Chapter 2
Introducing Wild-Growing Medicinal Plant into Cultivation: Dropwort (*Filipendula vulgaris* Moench)—A Rich Source of Phenolic Compounds

Katarzyna Bączek, Jarosław L. Przybył, Olga Kosakowska, and Zenon Węglarz

Abstract Dropwort is a wild-growing plant, long used in traditional European medicine. The species is a rich source of phenolic compounds. The plant raw materials are: flowers, herb, and underground organs (rhizomes with tuberous roots). They have been used in the treatment of difficult-to-heal wounds, cold, rheumatism, and kidney problems. Dropwort extracts reveal potential in the prevention of neurodegenerative disorders, as well. Due to dynamic changes in the use of agricultural lands, natural sites of this species gradually disappear. Introduction into the cultivation seems to be a chance to preserve its natural resources and to provide standardized raw materials for the industry. In this chapter, we present the results of our investigations concerning the factors affecting the quality of different raw materials obtained from cultivated dropwort plants.

Keywords Intraspecific variability · Plant development · Propagation · Raw materials · HPLC · Flavonoids · Phenolic acids

Abbreviations

BF	Beginning of flowering
EF	End of flowering

K. Bączek (✉) · J. L. Przybył · O. Kosakowska · Z. Węglarz
Institute of Horticultural Sciences, Warsaw University of Life Sciences—SGGW, Nowoursynowska Street 166, 02-787 Warsaw, Poland
e-mail: katarzyna_baczek@sggw.edu.pl

J. L. Przybył
e-mail: jaroslaw_przybyl@sggw.edu.pl

O. Kosakowska
e-mail: olga_kosakowska@sggw.edu.pl

Z. Węglarz
e-mail: zenon_weglarz@sggw.edu.pl

H. M. Ekiert et al. (eds.), *Medicinal Plants*, Sustainable Development and Biodiversity 28, https://doi.org/10.1007/978-3-030-74779-4_2

FF Full flowering
HPLC High performance liquid chromatography
MPM Malignant pleural mesothelioma
nd Not detected

2.1 Introduction

Dropwort (*Filipendula vulgaris* Moench, syn.: *Filipendula hexapetala* Gilib. or *Spiraea filipendula* L.) is a wild-growing perennial plant, occurring through Europe, western and central Asia and northwestern part of Africa (Meusel et al. 1965). The species is characteristic for dry grasslands or continental steppes and can be found on meadows, pastures, edges of arable lands, along sunny forest roads and railway embankments; it prefers non-acidic soils rich in humus and calcium (Kostarkiewicz-Gierlat and Stachurska-Swakon 2017). The species is well-adapted to drought and low temperatures (Cortan et al. 2019).

The genus *Filipendula* consists of 15 species of flowering plants in the family Rosaceae (Schanzer 1994). Among them dropwort is distinguished by characteristic structure of underground organs. They consist of a short rhizome with thin roots bearing tubers. The plant produces a rosette of leaves with flowering shoots up to 50–80 cm high. The leaves are strongly dissected. The panicle-shaped inflorescence consists of creamy-white or pale-pink fragrant flowers, up to 2 cm in diameter. Blooming usually takes place in June–July, and star-shaped fruits ripe at the end of July (Motyka and Panych 1936; Mowszowicz 1985) (Figs. 2.1, 2.2 and 2.3).

So far, low genetic variability both within and among dropwort populations has been found. Wind pollination along with long-distance insect pollination ensure gene flow between populations what prevent from genetic drift of the species (Weidema et al. 2000). However, the number of dropwort populations has declined. This is connected mainly with the change in the use of agricultural lands observed during the last decades. In Europe, dry grasslands, were it grows, occur mainly at the edges of arable lands or forests. The disappearance of plants specific for such sites is caused by overfertilization, ceased grazing, shrub encroachment or intensive mowing of meadows and roadsides, making impossible to release the seeds and in consequence—offspring of many plant species. Thus, dropwort populations are fragmented and small.

In Europe, dropwort has been used for ages in traditional medicine. The raw materials collected from this plant are: flowers (1); herb, consisting of root leaves and flowering stems (2); and underground organs (3). The biologically active compounds present in these organs are mainly phenolics including flavonoids, phenolic acids, salicylates, tannins, and traces of coumarins. Among these rutoside, hyperoside, luteolin, luteolin-7-glucoside, spireoside, astragalin, kaempferol, quercetin, quercitrin, avicularin, myricetin; some catechin derivatives, namely: (+)-catechin, (−)-epigallocatechin; as well as phenolic acids, i.e., gallic, ellagic, syringic,

Fig. 2.1 Flowers (all photographs in this chapter were prepared by authors of this chapter)

Fig. 2.2 Dropwort leaves

salicylic, chlorogenic, caffeic, and rosmarinic acids have been identified in dropwort leaves and flowers (Smolarz et al. 1999; Bączek et al. 2012; Pukalskienė et al. 2015; Movsumov et al. 2017). The aboveground organs contain also 0.05–0.1% of essential oil, with salicylaldehyde as a dominant compound (Pavlović et al. 2007; Radulović et al. 2007). The information on chemical composition of underground organs are much more scarce. So far, the following flavonoids have been identified in dropwort

Fig. 2.3 Underground organs

rhizomes and roots: rutoside, hyperoside, isoquercitrin, quercitrin, quercetin, avicularin, and spireoside (Smolarz et al. 1999). Capecka et al. (2012) indicate on high content of flavan-3-ols and phenolic acids (ellagic, gallic, and salicylic acids) in these organs, as well.

The application of dropwort in folk medicine is well documented (Radulović et al. 2007). Its flowers have been used in colds and rheumatism, similarly to meadowsweet flowers (*Filipendula ulmaria* L.). They reveal anti-inflammatory, antipyretic, diaphoretic, and diuretic activity. The leaves and flowers are used in the form of infusions to treat difficult-to-heal wounds and eye inflammation, whereas decoctions prepared from underground organs are applied in the treatment of sore throats, kidney diseases, and diarrhea (Radulović et al. 2007; HMPC 2011; Katanić et al. 2018). Nowadays, the abovementioned application finds its grounds in the laboratory studies on dropwort activity (Katanić et al. 2014, 2018; Pukalskienė et al. 2015; Smardžic et al. 2016, 2018). The essential oil obtained from dropwort leaves shows activity against pathogenic bacteria and fungi, such as: *Escherichia*

coli (ATCC 25922 and 95), *Staphylococcus aureus* (ATCC 6538), *Klebsiella pneumoniae* (ATCC 10031), *Pseudomonas aeruginosa* (ATCC 9027), *Salmonella enteritidis* (ATCC 13067), *Phialophora fastigiata* (FSB81), *Aspergillus niger* (ATCC 10031) or *Candida albicans* (ATCC 10231) (Radulović et al. 2007; Katanić et al. 2014). It has been shown that flower preparations prevent the formation of gastric ulcers and reveal anticancer activity against malignant pleural mesothelioma (MPM) management (Smardžic et al. 2018; Pulito et al. 2019). Dropwort preparations may also be useful in the therapy of neurodegenerative disorders such as Parkinson's or Alzheimer's and show nootropic potential (increasing brain activity) at a level similar to piracetam (Shilova and Suslov 2015; Neagu et al. 2015). Their antihyperalgesic and antioxidant activity have also been confirmed (Oszmiański et al. 2007; Smardžic et al. 2016, 2018).

As mentioned above, dropwort has been used in people medicine for ages. Modern analytical tools give the chance to discover its therapeutic potential from scratch, to document the activity and to find new indications or confirmation for its application. Currently, due to limited occurrence (loss of habitats) of dropwort, and thus limited availability of the raw material, the plant is used extremely rarely (Weidema et al. 2000). The only chance to produce significant amount of good quality raw materials is to introduce the plant into cultivation. This is also indispensable for the production of high-quality standardized extracts.

The aim of this work was to present the results of several-years studies on dropwort growing in cultivation conditions, with a special emphasis paid on the value potential of organs originated from this plant. The dynamics of the accumulation of biologically active compounds in aboveground and underground parts of dropwort was also shown. This altogether may indicate on the possibility of obtaining the plant material variable in respect of biological activity, and also easier for standardization.

2.2 Chemical Diversity of Wild-Growing Populations

The information on development and chemical diversity of dropwort wild-growing populations are relatively scarce. In Europe, the species is rare or even extremely endangered (Duda 2009; Weidema et al. 2000). The abundance of individual plants within dropwort population is strictly related with the habitat conditions, i.e., the soil humidity, its pH as well as with the presence of other vascular plants on the site. These factors significantly influence the development and reproductive possibilities of the species (Kostarkiewicz-Gierlat and Stachurska-Swakon 2017).

In our study, six wild-growing populations of dropwort were analyzed in situ in terms of chemical diversity of its herb and underground organs. The populations originated from eastern part of Poland (Table 2.1). The leaves and flowers (herb) were collected at the full-flowering stage whereas underground organs—in the early spring. The raw materials were dried at 40 °C and subjected for chemical analysis using high-performance liquid chromatography (HPLC). The analysis was carried out according to Bączek et al. (2012). The obtained results

Table 2.1 Geographical coordinates of dropwort populations

	Location	Coordinates	
1	Siemiatycze	N 52° 23.705′	E 022° 53.123′
2	Drohiczyn	N 52° 23.825′	E 022° 40.338′
3	Sytki	N 52° 23.620′	E 022° 40.452′
4	Goraj	N 50° 42.855′	E 022° 40.545′
5	Łada	N 50° 43.822′	E 022° 39.155′
6	Kozłowo	N 52° 37.389′	E 022° 44.900′

indicate on high intraspecific chemical diversity. In the herb of these populations, seven flavonoids (quercetin, astragalin, hyperoside, kaempferol, spireoside, (+)-catechin and (−)-epigallocatechin) and seven phenolic acids (gallic, ellagic, syringic, salicylic, caffeic, rosmarinic, and chlorogenic acids), were identified. Hyperoside, spireoside, and astragalin were the dominant compounds. All the abovementioned compounds reveal strong antioxidant activity (Raza et al. 2017; Kohlmünzer 2000). Moreover, some of them exhibit significant pro-health effects, e.g., astragalin reveals hypotensive activity; quercetin reduces the level of lipids in the blood, reveals antiaggregation, anti-inflammatory, hepatoprotective, and hypoglycemic properties, whereas hyperoside has diuretic and anti-inflammatory effects (Kohlmünzer 2000). In turn, dropwort underground organs are rich in flavan-3-ols, namely: (+)-catechin, (+)-epicatechin, (−)-epigallocatechin, (−)-epigallocatechin gallate, as well as gallic and ellagic acids. (+)-Catechin is a dominant here (480.4 mg × 100 g^{-1} DW). It has been introduced into the official medicine as a drug regenerating liver tissues damaged due to infections or intoxications (Kohlmünzer 2000). One of the most important raw material, listed in many pharmacopoeias, rich in this compound is oak bark (*Quercus cortex*). According to Elansary et al. (2019) the content of catechin in the bark of *Quercus robur* reach 44.52 mg × 100 g^{-1} DW. Thus, underground organs of dropwort, containing 10 times more catechin than oak bark, seem to be an interesting source of these substances.

The results of our experiment showed that the content of particular compounds in dropwort raw materials was very variable. This phenomenon was observed especially in the case of flavonols, e.g., spireoside, the content of which, depending on the population, ranged in the herb from 124.0 to 952.3 mg × 100 g^{-1} DW. Similar tendency was observed for hyperoside. Lower differences among analyzed populations were observed when regards flavan-3-ols and phenolic acids, especially in the case of underground organs (Table 2.2).

To sum up, the observed chemical variability of investigated wild-growing populations may be related to various factors, both endo- and exogenic. The most important seems to be genetic diversity followed by plant's age and stage of their development. Environmental conditions could have a crucial meaning here, as well.

Table 2.2 Intraspecific chemical diversity of wild-growing dropwort (mg × 100 g^{-1} DW)

Compounds	Herb			Underground organs		
	Mean	Min.	Max.	Mean	Min.	Max.
Flavonoids						
Quercetin	1.1	0.2	1.9	n.d.		
Astragalin	441.2	153.3	656.1	n.d.		
Hyperoside	536.7	157.0	809.5	n.d.		
Kaempferol	146.0	61.3	187.4	n.d.		
Spireoside	490.1	124.0	952.3	n.d.		
(+)-catechin	227.5	100.1	330.4	480.4	360.4	563.8
(+)-epicatechin	n.d.			281.8	155.4	372.9
(−)-epigallocatechin	176.1	55.7	340.2	202.9	57.0	384.2
(−)-epigallocatechin gallate	n.d.			80.0	53.9	122.5
Phenolic acids						
Gallic acid	79.6	35.6	130.2	104.4	61.4	127.6
Ellagic acid	94.3	13.7	141.3	13.0	4.2	22.6
Syringic acid	192.9	125.8	251.6	n.d.		
Salicylic acid	16.0	6.6	22.6	n.d.		
Caffeic acid	50.3	12.2	90.8	n.d.		
Rosmarinic acid	53.0	18.4	102.4	n.d.		
Chlorogenic acid	151.3	71.1	280.8	n.d.		

ND not detected

2.3 The Quality of Raw Material from Cultivated Plants

2.3.1 The Effect of Plant Propagation Method on the Yield and Quality of Raw Material

One of the most important problems when introducing wild-growing plants into cultivation seems to be production of propagating material. The use of seeds for establishing plantations is often unreliable. One of the most important traits typical for wild-growing plants in uneven, stretched over time seed germination. As a result of evolution, this phenomenon allows the species to survive in unfavorable environmental conditions. Hence, viable seeds can survive in the soil seed bank for up to several dozen years. Only favorable environmental conditions, during which the dormancy of seeds is broken, can induce germination. Developing a seed germination protocol for the purpose of plant cultivation is extremely laborious and time-consuming. In such cases, different methods of vegetative propagation are implemented, including the use of in vitro techniques. Sometimes, however, the use of simple methods related to obtaining cuttings gives satisfactory results.

In our investigation on dropwort, two methods of plant propagation have been used; i.e., traditional generative propagation with seeds and vegetative one via stem–root cuttings (obtained by the division of maternal plants) (Fig. 2.4, 2.5 and 2.6). The natural germination of dropwort seeds is relatively weak and uneven. Sowing seeds directly into the ground seems risky. Thus, the generative propagation which relies on the productions of seedlings used for plantation establishment should be recommended. In this study, we have compared the yield and quality of above- and underground organs of dropwort originated from plantations established by generative and

Fig. 2.4 Seeds

Fig. 2.5 Seedlings

Fig. 2.6 Rooted Cuttings

vegetative way of plant's reproduction. The underground organs were collected in the first (autumn, harvest in October) and in the second year of plant's vegetation (spring, harvest in May). Root leaves were harvested in the second year, in spring. The raw materials were weighted, dried, and subjected to chemical analysis concerning phenolic compounds (HPLC). The results showed that the plants obtained from cuttings provided visibly higher mass of both root leaves and underground organs. Irrespectively of the propagation method, the mass of underground organs increased from the first to the second year of plant's development (Table 2.3).

The method of plant's propagation affected the content and composition of phenolics in dropwort raw materials. Plants cultivated from seedlings contained more hyperoside, (+)-catechin, and syringic acid in the root leaves when compared to these grown from cuttings. Other identified compounds (except for astragalin) were present on the similar level (Table 2.4). More significant differences were noticed in

Table 2.3 Fresh mass of raw material (g × plant^{-1})

Plant organs/term of harvest	Seedlings	Cuttings
Root leaves		
Second year of plants vegetation	34.8 ± 5.6	55.7 ± 8.4*
Underground organs		
First year of plants vegetation (October)	86.0 ± 12.0	127.5 ± 17.9*
Second year of plants vegetation (May)	111.3 ± 17.8	155.2 ± 26.4*

*$p < 0.05$

Table 2.4 Chemical characteristics of root leaves (mg × 100 g^{-1} DW)

Compounds	Seedlings	Cuttings
Flavonoids		
Quercetin	1.6 ± 0.1	1.5 ± 0.1
Astragalin	55.4 ± 5.5	79.4 ± 6.4*
Hyperoside	389.4 ± 21.2*	327.3 ± 22.9
Kaempferol	12.3 ± 1.1	11.3 ± 1.0
Spireoside	17.3 ± 1.2	19.3 ± 1.4
(+)-catechin	230.3 ± 20.7*	201.1 ± 22.1
(-)-epigallocatechin	158.4 ± 12.7	144.3 ± 10.1
Phenolic acids		
Ellagic acid	45.9 ± 4.1	49.2 ± 3.4
Gallic acid	200.7 ± 14.0	188.3 ± 11.8
Syringic acid	236.9 ± 19.0*	187.2 ± 16.8
Salicylic acid	9.4 ± 0.7	6.4 ± 0.6
Caffeic acid	95.2 ± 8.6	89.6 ± 6.3
Rosmarinic acid	131.0 ± 14.4	144.3 ± 11.5
Chlorogenic acid	111.3 ± 12.8	99.3 ± 7.9

*$p < 0.05$

the case of underground organs. Independently from the harvest term, underground organs collected from the plants propagated by seedlings were more abundant with almost all detected phenolics than the plants from cuttings. Underground organs harvested in the first year were characterized by a visibly higher content of flavan-3-ols in comparison to those collected in the second year. This was specially visible when regards (−)-epicatechin. In contrary, the amount of ellagic and gallic acids in underground organs increased from the first to the second year of plant's vegetation (Table 2.5). This may be explained by the fact that phenolic acids are precursors in the biosynthesis of other phenolics (Kohlmunzer 2000). Based on the above observations, especially those concerning the mass of raw materials, it can be concluded that vegetative propagation of dropwort is more promising than the generative one. However, the quality of investigated raw materials, reflected in phenolics content, seems to be better in plants reproduced via seeds.

2.3.2 *Accumulation of Biomass and Biologically Active Compounds*

When collecting raw materials from wild-growing or cultivated plants, the data on their harvest conditions are particularly important. Although there are many rules

Table 2.5 Chemical characteristics of underground organs (mg × 100 g^{-1} DW)

Compounds	First year of plants vegetation			Second year of plants vegetation		
	Seedlings	Cuttings	Mean	Seedlings	Cuttings	Mean
(+)-catechin	317.2 ± 24.9	229.3 ± 13.8	273.3*	226.5 ± 20.4	131.9 ± 14.5	179.2
(−)-epicatechin	453.8 ± 25.8	389.1 ± 17.3	421.5*	232.2 ± 17.2	193.4 ± 15.5	212.8
(−)-epigallocatechin	334.4 ± 30.1	358.3 ± 21.1	346.4*	206.0 ± 16.5	239.3 ± 21.5	222.7
(−)-epigallocatechin gallate	52.2 ± 3.7	38.3 ± 2.7	45.3*	41.9 ± 3.8	25.2 ± 1.8	33.6
Ellagic acid	32.3 ± 2.9	12.7 ± 1.4	22.5	42.6 ± 3.6	28.7 ± 2.4	35.7*
Gallic acid	76.4 ± 8.4	69.3 ± 7.6	72.9	105.2 ± 8.7	94.0 ± 10.3	99.6*
Sum	1266.3*	1097.0		854.4*	712.5	

*$p < 0.05$

regarding this issue, the individual reaction of each species should be taken into consideration. In general, the accumulation of secondary metabolites (including phenolics) in plant's tissues is associated with their physiological function and strongly depends on the stage of ontogenetic development. In dropwort, the content of phenolic compounds fluctuated during ontogenesis and was related to plant's organs. Taking into account that in dropwort almost all organs provide herbal raw materials, the investigations on the above listed relations are meaningful in terms of its cultivation.

The mass and chemical composition of dropwort's above- and underground organs in connection with the age of plants and stage of their development were determined. Following raw materials were evaluated: flowers, root leaves, shoot leaves, as well as underground organs separated into rhizomes, roots, and tubers. Underground organs and root leaves were collected in both years of vegetation, in October. Flowers and shoot leaves were obtained in the second year, three times during plant's development: at the beginning of flowering, at the full-flowering stage, and at the end of flowering (Figs. 2.7 and 2.8). The investigated raw materials were weighted, dried, and analyzed by HPLC in respect of phenolic compounds (Fig. 2.9a, b, c).

The mass of rhizomes, roots, and tubers in the second year of vegetation was significantly higher than in the first year, while the mass of root leaves was comparable in both years (Table 2.6). The mass of flowers increased from the beginning to the end of flowering; opposite tendency was observed for shoot leaves (Table 2.7). The obtained results showed that the stage of plant's development affected not only the weight but also the chemical composition of investigated raw materials. Among dropwort organs, flowers seem to be especially interesting. Recent phytochemical and pharmacological studies confirm traditional usage of this raw material and support its importance in modern medicine. Besides significant antioxidant potential, the flowers reveal dose-related antihyperalgesic activity with a good safety profile. When given its gastroprotective activity, this raw material decreases production of pro-inflammatory eicosanoids ex vivo in human platelets. Such biological properties are associated with the unique chemical composition of dropwort flowers, especially

Fig. 2.7 Plants in the second year of vegetation (vegetative stage)

Fig. 2.8 Plants in the second year of vegetation (flowering stage)

with the presence of spireoside, kaempfeol, and astragalin derivatives as leading compounds (Smardžic et al. 2016, 2018). In our work, the following flavonoids were identified in the flowers: quercetin, astragalin, hyperoside, kaempferol, spireoside, (+)-catechin, and (−)-epigallocatechin, with a domination of spireoside and hyperoside. The highest content of astragalin, hyperoside, kaempferol, and spireoside was found at the beginning of flowering and then decreased significantly reaching its minimum at the end of flowering (Table 2.8). The opposite relation was noticed in the

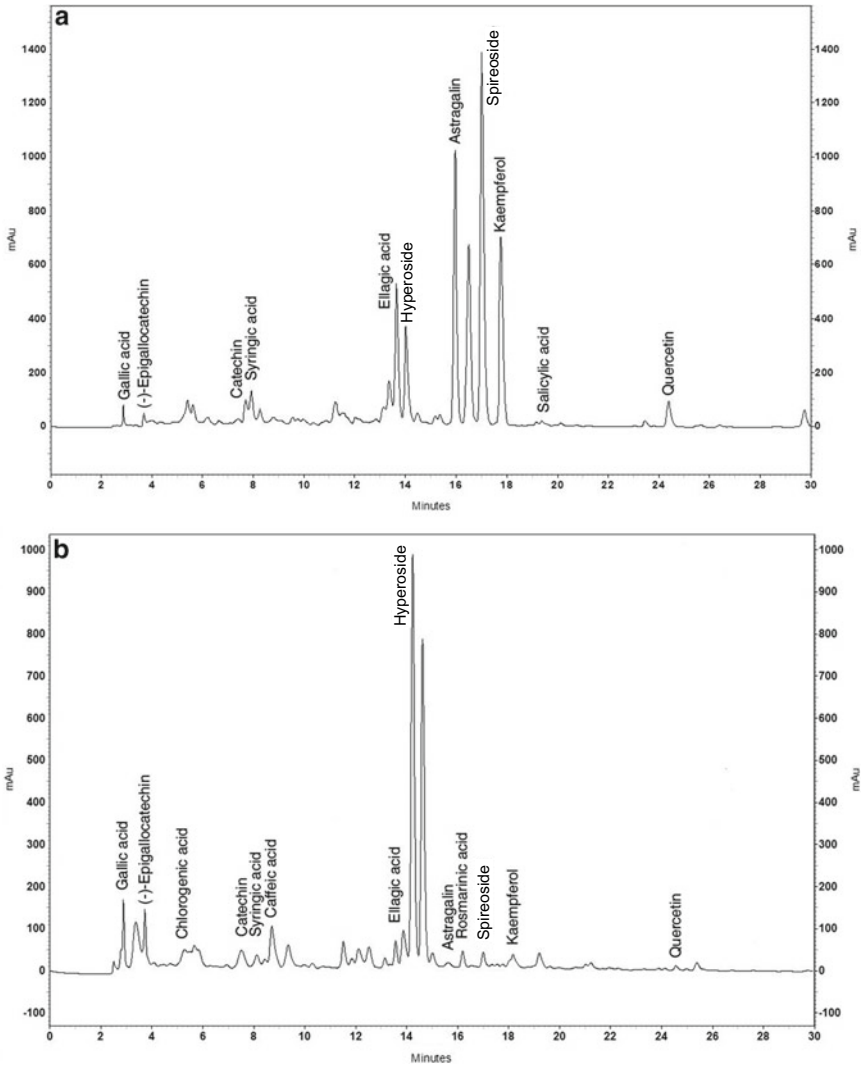

Fig. 2.9 Chromatograms of dropwort flower extracts (**a**), leaves extracts (**b**), and underground organs extracts (**c**)

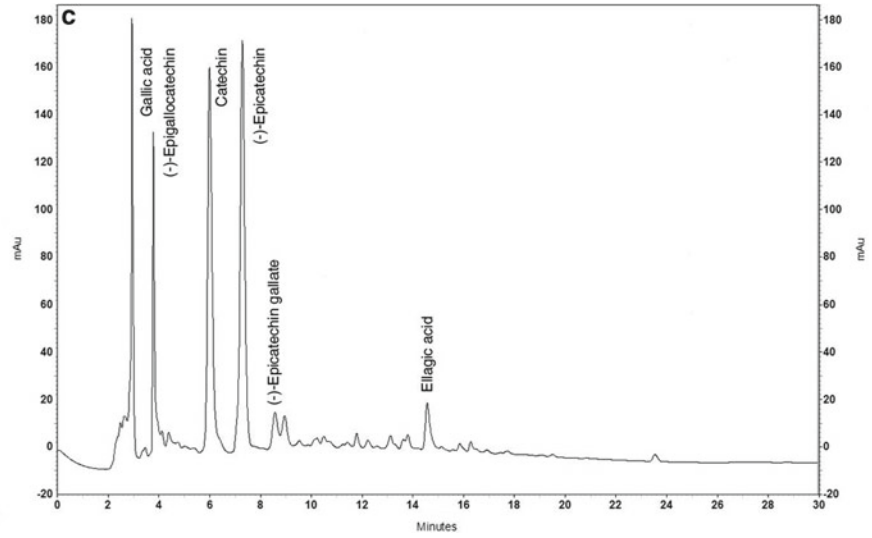

Fig. 2.9 (continued)

Table 2.6 Fresh mass of raw materials in the first and second year of vegetation (g × plant^{-1})

Plant organs	First year of plants vegetation	Second year of plants vegetation
Root leaves	111.19 ± 21.13	103.28 ± 15.49
Rhizomes	10.82 ± 1.51	70.53 ± 11.99*
Roots	5.98 ± 0.96	24.18 ± 4.35*
Tubers	81.25 ± 13.81	194.01 ± 22.98*

*$p < 0.05$

Table 2.7 Fresh mass of raw materials in the second year of vegetation (g × plant^{-1})

Plant organs	Term of harvest		
	BF	FF	EF
Shoot leaves	20.50 ± 2.46a	14.81 ± 2.07b	13.51 ± 2.03c
Flowers	28.89 ± 4.04c	48.21 ± 6.27b	61.87 ± 9.90a

*$p < 0.05$
BF beginning of flowering, *FF* full flowering, *EF* end of flowering

case of (+)-catechin and (−)-epigallocatechin. In turn, the highest level of all detected phenolic acids (ellagic, gallic, syringic, and salicylic acids) was shown during the full flowering stage. Here, syringic and gallic acid were the dominants (up to 485.9 and 450.2 g × 100 g^{-1} DW, respectively). These compounds reveal antioxidant, antimicrobial, anti-inflammatory, antiendotoxic, neuroprotective, hepatoprotective, cardioprotective, and gastroprotective activities (Srinivasulu et al. 2018; Kahkeshani

Table 2.8 Content of phenolic compounds in flowers (mg × 100 g^{-1} DW)

Compounds	Term of harvest		
	BF	FF	EF
Flavonoids			
Quercetin	64.6 ± 5.2a	69.7 ± 6.6a	11.3 ± 1.2b
Astragalin	542.3 ± 41.3a	341.3 ± 33.8ab	84.1 ± 8.7c
Hyperoside	651.8 ± 55.4a	489.5 ± 30.6b	155.4 ± 13.2c
Kaempferol	164.9 ± 15.5a	128.9 ± 12.2a	33.8 ± 3.1b
Spireoside	999.9 ± 73.0a	753.0 ± 55.0ab	126.0 ± 9.2c
(+)-catechin	63.1 ± 5.7c	90.3 ± 7.9b	147.0 ± 12.9a
(−)-epigallocatechin	46.8 ± 3.9bc	50.2 ± 4.7b	68.2 ± 5.9a
Phenolic acids			
Ellagic acid	204.1 ± 18.4b	346.0 ± 29.4a	89.8 ± 8.1c
Gallic acid	271.6 ± 19.8b	450.2 ± 32.4a	289.8 ± 20.6b
Syringic acid	286.1 ± 22.9b	485.9 ± 36.0a	169.4 ± 14.9c
Salicylic acid	68.3 ± 5.1a	69.3 ± 5.1a	26.8 ± 2.0b

*$p < 0.05$
BF beginning of flowering, *FF* full flowering, *EF* end of flowering

et al. 2019). In our work, the presence of salicylic acid in dropwort flowers should be underlined, since it is well known for significant anti-inflammatory properties (Kohlmünzer 2000). The high content of phenolics in dropwort flowers may be attributed to their physiological role in protecting the generative organs from biotic and abiotic stress factors (Figueiredo et al. 2008; Verma and Shukla 2015). Moreover, phenolic compounds effectively control certain steps of cell growth and differentiation and thus play an important role in the reproduction mechanisms (Agati et al. 2012; Ferreyra et al. 2012; Verma and Shukla 2015).

Besides flowers, others aboveground organs namely root leaves and shoot leaves were evaluated in our study. In both examined organs, the same phenolics were detected, and their content was on the similar level. Root leaves collected in the first year of plants vegetation contained slightly more identified phenolics (except for chlorogenic acid and spireoside) than those harvested in the second year. It was shown that the amount of phenolics in the shoot leaves depended on the stage of blooming. Here, the highest content of hyperoside, which was a dominant compound, was marked at the end of this phase (452.7 mg × 100 g^{-1} DW) (Table 2.9). Hyperoside is known for its various, multidirectional pharmacological activities. Besides anti-inflammatory, antioxidant, and diuretic effects, it also reveals antidepressant, neuroprotective, cardioprotective, antidiabetic, anticancer, antifungal, and gastroprotective activity (Raza et al. 2017). Among underground organs, rhizomes appeared to be the most abundant in all the identified phenolics, except for (+)-catechin and (−)-epigallocatechin. Underground organs harvested in the first year were characterized by higher content of phenolics in comparison to these collected in the second

Table 2.9 Content of phenolic compounds in leaves (g × 100 g^{-1} DW)

Compounds	Root leaves		Shoot leaves (Second year of plants vegetation)		
	First year of plants vegetation	Second year of plants vegetation	BF	FF	EF
Flavonoids					
Quercetin	1.0 ± 0.1	0.5 ± 0.0	0.2 ± 0.0b	9.9 ± 0.9a	7.3 ± 0.8a
Astragalin	50.7 ± 5.7	40.4 ± 4.2	61.0 ± 5.8a	62.0 ± 6.4a	48.7 ± 4.7b
Hyperoside	345.5 ± 29.0*	263.2 ± 22.6	384.8 ± 31.2b	370.5 ± 31.5b	452.7 ± 38.0a
Kaempferol	12.3 ± 1.1	9.5 ± 0.9	27.2 ± 2.6ab	36.8 ± 3.5a	28.3 ± 2.7ab
Spireoside	15.0 ± 1.1	19.7 ± 1.5	18.7 ± 1.5b	24.3 ± 1.8a	20.2 ± 1.5ab
(+)-catechin	61.3 ± 5.3	50.8 ± 4.5	41.1 ± 3.4c	55.3 ± 4.3b	72.4 ± 7.4a
(−)-epigallocatechin	91.1 ± 8.4	80.6 ± 7.5	56.0 ± 4.9	67.1 ± 5.7	76.7 ± 6.4
Phenolic acids					
Ellagic acid	82.5 ± 9.1	60.5 ± 6.4	21.7 ± 2.4b	44.6 ± 5.0a	19.3 ± 2.0b
Gallic acid	228.5 ± 24.4	222.8 ± 22.9	184.6 ± 17.6	165.9 ± 14.2	178.9 ± 18.6
Syringic acid	250.1 ± 22.3*	131.5 ± 12.8	192.4 ± 17.9c	234.8 ± 19.5b	305.6 ± 26.0a
Caffeic acid	73.0 ± 6.5*	39.1 ± 3.8	86.6 ± 8.1b	98.1 ± 8.1a	83.1 ± 7.1b
Rosmarinic acid	83.4 ± 7.4*	60.3 ± 5.8	122.2 ± 11.4a	109.7 ± 9.1b	86.0 ± 7.3c
Chlorogenic acid	111.9 ± 10.0	138.8 ± 13.5	67.6 ± 6.3c	128.9 ± 10.7a	96.2 ± 8.2b

*$p < 0.05$

BF beginning of flowering, *FF* full flowering, *EF* end of flowering

year (Table 2.10). This phenomenon may be associated with the need of physiological protection of younger, intensively growing plants against various stressors. It should be underlined that phenolics not only protect cells against free radicals, but also play an important role as antimicrobial and strengthening agents (Andersen and Markham 2006). For instance, phenolic acids as lignins components incrust cell walls making them more resistant against various pathogens (Weng and Chapple 2010). In turn, catechins (classified as tannins) due to their astringed properties indicate a high antibacterial activity (Kohlmünzer 2000).

2.3.3 *Diversity of Plants in Their Cultivation*

The introduction wild-growing plants into cultivation enables to obtain more homogenous raw materials. Dropwort belongs to the plants with an allogamous way of reproduction (Weidema et al. 2000). Thus, when the plantation is established via seeds originating from wild-growing population, the offspring may be highly differentiated, as a result of cross-pollination. A high range of phenotypic variability may create problems with raw material standardization. However, this phenomenon

Table 2.10 Content of phenolic compounds in underground organs (g × 100 g^{-1} DW)

Compounds	First year of plants vegetation				Second year of plants vegetation			
	Rhizomes	Roots	Tubers	Sum	Rhizomes	Roots	Tubers	Sum
(+)-catechin	293.3 ± 33.7b	396.0 ± 35.6a	213.7 ± 23.9c	903.0	280.9 ± 32.0b	321.6 ± 30.2a	215.4 ± 18.3c	817.9
(−)-epicatechin	212.9 ± 20.9a	175.5 ± 16.0b	68.8 ± 6.3c	457.2*	177.1 ± 16.1a	134.0 ± 13.3ab	59.3 ± 5.4b	370.4
(−)-epigallocatechin	222.4 ± 18.7b	268.7 ± 23.1a	294.7 ± 25.6a	785.8*	201.4 ± 15.7c	233.1 ± 14.5b	281.6 ± 18.3a	716.1
(−)-epigallocatechin gallate	98.4 ± 9.4a	80.9 ± 7.8a	28.7 ± 2.8b	208.0	94.1 ± 9.0a	70.7 ± 6.2b	38.6 ± 3.2c	203.4
Ellagic acid	29.1 ± 2.2a	20.9 ± 1.6ab	13.0 ± 1.1b	63.0	37.8 ± 2.8a	20.0 ± 1.4b	14.5 ± 1.4c	72.3
Gallic acid	151.6 ± 15.5a	131.0 ± 14.7ab	72.2 ± 8.3b	354.8*	128.8 ± 14.4a	113.0 ± 10.7b	63.9 ± 6.3c	305.7
Sum	1007.7a	1073.0a	691.1b		920.1a	892.4b	673.3c	

*$p < 0.05$

Table 2.11 Diversity of plant organs in terms of their mass (g × plant^{-1})

Raw materials	Mean	Min.	Max.
Flowers	61.3	35.6	111.8
Shoot leaves	30.50	7.0	60.3
Root leaves	102.6	25.9	176.5
Rhizomes	74.0	41.9	94.6
Roots	26.8	9.3	41.32
Tubers	301.9	192.7	447.9

opens a huge possibilities for breeders, where single plants may become valuable components for breeding (Carlen 2011).

High intraspecific variability of dropwort concerning the mass and chemical composition of raw materials was observed. Individual plants were separately assessed, and both minimum and maximum values of the investigated parameters were determined (Tables 2.11, 2.12 and 2.13). Concerning the mass of raw materials, the leaves were the most diverse (Table 2.11). Among the aboveground organs (flowers, shoot leaves, and root leaves), the richest in flavonoids, especially in astragalin, hyperoside, and spireoside, were flowers. It is worth noting that hyperoside

Table 2.12 Diversity of aboveground organs in terms of phenolic compounds content (mg × 100 g^{-1} DW)

Compounds	Flowers			Shoot leaves			Root leaves		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Flavonoids									
Quercetin	11.2	0.1	26.1	2.1	0.8	3.7	1.2	0.2	2.3
Astragalin	683.1	471.2	1221.5	60.0	29.1	111.9	32.4	26.2	61.2
Hyperoside	765.8	405.1	1654.2	409.8	57.7	637.6	389.7	239.2	508.3
Kaempferol	142.1	136.5	246.1	15.5	11.3	22.6	12.2	10.8	14.3
Spireoside	686.4	205.5	1236.9	15.1	8.8	28.3	10.7	8.1	16.7
(+)-catechin	41.2	21.3	87.4	120.3	64.2	211.3	95.4	35.3	184.9
(−)-epigallocatechin	72.48	43.9	150.8	246.0	141.0	480.3	168.9	51.6	589.7
Phenolic acids									
Gallic acid	382.8	270.3	1096.3	108.8	56.6	242.5	158.1	7.9	383.1
Ellagic acid	205.6	117.4	284.0	14.6	4.1	26.8	19.1	1.4	29.6
Syringic acid	346.7	270.2	598.2	289.4	112.3	450.4	360.4	118.3	546.7
Salicylic acid	26.5	5.8	83.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Caffeic acid	n.d.	n.d.	n.d.	70.1	40.4	114.0	51.6	21.9	101.8
Rosmarinic acid	n.d.	n.d.	n.d.	135.0	78.2	204.4	96.6	24.5	170.5
Chlorogenic acid	n.d.	n.d.	n.d.	173.0	70.1	247.7	106.3	32.2	216.2

ND not detected

Table 2.13 Diversity of underground organs in terms of phenolic compounds content (mg × 100 g^{-1} DW)

Compounds	Rhizomes			Tubers			Roots		
	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.
Flavonoids									
(+)-catechin	351.5	192.5	655.5	127.9	42.1	205.7	288.9	49.1	569.3
(−)-epicatechin	270.4	116.5	432.3	91.6	24.0	165.6	232.3	23.6	386.5
(−)-epigallocatechin	238.6	119.4	477.3	112.5	38.4	187.1	168.3	8.5	269.9
(−)-epigallocatechin gallate	105.4	26.6	220.6	49.1	27.1	79.3	80.7	32.1	118.9
Phenolic acids									
Ellagic acid	50.7	8.1	41.0	4.8	1.1	11.2	25.7	12.2	45.5
Gallic acid	71.1	31.6	128.4	35.2	13.1	51.5	64.5	17.9	162.0

was also present in significant amounts in the leaves. The most varied in terms of the content of flavonoids was spireoside. The highest content of phenolic acids in the aboveground organs was also found in the flowers. However, syringic acid was present in high quantities in the leaves, as well. Gallic acid was present in all three aboveground organs and clearly differentiated these organs (Table 2.12). Among the underground organs, the highest content of phenolics was detected in the rhizomes. Rhizomes were the most differentiated as to (−)-epigallocatechin gallate content (26.6–220.6 mg × 100 g^{-1} DW), tubers—(−)-epicatechin (24.0–165.6 mg × 100 g^{-1} DW), and roots—(−)-epigallocatechin (8.5–269.9 mg × 100 g^{-1} DW).

2.4 Perspectives

Due to the need for protection of dropwort natural recourses, as well as in order to obtain a considerable amount of standardized raw materials, the species should be introduced into cultivation. The presented work summarizes our efforts concerning this issue. Taking into account that wild-growing dropwort populations are small, scattered and highly diversified as to morphological and chemical traits, they provide heterogeneous raw materials in the amount not sufficient for industrial purposes. Thus, crucial questions concerning agrotechnical problems including, i.e., the range of intraspecific variability between individual plants in cultivation, the way of plantation establishment as well as the raw materials quality depending on the plant's age and developmental phase, have appeared. It was shown that dropwort plantation may be successfully established both by seedlings production and *via* vegetative propagation (by stem–roots cuttings), however, the latter one seems more promising. Further works on effective ways of plants propagation, including in vitro techniques and/or trials on seeds germination improvement, should be undertaken. Our results show that when being cultivated, dropwort produces high and stable yield of both

above- and underground organs. The accumulation of biologically active compounds in these organs is strongly associated with the age of plants and stage of their development. Thus, depending on the harvest term, it is possible to obtain raw materials with variable quality. Taking into consideration medicinal potential of dropwort organs reflected in a high content of phenolics, future works should focus on the production of standardized extracts from this plant followed by the determination of their pharmacological activity.

Acknowledgements The work was supported by Polish Ministry of Science and Higher Education, project NCBiR No. R12 06803.

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