions, geographic origins, diseases and pests, choice of the plant organ, and harvesting age (plant and flower ages) as well as the species contribute to the variations in the quality of different *Echinacea* species.

METHODOLOGY

Raw materials were obtained from various international and national sources, commercial herb growers and experimental stations. Selected plants were grown under similar field conditions in Trout Lake Washington, US from 1996 to 1998. We compared yield and quality of field- and hydroponically-grown plants. We determined product quality by measuring essential oil and caffeic acid derivatives such as cichoric acid, echinacoside, chlorogenic acid, and alkyl isobutylamides. HPLC chromatographic methods were based on Bauer et al. (1988) and Bauer and Remiger (1989) with slight modification. All plant parts were separated by hand, while seeds were separated using a seed thresher. Essential oil content was determined by subjecting 30 g of dried plant material to the standard hydrodistillation method for 2 hr, using Clevenger type apparatus.

THE WORLD SUPPLY OF ECHINACEA

Commercial cultivation of echinacea is mostly located in North-Western United States, and Western Canada (Table 1). Highest echinacea yields are reported in California (8500 kg/ha) and cichoric acid content of samples (2.29%) indicate an average yield of 195 kg/ha (Table 1). Austria, Germany, Russia, New Zealand, Ukraine, Yugoslavia, the Republic of South Africa (RSA) also have well-established cultivation of echinacea, though mostly *E. purpurea* or *E. pallida*. The highest cichoric acid content (4.93%), and calculated yield (276 kg/ha) was obtained from a Russian source, followed by samples grown in New Zealand (3.46%), Germany (2.86%, 212 kg/ha), and Austria (2.65%, 191 kg/ha).

The Russian geneticist N.I. Vavilov introduced *E. purpurea* from North America to Russia as early as 1924, while the first field production started in southern Russia in 1936 (A. Kodash, pers. commun., 1996). Further improvement and cultivation programs in Russia took shape during the early 1960s (Balabas et al. 1965). A Russian field study from 1971 to 1994 with two different populations (Ukrainian and Samaritan) of *E. purpurea* under Chernozem soil (black soil with 7%–9% organic matter content) indicates a positive influence of soil fertility on the concentration of cichoric acid (Gladisheva 1995). This may explain the relatively higher cichoric acid content in the Russian samples obtained either from Samara or Krasnodar region. *E. purpurea* cultivation extends as far as Ural mountains and Altai highlands in Siberia with an increasing ten-

*We thank Jules Janick for his assistance with this manuscript. Herba Medica (Letchamo Naturals International) is thanked for sponsoring the scientific study, presentation, and publication of this manuscript.

dency in size and processing capacity. Echinacea is widely adapted and can be grown under extremely varying climatic or vegetative conditions varying from 135 days in Siberia to 365 days in tropical/subtropical environments. It is important however that cultivars be selected for different ecological zones.

Brazil, Chile, Argentine, and Costa Rica have established field production of echinacea since 1998 (Table 1). Experimental fields of echinacea have been established in Egypt, Botswana, and Zambia. In Tanzania, echinacea is cultivated for export of off-season cut flowers to Europe. Presently the RSA has commercial production that supplies some of the Western European echinacea raw material, and prepares hydroalcoholic extracts based on cheaper sugarcane-based ethanol of African origin. Extracts are transported from the RSA to Europe and North American markets.

HYDROPONIC CULTIVATION

After 8 months of growth under hydroponic condition, *E. purpurea* yields were 7840 kg/ha with 2.10% cichoric acid content or 165 kg/ha (Table 1). Root yield was about 2.3 times as high as average of North American field production. This finding suggests that high quality echinacea tops and roots can be harvested from a hydroponic culture system within 6–8 months as compared to 36 months for field cultivation. Roots developed hydroponically were much easier to clean because of the absence of soil, stones, and weeds, had minimum microbial contamination, and few problems with soil born diseases. Fine roots that are known to contain higher cichoric acid concentration can be well maintained in a hydroponics system. During normal commercial root harvesting process from fields, about 12%–15% of the fine roots remain in the ground, while 17%–21% of the harvested thin roots are lost during root washing.

Hydroponic cultivation might prove valuable to reduce loss of chemical constituents, including polysaccharides, essential oils, and other hydrophilic components. Recent research findings suggest that the application of natural elicitors, such as chetosan, with simultaneous root aeration, can enhance the chemical yield compared to conventionally produced root samples (I. Raskin, pers. commun., series of lectures 2001).

DISTRIBUTION OF CICHORIC ACID, ISOBUTYLAMIDES, AND ESSENTIAL OIL

Relative distribution of cichoric acid and isobutylamides in different organs of *E. purpurea*, *E. angustifolia*, *E. pallida* and *E. paradoxa* is presented in Table 2. Ligulate florets showed the highest concentration of cichoric acid, while endosperm and seed coat had none. In some selected red or pink-flowered *E. purpurea* clones, cichoric acid content reached 12% but was lower in white-flowered *E. purpurea* ('White Swan') and *E. pallida*. Among 12 different lines of white-flowered *E. purpurea* ligulate florets, cichoric acid only reached 2.6%. The highest relative concentration of isobutylamide in all species was in seed coats followed by roots; it was not found in ligulate florets and endosperm. The highest essential oil content in all species was obtained from roots. *E. paradoxa* followed by *E. pallida* roots had the highest essential oil concentration; the lowest was obtained in *E. purpurea*. Results summarized in Table 3 are based on a mean data obtained during the 1996, 1997, and 1998 growing seasons. *E. paradoxa* and *E. pallida* roots might be good sources for essential oil production for specialized aromatherapy, personal care, and cosmetic applications. There were differences in the compositional profile of the hydrophilic and lipophilic components among the species investigated.

DISEASES AND INSECTS

Echinacea was generally considered to have few or no disease or insect problems (Hobbs 1989). However, with increased cultivation practices, numerous diseases and insect problems occur, including cucumber mosaic virus, broad bean wilt, and mosaic diseases with flower phyllody symptoms due presumably to a mycoplasma-like organism (Fig. 1). Some of the diseases include shoot fungus (*Cercospora* sp.) (Fig. 2), root rot (*Phymatotrichum omnivorum*) on *E. purpurea* (Fig. 3), and *E. angustifolia*. Most of these problems have been identified to be widespread in organically certified commercial field cultivation (Table 3).

Root rot infection on *E. angustifolia* usually appears during the second year of vegetation. During the first year, the infection does not show up either on shoots or roots. However, as plants age, infection spreads within the roots and invades neighboring plants. The use of susceptible lines, dense planting, and frequent irrigation can increase the incidence of disease.

Table 1. Mean yield and content of cichoric acid in three year old *Echinacea purpurea* tops, cultivated under various ecological conditions, including hydroponically grown *E. pupurea*.

Country of origin	Dry matter yield (kg/ha)	Cichoric acid content (% dry matter)	Calculated cichoric acid yield (kg/ha)
US			
California	8500	2.29	195
Florida	5900	2.05	121
Montana	ND	1.91	ND
Oregon	7080	2.13	151
New Mexico	6860	1.92	132
New York	ND	1.72	ND
Washington	6820	2.11	144
Hydroponically grown tops	7840	2.10	165
Hydroponically grown roots	5321	2.21	118
Canada			
Alberta	6200	1.87	116
British Columbia	6160	2.03	125
Ontario	6010	2.06	124
Quebec	5680	2.09	119
Europe			
Austria	7200	2.65	191
Germany	7400	2.86	212
Finland	6090	2.39	146
Norway	ND	1.88	ND
Yugoslavia	5990	2.07	124
Russia	5600	4.93	276
South America			
Costa Rica	ND	1.98	ND
Chile	ND	2.05	ND
Africa			
Egypt	5570	2.60	145
Tanzania	4600	2.06	95
South Africa (RSA)	5670	2.01	114
Botswana	4572	ND	ND
Pacific			
Australia	ND	1.12	ND
New Zealand	ND	3.46	ND

ND = Not determined

Mystery of "Green Colored" Extracts

The problem of "green colored" *E. angustifolia* hydroalcoholic extracts has been a matter of speculation since 1995 in North American herbal industry. In fact, most vendors (bulk suppliers of certified organically grown roots) regarded this feature as a positive attribute and even promoted it as a "uniquely useful property" in their marketing campaigns. In our 1996–1998 field investigations and laboratory analyses, we found that in some organic commercial fields, root rot affected about 55%–60% of the second and third year *E. angustifolia*, and 30%–38% of *E. purpurea* plants. As the disease progresses, roots change color to dark brown, while the leaves wilt and die back very slowly (Fig. 4). Though the root may be infected, the plants can still grow beyond the first and second years. In most cases, however, infected roots are harvested and processed for

Fig. 1. *E. purpurea* infected by a mycoplasma-like organism in commercial fields.

Fig. 2. A slow but sure death of *E. purpurea* due to a leaf spot or shoot fungus (*Cercospora* sp.) infection is common in commercial cultivations.

Table 2: Distribution of cichoric acid, isobutylamides, and essential oil in four different *Echinacea* spp. cultivated in Trout Lake Washington (1996–1998).

Compound	Relative amount
Cichoric acid	Ligulate florets>roots≥leaves>root crown>tubular florets≥stems>seed coat>endosperm
Isobutylamides	Seed coat>roots>root crown>stems>tubular florets>leaves>ligulate florets=endosperm
Essential oils	Roots>root crown≥tubular florets≥seed coat>leaves>ligulate florets=endosperm
	E. paradoxa≥*E. pallida*>*E. angustifolia*>*E. purpurea* (results based on dried root samples)

Table 3. Influence of insects and diseases on cichoric acid and essential oil content in various populations of unselected echinacea species under organically certified field-growing conditions in Washington state.

Condition	Cichoric acid content (% of dry matter)	Essential oil content (% of fresh roots)
	Echinacea purpurea	
Healthy	2.01–2.68	0.12–0.38
Flower head borer infected	1.82	0.09
Root rot infected	1.02	0.01
Mycoplasma infected	0.88	0.00
	Echinacea angustifolia	
Healthy	0.02–0.49	0.56–1.13
Flower head borer infected	0.03	0.26
Root rot infected	0.02	0.11
Mycoplasma infected	0.00	0.00
	Echinacea pallida	
Healthy	0.09–0.21	1.78–2.03
Flower head borer infected	0.05	0.46
Root rot infected	0.01	0.23
Mycoplasma infected	0.02	0.63
	Echinacea paradoxa	
Healthy	0.32–0.57	1.24–2.43
Flower head borer infected	0.03	0.53
Root rot infected	0.02	0.31
Mycoplasma infected	0.00	0.60

Fig. 3. Root rot (*Phymatotrichum omnivorum*) of *E. purpurea*. Left: the beginning of root infection, see arrow. Right: advanced stage of the infection. Root rot is among the most common causes responsible for low quality commercially produced echinacea products.

Fig. 4. Damage caused by root rot of *E. angustifolia* that results in the green coloration of the extract can be recognized by cutting roots, as shown here. Left: healthy roots; Right: infected roots just before being chopped for commercial extraction.

marketing. The problem of "green colored extract" was mostly prevalent in roots originating from the "certified organically produced" echinacea. After the first week following extraction, the green extracts developed an offensive odor. The problem appears to be due to a fungal (bacterial) infection of the roots which contaminates the liquid extracts. Blanching or treatment of the samples with hot steam for 15 minutes before or after extraction did not solve the problem. The green color was not found when extracts were prepared from healthy root samples.

The content of the reported active substances in all the diseased or infected roots or tops was significantly lower than the samples obtained from healthy plants (Table 3). In Russia, a biological control method, using a bio-product known as Bactofit (*Bacillus subtilis* strain IMP-215) effectively controlled fungal and bacterial diseases of *E. purpurea*.

Insects

Sunflower moth (*Homoesoma electellum*) is one of the most common insects damaging *E. purpurea* and *E. angustifolia* flowerheads (Fig. 5). The females lay eggs on the bracts of developing flower buds. The larvae feed on the florets and pollen. Older larvae tunnel through immature seeds and flowerheads, resulting in extensive damage to the head, and creating secondary infections, fungal damage, head rot and attracting other opportunistic diseases to the whole plant. So far about 60% to 65% of the commercially grown *E. purpurea* and *E. angustifolia* in North-Western US have been found infected. *Echinaceae pallida* and *E.*

paradoxa cultivated under experimental "certified organically grown" fields were observed to be infected with the above insects and microorganisms (Table 3). Significant reduction in the content of some of the chemical components indicated the need for resistant cultivars and choosing the right harvesting stage (Fig. 6).

As the number of growers attracted to organic cultivation increases, non-chemical prevention of plant diseases should be increasingly attractive. The selection of disease and pest resistant cultivars, implementing appropriate agronomic practices, including proper crop rotation, soil and water management programs, and establishing early detection and a removal system for infected plants, represent a sensible approach to a clean healthy product. However, as the effect of pathogenic toxins are unknown it is prudent to use approved pesticides and fungicides for disease and pest control.

GENETIC SELECTION AND IMPROVEMENT

Echinacea selection and breeding efforts could develop cultivars with higher root and shoot yield, suitable for mechanical harvesting, uniform growth, flowering, seed ripening, good leaf to stem ratios, and higher content of cichoric acid, isobutylamides, flavonoids, polysaccharides, and essential oil. The effect of genetic improvement on the chemical content of selected clones of *E. purpurea* 'Sorgogo' and *E. angustifolia* 'Ergogo' is shown in Table 4. The identification and development of *E. purpurea* cv. 'Magical Ruth' and the influence of flower developmental stages in its quality has been described earlier (Letchamo et al. 1999).

The effect of selection was evaluated for *E. purpurea* 'Sorgogo' and *E. angustifolia* 'Ergogo' for cichoric acid, echinacoside, and isobutylamides (Table 4). Selected clones before and after selection were measured in

Fig. 5. View of the damage caused by flower borer flies.

Fig. 6. Selected clones from left to right: 'L-96/96' (white), 'M-98-96', 'Andre', and 'Sorgogo'. Note the uniformity and healthy conditions of the selected clones at optimum harvesting stage. All the lines have unique characteristic that can also be used for ornamental purposes.

four stages of flower development. In all cases selection increased the content of measured constituents. Maximum content of cichoric acid was found in stage 1 (early) while the maximum echniacoside echniacoside content was found in stage 3 or 4 (mature and overblown). There was narrow developmental stage based difference for isobutylamides.

Results of four years of field experiments with locally adapted and partially improved *E. purpurea* seeds in Russia (Moscow region) are presented in Table 5. The highest cichoric acid content in leaves (5.37%), and roots (5.46%) was obtained during the first year at the end of vegetation. During the second, third, and fourth years of vegetation, the highest concentration of cichoric acid in leaves, stems, inflorescence, and roots was found at the massive bud formation stage.

CONCLUSIONS

The chemical composition of echinacea raw material is of interest to both the herbal industry and regulatory agencies as a determinant of product quality and authenticity, with an end towards to protecting consumers from low quality or fraudulent products. The degradation of the chemical constituents during *E. purpurea* processing has been well known (Bauer 1998; Livesey et al. 2000). Results were obtained from various investigations in 1996–1998 that were conducted with numerous clones, and accessions developed under different agronomic and processing practices (W. Letchamo, unpubl. 1998). Our investigation indicated that unique cultivars with various levels of chemical constituents, resistance, freedom from diseases and pests, and yield can be developed within a short period of time. Based on those findings, we suggest establishing 2.2% cichoric acid content as a minimum standard for any commercial *E. purpurea* raw material the can be processed for health applications.

So far most of the chemical and clinical studies of echinacea products have been done using plant samples of unknown origin, cultivation, cultivar, health status of plants and questionable agronomic practices. Therefore, it is highly recommended that future medical or clinical studies on efficacy, safety, and toxicity of echinacea be based on known healthy cultivars, standard agronomic practices, specific plant developmental stages, and geographic sources. By doing this, it will be possible to protect consumers from hidden health dangers from microbial and fungal toxic metabolites.

Table 4. Effects of plant selection and flower developmental stages on chemical content of *E. purpurea* and *E. angustifolia* clones under commercial cultivation in the US.

	Content (% dry matter)					
	Cichoric acid		Echinacoside		Isobutylamides	
Flower developmental stages	Before selection	After selection	Before selection	After selection	Before selection	After selection
			E. purpurea 'Sorgogo'			
1 (early)	2.56	3.97	0.002	0.007	0.008	0.011
2 (medium)	1.89	2.35	0.023	0.011	0.004	0.012
3 (mature)	0.39	0.76	0.034	0.081	ND	0.016
4 (overblown)	0.06	0.43	0.048	0.072	ND	0.015
Mean	1.23	1.88	0.027	0.043	0.006	0.014
			E. angustifolia 'Ergogo'			
1 (early)	0.26	0.65	0.016	0.056	0.038	0.048
2 (medium)	0.14	0.25	0.121	0.130	0.025	0.038
3 (mature)	0.10	0.08	0.245	0.605	0.019	0.039
4 (overblown)	0.07	0.03	0.168	0.587	0.032	0.036
Mean	0.14	0.25	0.135	0.344	0.029	0.040

ND = Not determined

Table 5: Developmental variations in cichoric acid content in *E. purpurea* grown in Russia.

Developmental stages	Cichoric acid content (% of dry matter)			
	Leaves	Stems	Inflorescence	Roots
	1st year of vegetation 1994			
1st year leaves	5.14	NA	NA	3.55
Stem development	4.69	NA	NA	4.00
End of vegetation	5.37	NA	NA	5.46
Massive bud formation	5.47	1.79	NA	4.83
	2nd year of vegetation 1995			
Massive flowering	5.31	1.74	4.50	4.75
Seed ripening	4.52	1.57	NA	3.64
End of vegetation	4.91	NA	NA	4.15
Massive bud formation	6.74	2.28	NA	4.37
	3rd year of vegetation 1996			
Massive flowering	5.68	2.06	2.85	3.26
Seed ripening	4.50	1.27	NA	3.24
End of vegetation	NA	NA	NA	4.00
Massive bud formation	6.41	2.70	NA	3.50
	4th year of vegetation 1997			
Beginning of flowering	6.34	1.20	3.06	2.92
Massive flowering	5.05	1.37	3.34	3.43
End of vegetation	NA	NA	NA	3.12

NA = Not available

REFERENCES

Bauer, R., I.A. Khan, and H. Wagner. 1988. In TLC and HPLC analysis of *E. pallida* and *E. angustifolia* roots. Planta Medica 54:426.

Bauer, R. and P. Remiger. 1989. in TLC and HPLC analysis of alkylamindes in echinacea drugs. Plant Medica 55:367.

Bauer, R. 1998. Biological effects and active principles. ACS symposium series, phytomedicine of Europe, chemistry and biological activity. L.D. Lawrence and R. Bauer (eds.). p. 140–157.

Balabas, D.G. et al. 1965. Introduction of medicinal, aromatic and technical plants. Acad. Sci. USSR M.L.

Gladisheva, O.N. 1995. Experimental studies on production and processing technology, and establishment of raw material basis and seed plantation of *E. purpurea* under Samara Region. Russian Acad. Agr. Sci., N.P.O, VILAR. Mid-Volga zonal experimental station for medicinal plants. (Prog. Rpt., 1991–1994).

Hobbs, C. 1989. Echinacea, the immune herb, L.Ac. Botanica Press.

Porada, A.A. 1989. Growth and development of *E. purpurea* under Ukrainian conditions. Proc. 9th young scientists N.P.O., All Union Sci. Res. Inst. Med. Plant, Moscow. p. 18–19.

Polydeonny, L.V. et al. 1993. Studies on seed treatment and ontogeny of *E. purpurea* under Moscow growing condition. Prog. Rpt. Moscow Timiriazev Agr. Acad., Russia.

Letchamo, W., T.J. Arnason, J. Livesy, C. Bergeron, and V. Krutilina. 1999. Cichoric acid and isobutylamide content as affected by flower developmental stages of *E. purpurea*. p. 494–498. In: J. Janick (ed.), Perspectives on new crops and new uses. ASHS Press, Alexandria VA.

Livesey, J.F, D.V.C. Awang, J.T. Arnason, W. Letchamo, M. Barrett, and G. Royal. 2000. Effect of temperature on stability of marker constituents in *Echinacea purpurea* root formulations. Phytomedicine 60:347–349.

Rawls, R. 1996. Europe's strongest herbal brew. Chem. Engin. News Sept. 23, 53–60.