Chapter 3
Wild-Growing Species in the Service of Medicine: Environmental Challenges and Sustainable Production

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Abstract Wild fruits are underutilized plants that are well adapted to the local climatic conditions. Extreme environmental conditions due to climate change or variability are a threat to wild-growing species, crop production, productivity, and livelihood. Wild fruit fields could be affected by not meeting winter chilling requirements, which is specific for every fruit species. On the other hand, the plants' secondary metabolites and other bioactive compounds can be attributed to the changing conditions as a response to various types of environmental stresses which affect their production. Secondary metabolites refer to small molecules that are non-essential for the growth and reproduction of plants, but have a wide range of effects on the plant itself and other living organisms. Blackthorn (*Prunus spinosa* L.), Cornelian cherry (*Cornus mas* L.), dog rose (*Rosa canina* L.), and hawthorn (*Crataegus monogyna* Jacq.) are important wild plants with powerful health-promoting properties. Due to their chemical composition and nutritive value, they have a strong effect on regional food security and poverty alleviation. Positive health effects, forceful impact on the quality of life, and market potential are additional attributes of these plants, which may have significant economic impact.

Keywords Blackthorn · Cornelian cherry · Dog rose · Hawthorn · Environmental conditions · Secondary metabolites · Health-promoting properties

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T. Aftab (ed.), *Environmental Challenges and Medicinal Plants*, Environmental Challenges and Solutions, https://doi.org/10.1007/978-3-030-92050-0_3

Abbreviations

GC	Gas chromatography
GC-FID	Gas chromatography with flame ionization detection
GC-MS	Gas chromatography-mass spectrometry
HPLC	High performance liquid chromatography
HPLC-DAD	High performance liquid chromatography coupled with diode-array detection
HPLC-DAD-ESI/MS	High performance liquid chromatography coupled with diode-array detection—electrospray ionization mass spectrometry
HPLC-ESIQ-TOF-MS	High performance liquid chromatography coupled to electro spray ionisation and quadrupole time of flight mass spectrometry
HPLC-MS	High performance liquid chromatography with mass spectrometry
HPLC-RI	High performance liquid chromatography with refractive index detectors
ICP-OES	Inductively coupled plasma—optical emission spectrometry
LC-DAD/ESI/MS	Gas chromatography with diode-array detection—electrospray ionization mass spectrometry
LC-MS/MS	Liquid chromatography with tandem mass spectrometry
UHPLC-DAD-ESI-MS/MS	Ultrahigh performance liquid chromatography coupled with diode-array detection—electrospray ionization tandem mass spectrometry
UPLC-MS/MS	Ultra-performance liquid chromatography-tandem mass spectrometry
UPLC-MS^2	Ultra-performance liquid chromatography-tandem mass spectrometry
UV/Vis	Ultraviolet-visible spectroscopy.

3.1 Wild Fruits and Environmental Challenges

Wild fruits are underutilized, less known, polycarpic plants that bear fruits and are well adapted to the local climatic conditions. All these species have strong effect on regional food security and poverty alleviation. Due to their positive health effects and market potential, the gathering of these plants has a forceful impact on the quality of life and economics. These species that today have fallen somewhat into disuse were widely consumed in the past and especially in times of scarcity (Tardío et al. 2006).

The introduction of wild fruit species into the commercial fruit growing can be useful for several reasons: diversification of agriculture throughout the region, introduction of new raw materials into the food industry, as well as the preservation of agro-biodiversity. A number of wild relatives of cultivated fruit trees could be used in the future as rootstock in fruit production or for organized production, either organic or conventional. In the intensive fruit production, there are more and more problems with the susceptibility of cultivars to diseases and pests, which imposes numerous and obligatory applications of protective chemicals, which in addition to mineral fertilizers are reducing biological value of the cultivated fruits. Since wild fruit genotypes carry resistance genes for the most economically important pests, they can be used in breeding fruits and vines. Wild fruit species are also used as planting material for afforestation and prevention of erosion, some in cosmetic industry, and some as decorative forms in landscape architecture, while some species are important bee pastures (Mratinić and Fotirić-Akšić 2014).

Wild fruits are crucial for poor rural inhabitants and unemployed youths by giving them the possibility to make new varieties of edible products such as baking products, jelly, jam, preserves, marmalade, chocolate candy, dry berries, pickled (especially Cornelian cherry), pudding, butter, sauce, wine, juice, salad dressing, pie, tart, syrup, sauce, sherbet, candy, wine, cider, blossom fritters (especially from elderberry), and even beer. Wild fruits can be sold as potted trees; wood can be used for making furniture, jewelry, and traditional musical instruments. A community can be developed by starting small businesses. Wild fruit gathering can be organized as a recreation and tourism activity, promoting native recipes, cooking traditions, making festivals, and spreading local history.

In the last decade, wild fruits have received increasing interest due to their medicinal properties and nutritional value (Mikulic-Petkovsek et al. 2015; Li et al. 2016). They are a rich source of various bioactive compounds such as carbohydrates, organic acids, proteins, phenolic compounds, carotenoids, tocopherol, volatile oils, pectins, tannins, fatty acids, oils, aromatic substances, enzymes, vitamins, minerals (K, Ca, P, Fe, Mg, and Mn), dietary fibers, and others (Demir et al. 2014; Krstić et al. 2019, Popović-Djordjević et al. 2021).

All those phytochemicals together combat the oxidative stress which performs an essential role in multiple chronic diseases. Bioactive compounds from wild fruits have antioxidant, anti-inflammatory, antimicrobial, anti-ulcerogenic, antidiabetic, anti-mutagenic, and anti-cancer activities, and they act against rheumatoid arthritis, osteoporosis, hyperlipidemia, obesity, renal disturbances, skin disorders, and aging (Mármol et al. 2017; Tumbas et al. 2012). Therefore, wild fruits have the potential to become a functional food that will be used in preventing and treating chronic diseases. New application of wild fruits includes using natural antioxidants to extend the shelf life of food products and replace synthetic antioxidants, avoiding potential health risks and toxicity (Lourenço et al. 2019).

The wild fruits are very healthy food of high nutritional and, above all, vitamin value (Fernandez-Ruiz et al. 2017). The source of vitamin C among wild fruits is found in rose hips (*Rosa* sp. – 130–6694 mg/100 g), young walnut husk (500–2459 mg/ 100 g), and then currants, bilberry, and cranberry (Gergelezhiu 1937; Yoruk et al.

2008; Milivojević et al. 2013). Rowan (*Sorbus aucuparia*), seaberry (*Hippophae rhamnoides*), dog rose (*Rosa* sp.), and hawthorns (*Crataegus* sp.) are rich in carotenes. Rose hips, wild strawberries, and bilberries contain a relatively large amount of niacin. Vitamins B, K, and E are abundant in currants and gooseberries, dog rose, rowan, and guelder-rose. Fresh wild fruit extracts are an excellent source of polyphenolic compounds, acting as free radical scavengers, which can prevent neurodegenerative and cardiovascular diseases and even cancer (Zafra-Stone et al. 2007; Jing et al. 2008).

Wild fruits usually have more moisture, energy value, and more complex phytochemical composition than the cultivated varieties (Thole et al. 2006). Moreover, their main advantage is that they grow in nature without human influence, which means without watering, spraying with chemicals, or fertilization with synthetic fertilizers, and they are richer in the quantity of bioactive compounds. On the other hand, these fruits grow in optimal natural conditions, so they are more biologically resistant and less endangered by pathogens and pests, and their fruits are more abundant in bioactive substances. However, when collecting wild fruits, it should always be kept in mind that the picking should be done rationally, and some plants should leave in order to allow them to grow and reproduce.

Extreme environmental conditions due to climate change or variability are a threat to wildlife, crop production, productivity, and livelihood. In most cases, climate change is associated with elevated temperatures, solar radiation, drought, strong winds, and hails. The prediction is that the temperature will be higher by 1–3 °C, so the rainfall, snowfall, UV radiation, and amount of ozone, aerosols, and clouds in the atmosphere will be altered (Bais et al. 2014). According to Wessels et al. (2021), under a low-warming scenario, 60% of wild food plant species will experience an increase in the range extent, while 40% will experience a decrease, whereas in a high-warming scenario, reduction of 66% in wild-harvested food plant species will be observed. Therefore, according to Arslan et al. (2020), 170,596 km^2 is currently a "highly suitable" area for *Rosa canina* L., but in a "milder" scenario, the area will contract to 114,474 km^2 by 2070, and in the "warmer" scenario, it will be just 41,146 km^2 by 2070.

Climate change will diminish wild fruit fields, first of all, by not meeting winter chilling requirements, which is specific for every fruit species, delay of flowering and/or fruiting, and higher fruit abscission. Also, it can happen that due to the warming up, invasive species might divert pollinating insects away from the native wild fruit-producing plants. If winter precipitation decreases and if summer temperatures substantially increase, changing locations for wild fruits will be observed, which can be a problem for people who have developed traditional berry-gathering sites (Kellogg et al. 2010). On the other hand, climate change can positively affect the production of bioactive compounds, but in some cases, it would lead to deterioration in quality parameters such as fruit weight (Romero-Román et al. 2021).

3.2 Description of Selected Wild Fruit Plants

3.2.1 Blackthorn

Photo was taken by Nenad Mićanović, Serbia

Blackthorn or sloe (*Prunus spinosa* L.) belongs to the Rosaceae family. It occurs in most of South-Central Europe and northward to the southern part of the Scandinavian Peninsula and eastward to the Asia Minor, the Caucasus, and the Caspian Sea. Southward, it can be found in North Africa (in Tunisia and Algeria). It is naturalized in many other parts of the world (North America and New Zealand). The specific name "*spinosa*" comes from a Latin term indicating thorn-like spur shoots. The evidence of the early use of sloes by man is found in the famous case of a 5300-year-old human mummy discovered in 1991 in the Ötztal Alps along the Austrian-Italian border.

It is a deciduous shrub or, very rarely, small tree growing to 5 m. Since it readily produces suckers and 1-year branches have savage thorns, traditionally, it was used in making a cattle-proof hedge. Flowers are small, pentapetalous, single or in pairs, bisexual, and creamy-white. It blossoms very early (in March/April), much before leafing. The fruits ripen in late August and are called "sloe." It is a black drupe with a purple-blue waxy bloom which gives the young fruit a matt appearance. It contains one large and rough stone, either cling or noncling. It has a very strong astringent flavor, but best for consumption is after the first frosts. Fruits can remain attached to the plant for a prolonged period, even until the spring.

It is a heliophyte and xerothermophilic species which grows on glades, forest borders, gullies, and river valleys, in meadows and pastures, and on mountain slopes. It makes a dense belt of shrubs adjacent to the forest between woodland and grassland communities where it is left untrimmed and ungrazed. Blackthorn prefers deep and moist soils (except acid peats) regardless of geological basis. It is characterized by broad adaptability and good viability so it can survive on dry and eroded soils along the banks of gorges and on stony slopes (Dzhangaliev et al. 2003). It can be found at altitudes of up to 1600 m, and it can sustain frosts up to $-30\,^{\circ}C$ (Mratinic and Fotiric-Akšic 2019). Crossing combination blackthorn × European plum

(*Prunus domestica*) forms *Prunus* × fruticans hybrids. Since the plant is hard and grows in a wide range of conditions, it is used as a rootstock for plum and apricot. It is also an important plant for wildlife, its early spring flowers provide nectar for early pollinators, and its branches create a spiny thicket, providing secure nesting for birds and protection and food for small mammals (Popescu and Caudullo 2016). It is suitable for stabilizing stony slopes of gorges and preventing landslides in the mountains (Dzhangaliev et al. 2003).

The fruits are mostly used in jellies, syrups, vinegar, and conserves and for liquor making (like gin, kvass, patxaran, flavored beers, vodka, “Porto” wine, “pacharán,” “troussepinette,” “bargnolino,” “eau de vie de prunelle,” “vin d’épine”) or as ingredients of various pastries (Yuksel 2015; Popescu and Caudullo 2016). Sloes can also be made into jam and used in fruit pies, and if preserved in vinegar, they are similar in taste to Japanese “umeboshi.” The flowers, petals, leaves, and dried fruits are used as herbal tea (Alarcón et al. 2015). The juice of the fruit dyes linen a reddish color that washes out to a durable pale blue. Blackthorn makes excellent firewood that burns slowly with good heat and little smoke. The wood has light yellow sapwood and brown heartwood. It is hard and tough and polishes up well. Traditionally, blackthorn wood is used for walking sticks and for the Irish shillelagh (Knaggs and Xenopoulou 2004).

3.2.2 Cornelian Cherry

Photo was taken by Milica Fotirić-Akšić, Serbia

Cornelian cherry or dogwood (*Cornus mas*) belongs to the genus *Cornus* (contains 45 species) and family Cornaceae. This species primarily grows in the temperate zone of Eurasia, and it is highly tolerant to diverse abiotic and biotic conditions. It grows spontaneously along oak forest edges and in woodland clearings; it is a light-loving plant and can live up to 300 years. In its distribution area, most individuals occur spontaneously as a result of open pollination, which varies widely in terms of productivity and fruit characteristics (Murrell 1993).

It is a deciduous shrub or a small tree 3–4 m high. The bark of older plants is gray, thin, and with shallow cracks, and juvenile branches are gray, smooth, and shiny (Mratinic and Fotiric-Akšic 2019). The flowers are small with four yellow petals, arranged in umbel inflorescence. It blooms at the end of winter/beginning of spring (February/March). The fruit is an oblong, olive-shaped, red drupe containing a single seed. When ripe (mid- to late summer), fruits resemble coffee berries. Fruits are edible but astringent. When ripe, the fruit is dark ruby red or a bright yellow.

This is a thermophyte and xerophilic species. It tolerates shade well, and it is very adaptive. It can be found on altitudes of up to 1300 m, on hills and slopes, and in forest clearings, as a companion tree in hornbeam, oak forests, and manna ash. *Cornus mas* can grow in all kinds of soils, from light sandy to heavy clay, with a pH ranging from slightly acid to very alkaline (Jaćimović et al. 2002; Bijelič et al. 2011). It can survive up to −30 °C, while it is sensitive to salt and marine exposures. The Cornelian cherry is free of disease and pest problems (Da Ronch et al. 2016).

Cornelian cherries can be consumed fresh or dried, but due to their acidic flavor, they are mainly used for making jams, juices, sauces, and alcoholic drinks such as vodka, brandy, and rakia (Bijelič et al. 2011). The oil-rich seeds of Cornelian cherry can be roasted, ground, and used as a coffee substitute (Facciola 1990), or the oil can be extracted and used in traditional medicine (Mamedov and Craker 2002). The stones and seeds can be converted to oil that can serve as biofuel (Akalın et al. 2012). The stones are sometimes made into beads (Smith and Branting 2014). The plant also has ornamental usage and is considered as a nectariferous, hedge, and shade plant (Mamedov and Craker 2002). Many European countries, such as Turkey, Ukraine, the Czech Republic, and Serbia, have breeding programs and select superior genotypes from natural populations (Mratinić et al. 2015).

Wood, leaves, fruits, and seeds have application in medical therapy (Hosseinpour-Jaghdani et al. 2017) and traditional Chinese medicine. The wood of *C. mas* is extremely dense and, unlike the wood of most other woody plant species, sinks in water (Demir and Kalyoncu 2003). Some ethnographic sources from south-east Europe describe *Cornus* tree as highly valued for its tough and durable wood that was used in the manufacturing of weapons, tools, instruments, and wickerwork (Filipović et al. 2020).

In the recent history of East European countries, Cornelian cherry tree had a special place in the life of rural communities and played an important role in celebrations and rituals. Some of the illustrative examples include the use of the inflorescence to make wedding wreaths for groom and bride, while the young shoots were eaten; the branches were placed on house roofs for protection against thunder, and they were soaked in bathing water; small pieces of wood were kneaded into Christmas bread; rods made from the branches were beating sticks for fighting off werewolves and witches; child swings were hung from Cornelian cherry tree (Čajkanović 1994).

3.2.3 Dog Rose

Photo was taken by Milica Fotirić-Akšić, Serbia

Dog rose (*Rosa canina*), which belongs to the Rosaceae family, is a climbing, wild rose species native to the northern hemisphere (Europe, Northwest Africa, and West Asia). It is a deciduous medium-developed shrub with a height of up to 3 m. Its stems are thin and covered with very strong, uneven, hooked prickles. The leaves are long, alternate- and odd-pinnate, and composed of 7–9 leaflets. The leaflets are usually elliptical, bare, and smooth on both sides. The flowers are large, pale pink, bisexual, and usually in large corymb-like inflorescence of 3–7 blossoms. The corolla has five white petals. The gynaeceum has many free, fairly protruding styles. A pseudo fruit is a red-orange "hip," which is an aggregate fruit consisting of several achenes (30–35% of fruit weight) enclosed by an enlarged, red, fleshy floral cup (hypanthium) (65–70% of fruit weight) (Pećinar et al. 2021).

Rose hip achenes contain neurotoxic substances, and the hairs are extremely irritable for the skin and mucous membranes (Ghrabi 2005). It blossoms in May and June and ripens in September and October. Fruits persist on the plant for several months and become black. Plants reproduce sexually by seed and vegetatively by suckering and layering.

Rosa canina can be found in lowlands, hills, or mountain regions, in deciduous and coniferous forests, along roadsides, in pastures, on forest clearings and edges, and among bushes. It is very adaptive to different geological rocks (silicate and limestone) and different soil types. It can grow in semi-shade or on direct sun. It can tolerate strong winds but not maritime exposure. Birds and other wildlife consume the hips of dog rose and spread the seed. In some areas, it is an invasive species (Pavek 2012).

The plant was described for the first time by Pliny the Elder (23–79 BC), who attributed the plant's name to a belief that the root could cure the bite of a mad dog (Hass 1995). The plant had also been known by sailors as a means of protection against scurvy, due to its high concentration of vitamin C (up to 1500 mg/100 g), and thus it spread to several continents (Winther et al. 2016). Today, these deciduous flowering shrubs are widely grown in gardens for their flowers and fruits (Ercisli 2005).

The fruit is used in the making of traditional probiotic drinks, beverages, soups, and yogurts, herbal teas, pies, stews, and wine, whereas the flowers can be made into syrup, eaten in salads, candied, or preserved in vinegar, honey, and brandy (Ahmad et al. 2016; Chrubasik et al. 2008). Distilling 1 kilo of flowers gives 1 liter of pure rose water (Ghrabi 2005). In traditional folk medicine, aqueous extracts of petals, fruit, and leaves of *Rosa canina* plants are applied in the treatment of various diseases such as nephritis, common cold, the flu, coughing, bronchitis, eczema, itching, and biliary diseases (Kultur 2007). The substances within the dog rose hips are endowed with vitaminisant, astringent, colagogue, choleretic, diuretic, antidiarrhoea, antioxidant properties (Roman et al. 2013).

3.2.4 Hawthorn

Photo was taken by Milica Fotirić-Akšić, Serbia

Common hawthorn or single-seed white hawthorn (*Crataegus monogyna*) is an endemic member of the Rosaceae family (Chang et al. 2002). The generic name *Crataegus* stems from the Greek "Kratos" meaning strength, and the species' name *monogyna* reveals that this species contains one ("mono") seed ("gyna"). It is native to Europe, Northwest Africa, and West Asia, but has been introduced in many other parts of the world. The plant forms a bush or a small tree, 3–10 m high. The crown is round and dense. One-year-old shoots, the leaves, stems, and flowers are completely bare or slightly ciliate on the receptacle and the flower's stem. The younger stems bear sharp thorns. The leaves are obovate and lobed at a wide angle. The flowers are bisexual, white, or pink and organized in corymbs with 4–33 blossoms together. The fruits are tiny (10 mm). Oval dark red haws, delicate in taste, contain only one seed (Mratinic and Fotiric-Akšic 2019).

It blossoms from late April until mid-June, and it is a sign that spring is turning to summer. The fruits ripen in the second half of September. The most widely known hybrid is *C.* × *media* (*C. monogyna* × *C. laevigata*), from which "Paul's Scarlet" genotype (with dark pink double flowers) was derived. Seedling trees take from 5 to 8 years before they start bearing fruit. The plant may be invasive.

This plant is an extreme heliophyte and can be found at altitudes of up to 1600 m. The tree is quite adaptive and can thrive in both carbonate and silicate soil. It appears most frequently on the fringes of forests and on waysides and roadsides. The hawthorn has developed resistance to drought, overly moist environments, wind, and atmospheric pollution. Common hawthorn can live long. In Mayenne (France), there is one hawthorn tree that is traced back to the third century.

Traditionally, *C. monogyna* has been used in folk medicine as a primary heart tonic, to correctly balance high and low blood pressure. Hawthorn is mainly used for hedging, especially in agriculture because it is stock- and human-proof. Being small in size, the use of its timber covers wood engravers' blocks, mallet heads, and tool handles. Since it grows in twisted shape, it is an excellent wood for carving ornaments. It is good firewood which burns with good heat and little smoke (Knaggs and Xenopoulou 2004).

The fruits of *C. monogyna* are used for different culinary purposes, such as the preparation of jellies, jams, syrups, candies, and pickles, and they are used to make wine or to add flavor to brandy (Sallabanks 1992). The fruit can be dried, ground, mixed with flour, and used for making bread and roasted seed for "coffee." The petals are also edible, as are the leaves, which if picked in spring when still young are tender enough to be used in salads (Kunkel 1984).

In folk medicine, the hawthorn is the center of many folklore tales, legends, and beliefs. It was primarily used to protect against all forms of evil spirits and demons. To ward them off, hawthorn amulets were carved and hung above doors or worn for protection. For example, in Serbian and Croatian folklore, hawthorn stakes were used to slay vampires, while in Gaelic folklore, the hawthorn symbolized the entrance into the other world and was strongly connected to fairies. Hawthorn bears both Pagan and Christian symbolism since it is believed that the stems that were used to make the crown of thorns given to Jesus before his crucifixion were made of hawthorn (Eberly 1989).

3.3 Chemical Composition of Selected Wild Plants

Compounds from different classes were found in fruits and other plants' parts of blackthorn, Cornelian cherry, dog rose, and hawthorn. These wild plants are good source of sugars, organic acids, fatty acids, amino acids, essential elements, and vitamins. The common sugars are fructose, glucose, sucrose, pectines, and cellulose. Among organic acids, malic, citric, oxalic, tartaric, quinic, and succinic are most represented in various parts of described plants (Barros et al. 2010; Babalau-Fuss et al. 2018; Cunja et al. 2016; De Biaggi et al. 2018; Ilyasoğlu 2014; Kubczak et al. 2020; Milić et al. 2020; Nađpal et al. 2016; Özderin et al. 2016; Paunović et al. 2018; Popović-Djordjević et al. 2021; Sikora et al. 2013; Vasić et al. 2020). Moreover, they are rich in secondary metabolites especially polyphenolic compounds including phenolic acids, flavonoids, anthocyanins, and tannins (Alirezalu et al. 2020; Bajić-Ljubičić et al. 2018; Bekbolatova et al. 2018; Cunja et al. 2016; Garofulić et al. 2018; Gironés-Vilaplana et al. 2012; Guimaraes et al. 2013, 2014; Jiménez et al. 2017; Kerasioti et al. 2019; Kubczak et al. 2020; Liu et al. 2011; Medveckiene et al. 2020; Milenković-Andjelković et al. 2015; Moldovan et al. 2016; Nađpal et al. 2016; Okan et al. 2019; Ouerghemmi et al. 2016; Natić et al. 2019; Popović et al. 2020; Pozzo et al. 2020; Polumackanycz et al. 2020; Szumny et al. 2015; Veličković et al. 2014; Zhang et al. 2020; Živković et al. 2015). These compounds contribute to antioxidant activity and other health-beneficial properties of fruit extracts as well as extracts obtained from flowers, leaves, twigs, and seeds. Other important secondary metabolites found in selected wild plants are carotenoids, terpenes, terpenic acids, and sterols (Cunja et al. 2016; De Biaggi et al. 2018; Kerasioti et al. 2019; Medveckiene et al. 2020; Ouerghemmi et al. 2016).

Secondary metabolites are substances produced by plants in response to various types of environmental stress and mediate interactions between organisms. Unlike primary metabolites, secondary metabolites are associated with small molecules that are non-essential for the growth and reproduction of the plants, but have a wide range of effects on the plant itself and other living organisms. They cause flowering, fruit set, and shedding; maintain perennial growth or signal deciduous behavior; have a defensive function in protecting plants from pathogens, pests, and herbivores; act as antimicrobial drugs; and act as attractants or as repellents. Over 50,000 secondary metabolites have been discovered in the plant world. The basis for the positive health effects of medicinal plants and many modern medicines lay in secondary herbal metabolites (Pang et al. 2021; Teoh 2016).

Chemical compositions of extracts of different parts of blackthorn, Cornelian cherry, dog rose, and hawthorn plants obtained by various solvents (or solvent mixtures) are presented in Tables 3.1, 3.2, 3.3, and 3.4, respectively.

Chemical structures of most prominent compounds (major compounds and secondary metabolites) isolated from described wild plants are given in Figs. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, and 3.8.

Table 3.1 Chemical composition of blackthorn (*Prunus spinosa* L.)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
Serbia (Belgrade)	Fruit	UHPLC-DAD-ESI-MS/MS	70% methanol	*Phenolic acids* (mg/kg): protocatechuic acid (1.14); vanillic acid (3.17); ellagic acid (1.87) *Flavonoids* (mg/kg): rutin (33.92); quercetin 3-*O*-galactoside (3.30); naringin (1.83); kaempferol 3-*O*-glucoside (6.16)	Natić et al. (2019)
Serbia (Fruška Gora)	Fruit	HPLC	Water	*Phenolic acids* (mg/100 g): 3-caffeoylquinic acid (422.04); 3-*p*-coumaroylquinic acid (9.99); 5-caffeoylquinic acid (4.09) *Flavonols* (mg/100 g): quercetin 3-galactoside (1.82); quercetin 3-glucoside (11.22); quercetin 3-rutinoside (32.85); quercetin (0.20) *Anthocyanins* (mg/100 g): cyanidin 3-glucoside (157.85); cyanidin 3-rutinoside (185.62); peonidin 3-glucoside (17.58); peonidin 3-rutinoside (48.61)	Popović et al. (2020)
Southeast Serbia	Fruit	HPLC-DAD	Ethanol	*Phenolic acids* (mg/L): neochlorogenic acid (12.26); caffeic acid (2.12) *Flavonol* (mg/L): quercetin (4.02) *Anthocyanins* (mg/L): cyanidin-3-*O*-glucoside (1.10); cyanidin-3-*O*-rutinoside (1.10)	Veličković et al. (2014)
			Ethanol/water (1:1)	*Phenolic acids* (mg/L): neochlorogenic acid (16.95); caffeic acid (9.73) *Flavonols* (mg/L): quercetin (3.83) *Flavone* (mg/L): myricetin (8.86) *Anthocyanins* (mg/L): cyanidin-3-*O*-glucoside (0.90); cyanidin-3-*O*-rutinoside (3.10); peonidin-3-*O*-glucoside (1.20)	
			Methanol	*Anthocyanins* (mg/L): cyanidin-3-*O*-glucoside (1.10); cyanidin-3-*O*-rutinoside (1.50); peonidin-3-*O*-glucoside (2.20)	
Portugal	Fruit	HPLC-DAD-ESI/MS	Methanol	*Phenolic acids* (mg/100 g): 3-*O*-caffeoylquinic acid (22.09), 3-*p*-coumaroylquinic acid (0.80), 4-*O*-caffeoylquinic acid (3.41), 3-*O*-feruloylquinic acid (1.76), 4-*p*-coumaroylquinic acid (0.64)	Guimaraes et al. (2013, 2014)

				Flavonols (mg/100 g): quercetin pentosylhexoside (1.36); quercetin rhamnosylhexoside (2.22); quercetin 3-*O*-rutinoside (15.63); quercetin pentosylhexoside (6.83); quercetin 3-*O*-glucoside (1.36); quercetin hexoside (4.70); kaempferol 3-*O*-rutinoside (1.90); isorhamnetin 3-*O*-rutinoside (0.87) *Anthocyanins* (µg/100 g): cyanidin 3-*O*-glucoside (19.83); cyanidin 3-*O*-rutinoside (31.12); peonidin 3-*O*-glucoside (10.73); peonidin 3-*O*-rutinoside (34.47); cyanidin 3-*O*-pentoside (1.49); peonidin 3-*O*-pentoside (0.26); cyanidin 3-*O*-acetylglucoside (1.77); peonidin 3-*O*-acetylglucoside (0.73)	
Spain	Fruit	HPLC-DAD-ESI/MS	Citric acid buffer (pH 2.46)	*Phenolic acids* (mg/100 mL): caffeoyldihydrocaffeoylquinic acid (1.96); 3-*O*-caffeoylquinic acid (31.26); 3-*O*-*p*-coumaroylquinic acid (3.42); 4-*O*-caffeoylquinic acid (4.42); 3-*O*-feruloylquinic acid (1.44) *Flavonols* (mg/100 mL): quercetin 3-*O*-rutinoside (1.11); quercetin 3-*O*-hexoside-5-*O*-pentoside (1.21); quercetin 3-*O*-xyloside (1.52) *Anthocyanins* (mg/100 mL): cyanidin 3-*O*-glucoside (0.70); cyanidin-3-*O*-rutinoside (1.59); peonidin 3-*O*-glucoside (0.24); peonidin 3-*O*-rutinoside (1.18)	Gironés-Vilaplana et al. (2012)
		GC-FID	Methanol/sulfuric acid/toluene (2:1:1)	*Fatty acids* (*predominant*) (%): oleic acid (57.58); linoleic acid (23.57); α-linolenic acid (2.79); palmitic acid (6.50)	Barros et al. (2010)
		HPLC-RI	80% ethanol	*Sugars* (g/100 g): fructose (6.95); glucose (29.84); sucrose (0.27)	
		HPLC	Hexane	*Tocopherols* (mg/100 g): α-tocopherol (7.18); β-tocopherol (0.06); γ-tocopherol (1.91); δ-tocopherol (0.10)	
		Spectrophotometer	1% metaphosphoric acid	*Ascorbic acid* (15.69 mg/100 g)	
		UV/Vis	Acetone/hexane (4:6)	*β-Carotene* (0.78 mg/100 g)	

(continued)

Table 3.1 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
Italy	Fruit	HPLC-DAD	Water	*Phenolic acids* (mg/kg): gallic acid (41.10); 4-hydroxybenzoic acid (73.93); caffeic acid (3.36); *trans p*-coumaric acid (2.99); *trans*-ferulic acid (4.93); *trans*-sinapic acid (37.69); rosmarinic acid (3.23) *Flavonoids* (mg/kg): rutin (183.94); myricetin (1.47); quercetin (9.94); genistin (1.74)	Pozzo et al. (2020)
Croatia	Flower	UPLC-MS^2	Ethanol (ultrasound-assisted)	*Phenolic acids* (mg/100 g): gallic acid (1.75); *3*-O-caffeoylquinic acid (192.00); 3-*p*-coumaroylquinic acid (216.28); chlorogenic acid (55.47); feruloylquinic acid (132.20); caffeic acid (34.32); 4-*p*-coumaroylquinic acid (61.53); ferulic acid (8.69) *Flavonoids* (mg/100 g): catechin (85.67); epicatechin (70.16); kaempferol rhamnosylhexoside (49.79); quercetin-pentosyl-hexoside (56.81); quercetin-3-rutinoside (82.35); quercetin-3-glucoside (31.29); quercetin-pentoside (226.75); kaempferol-3-rutinoside (51.84); kaempferol-pentosylhexoside (50.27); kaempferol-pentoside (494.94); quercetin-rhamnoside (81.15); kaempferol-rhamnoside (436.62); quercetin-acetylhexoside (2.34); kaempferol-acetylhexoside (0.92); luteolin (6.68); apigenin-pentoside (3.23) *Procyanidins* (mg/100 g): procyanidin B1 (70.21)	Garofulić et al. (2018)
Romania	Fruit	GC-FID	Chloroform/methanol (2: 1)	*Fatty acids* (%): oleic acid (57.4); linoleic acid (23.4); α-linolenic acid (2.62)	Babalau-Fuss et al. (2018)
Poland	Fruit	UV/Vis	Methanol	*β-Carotene* (0.04 mg/100 g) *Vitamin C* (23.84 mg/100 g)	Sikora et al. (2013)

Table 3.2 Chemical composition of Cornelian cherry (*Cornus mas*)

Country of origin	Plant part	Analytical technique	Type of extract	Compounds	References
Serbia (Fruška Gora)	Fruit	UHPLC-DAD-ESI-MS/MS	70% methanol	*Phenolic acids* (mg/kg): gallic acid (6.56); protocatechuic acid (0.83); *O*-caffeoylquinic acid (16.17); caffeic acid (0.85); syringic acid (1.11); *p*-coumaric acid (0.88); ellagic acid (15.17); ferulic acid (0.18) *Flavonoids* (mg/kg): rutin (10.62); quercetin 3-*O*-galactoside (1.81); naringin (0.27); phlorizin (1.16)	Natić et al. (2019)
Southeast Serbia	Fruit	HPLC-DAD	Methanol/acetone/water/formic acid	*Phenolic acids* (mg/g): gallic acid (0.62); ellagic acid (2.11); chlorogenic acid (0.85) *Flavonoids* (mg/g): quercetin-3-glucoside (0.20); quercetin-3-galactoside (0.57); rutin (0.81); kaempferol-3-glucoside (1.11); catechin (3.91); epicatechin (2.11) *Procyanidins* (mg/g): procyanidin B2 (1.55) *Anthocyanins* (mg/g): cyanidin 3-galactoside (3.27); pelargonidin 3-glucoside (10.23); delphinidin-3-galactoside (0.53)	Milenković-Andjelković et al. (2015)
	Leaf			*Phenolic acids* (mg/g): gallic acid (0.37); ellagic acid (2.62); chlorogenic acid (0.33) *Flavonoids* (mg/g): quercetin-3-glucoside (9.37); rutin (6.09); luteolin-3-glucoside (0.15); kaempferol-3-glucoside (4.37); catechin (2.28); epicatechin (4.15)	
Western Serbia	Fruit	LC-MS/MS	70% methanol	*Phenolic acids* (µg/g): neochlorogenic acid (37.64) *Flavonoids* (µg/g): quercetin 3-*O*-glucuronide (151.82); quercetin 3-*O*-galactoside (13.55); quercetin 3-*O*-glucoside (7.42); quercetin 3-*O*-rutinoside (9.12); quercetin 3-*O*-rhamnoside (0.23)	Bajić-Ljubičić et al. (2018)
Poland	Fruit	UPLC-MS/MS	80% ethanol	*Phenolic acids* (mg/g): 3-*O*-caffeoylquinic acid (3.47); 5-*O*-caffeoylquinic acid (10.89) *Flavonoids* (mg/g): quercetin 3-*O*-glucuronide (4.86); kaempferol 3-*O*-galactoside (4.03) *Anthocyanins* (mg/g): delphinidin 3-*O*-galactoside (0.63); cyanidin 3-*O*-galactoside (15.79); cyanidin 3-*O*-robinobioside	Szumny et al. (2015)

(continued)

Table 3.2 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compounds	References
				(6.38); pelargonidin 3-*O*-galactoside (29.94); pelargonidin 3-*O*-robinobioside (5.95)	
Italy	Fruit	HPLC		*Phenolic acids* (mg/100 g): gallic acid (0.05); ellagic acid (23.56); caffeic acid (0.66); chlorogenic acid (11.27); coumaric acid (3.86); ferulic acid (2.14) *Flavonoids* (mg/100 g): hyperoside (1.00); rutin (0.29); catechin (14.38); epicatechin (21.74) *Tannins* (mg/100 g): vescalagin (4.66) *Organic acids* (mg/100 g): citric acid (58.24); malic acid (48.59); oxalic acid (2.11); succinic acid (2.67); tartaric acid (40.35) *Monoterpenes* (mg/100 g): limonene (115.63); phellandrene (18.49); γ-terpinene (18.44); terpinolene (1.42) *Vitamin C* (mg/100 g): ascorbic acid (41.98); dehydroascorbic acid (19.44)	De Biaggi et al. (2018)
Romania	Fruit	HPLC	Acetone	*Phenolic acids* (mg/100 g): ellagic acid (187.91); caffeic acid (27.12); chlorogenic acid (32.76) *Flavonoids* (mg/100 g): quercetin-3-*O*-glucuronide (471.01); kaempferol-3-*O*-galactoside (366.88); catechin (37.06); epicatechin (66.89) *Anthocyanins* (mg/100 g): cyanidin-3-*O*-galactoside (3.82); pelargonidin-3-*O*-glucoside (58.62); pelargonidin-3-*O*-rutinoside (33.8)	Moldovan et al. (2016)
Turkey	Fruit	HPLC	Methanol	*Phenolic acids* (μg/g): gallic acid (12.60); protocatechuic acid (9.88); chlorogenic acid (0.81); ferulic acid (0.92) *Flavonols* (μg/g): quercetin (3.34)	Okan et al. (2019)
			80% ethanol	*Sugars* (%): fructose (2.00); glucose (2.50); sucrose (0.57)	

Table 3.3 Chemical composition of dog rose (*Rosa canina* L.)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
Northern Serbia	Fruit	LC-MS/MS	Water	*Phenolic acids* (μg/g): gallic acid (11.3); protocatechuic acid (9.79) *Flavonoids* (μg/g): quercitrin (40.4); quercetin-3-*O*-glucoside (2.54); hyperoside (2.53); epicatechin (2.35); catechin (7.83)	Nađpal et al. (2016)
		UV/Vis		*Vitamin C*: 1.96 mg/g	
		LC-MS/MS	Methanol	*Phenolic acids* (μg/g): gallic acid (1.86); protocatechuic acid (8.04); *p*-coumaric acid (1.53) *Flavonoids* (μg/g): kaempferol-3-*O*-glucoside (1.77); quercitrin (95.2); quercetin-3-*O*-glucoside (9.40); hyperoside (7.73); epicatechin (2.92); catechin (4.23)	
		UV/Vis		*Vitamin C*: 1.87 mg/g	
Serbia	Seed	ICP-OES		*Major and trace elements* (mg/kg): Mg (848–1072); Ca (3236–3567); K (2494–3481); Ba (4.86–5.26); Cu (4.16–5.37); Fe (15.87–19.30); Mn (17.76–31.97); P (1178–2184); S (567–959); Zn (0.36–3.53)	Popović-Djordjević et al. (2021)
	Mesocarp			*Major and trace elements* (mg/kg): Mg (675–1670); Ca (2310–5042); K (8750–8953); Ba (4.35–9.60); Cu (0.75–1.60); Fe (3.03–3.90); Mn (25.50–34.67); P (731–872); S (279–427); Zn (0.85–1.10)	
Southern Serbia	Leaf	HPLC-DAD	Methanol	*Flavonoids* (μg/g): rutin (343.81); hyperside (585.24); isoquercetin (1022.95); isorhamnetin-3-*O*-rutinoside (1568.34)	Živković et al. (2015)
Serbia	Seed	GC	*n*-Hexane	*Fatty acids* (%): linoleic acid (51.1–53.4); oleic acid (18.4–19.6); α-linolenic acid (19.4–20.8); palmitic acid (2.6–4.9); arachidic acid (1.1–1.5)	Milić et al. (2020)
Western Serbia	Seed	GC-FID	*n*-Heptane	*Fatty acids* (%): linoleic acid (35.4); arachidic acid (28.2); palmitoleic acid (18.2); *cis*-8,11,14-eicosatrienoic acid (23.1); *cis*-11,14,17-eicosatrienoic acid (14.7); arachidonic acid (13.2); heneicosylic acid (21.4)	Vasić et al. (2020)

(continued)

Table 3.3 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
Slovenia	Fruit	HPLC-MS	Methanol (with 3% formic acid)	*Phenolic acids* (μg/g): ellagic acid derivatives (50.6); total hydroxybenzoic acids (499); hydroxycinnamic acids (195) *Flavanols* (μg/g): catechin and derivatives (1111) *Flavonols* (μg/g): isorhamnetin glycosides (11.1); kaempferol derivatives (3.07); quercetin glycosides (68.0) *Flavanones* (μg/g): eriodictyol derivatives (77.7); naringenin derivatives (98.9); taxifolin derivatives (177) *Anthocyanins* (μg/g): cyanidin glucoside (83.0)	Cunja et al. (2016)
		HPLC	Water	*Sugars* (mg/100 g): glucose (20.5); fructose (20.8); sucrose (5.14) *Organic acids* (mg/100 g): citric acid (11.6); quinic acid (1.49); malic acid (10.3); tartaric acid (341); shikimic acid (8.50); fumaric acid (9.41)	
			2% metaphosphoric acid	*Ascorbic acid:* 1835 mg/100 g	
		HPLC-MS	Acetone	*Carotenoids* (μg/g): β-carotene (2126); lycopene (1550)	
Tunisia	Leaf	HPLC-DAD	Ethyl acetate	*Flavonoids* (mg/100 mg): catechin (0.07); epicatechin gallate (0.17); rutin (0.02); quercetin 3-*O*-glucoside (0.67); kaempferol *O*-hexoside-deoxyhexoside (0.60); kaempferol 3-*O*-rutinoside (0.03); kaempferol 7-*O*-glucoside (0.02); kaempferol 3-*O*-glucoside (0.14)	Ouerghemmi et al. (2016)
			Methanol	*Flavonoids* (mg/100 mg): catechin (0.33); quercetin di-*O*-hexoside (0.17); epicatechin gallate (0.46); epicatechin (0.46); rutin (0.15); quercetin 3-*O*-glucoside (2.27); kaempferol *O*-hexoside-deoxyhexoside (0.83); kaempferol 3-*O*-rutinoside (0.11); kaempferol 7-*O*-glucoside (0.12); kaempferol 3-*O*-glucoside (0.28); quercitrin (0.10)	
Iran	Fruit	HPLC	80% methanol	*Phenolic acids* (μg/g): *p*-coumaric acid (11.7); cinnamic acid (8.3); chlorogenic acid (5.7 ± 0.02); caffeic acid (13.1); gallic acid (81.3) *Flavonoids* (μg/g): apigenin (2.7); quercetin (1.1); rutin (19.6)	Shameh et al. (2019)

		UV/Vis	Acetone	*β-Carotene*: 9.1 μg/g	
		UV/Vis	1% metaphosphoric acid	*Vitamin C*: 62.90 mg/g	
Kazakhstan	Leaf	HPLC	Ethanol/water (1:1)	*Phenolic acids* (mg/g): gallic acid (0.805); α-resorcylic acid (0.138); protocatechuic acid 0.153); neochlorogenic acid (57.148); 4-hydroxybenzoic acid (1.182); gentisic acid (1.577); chlorogenic acid (4.609); vanillic acid (0.102); caffeic acid (0.035); syringic acid (0.613); *p*-coumaric acid (0.520); ferulic acid (0.439); sinapic acid (0.214); ellagic acid (35.881); *o*-coumaric acid (0.711); rosmarinic acid (4.406); salicylic acid (0.457) *Flavonols* (mg/g): epigallocatechin (0.207); catechin (2.804); epicatechin (1.822); rutin (26.66); myricetin (3.928); quercetin (0.156) *Flavone* (mg/g): coumarin (1.285); luteolin 7-*O*-β-D-glucoside (1.614); hesperidin (4.013); luteolin (0.911); kaempferol (0.148); 3-hydroxyflavone (0.103) *Anthocyanins* (mg/g): cyanidin (47.448) *Vitamins* (mg/g): B1 (1.12); B2 (0.48); B3 (2.10); B5 (3.30); B6 (5.70); Bc (0.97); α-tocopherol (0.54); β-tocopherol (0.13); γ-tocopherol (0.18) *Amino acids* (mg/g): arginine (4.979); lysine (3.378); tyrosine (3.023); phenylalanine (6.045); histidine (0.960); leucine + isoleucine (6.900); methionine (1.494); valine (0.460); proline (10.491); threonine (4.445); serine (4.801); alanine (5.334); glycine (4.801)	Kubczak et al. (2020)
	Twig	HPLC	Ethanol/water (1:1)	*Phenolic acids* (mg/g): gallic acid (0.357); α-resorcylic acid (0.117); protocatechuic acid (13.911); neochlorogenic acid (0.258); 4-hydroxybenzoic acid (0.323); gentisic acid (0.340); chlorogenic acid (0.934); vanillic acid (0.379); caffeic acid (0.203); syringic acid (0.134); *p*-coumaric acid (0.247); ferulic acid (0.081); sinapic acid (0.140); ellagic acid (14.448); *o*-coumaric acid (0.149); rosmarinic acid (1.851); salicylic acid (0.474) *Flavonols* (mg/g): epigallocatechin (1.680); catechin (17.798);	

(continued)

Table 3.3 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
				epicatechin (1.379); rutin (4.431); myricetin (7.175); quercetin (0.241) *Flavones* (mg/g): coumarin (0.170); luteolin 7-*O*-β-D-glucoside (1.417); naringenin (0.633); luteolin (0.364); kaempferol (0.167); 3-hydroxyflavone (0.128) *Anthocyanins* (mg/g): cyanidin (4.453) *Vitamins* (mg/g): B1 (0.77); B2 (0.51); B3 (2.70); B5 (3.10); B6 (6.20 ± 0.10); Bc (0.86); α-tocopherol (0.31); β-tocopherol (0.15); γ-tocopherol (0.09) Amino acids (mg/g): lysine (1.426); tyrosine (0.713); phenylalanine (2.262); histidine (0.565); leucine + isoleucine (1.819); methionine (0.787); valine (0.713); proline (3.196); threonine (1.770); serine (2.040); alanine (1.573)	
Lithuania	Fruit	HPLC	Methanol	*Phenolic acids* (mg/100 g): gallic acid (22.67); chlorogenic acid (9.80); caffeic acid (22.08); *p*-coumaric acid (48.22); ferulic acid (19.03) *Flavonoids* (mg/100 g): rutin (11.62); kaempferol-3-*O*-glucoside (4.40); luteolin (7.46); quercetin (9.77); quercetin-3-*O*-glucoside (2.35)	Medveckiene et al. (2020)
			n-Hexane	*Carotenoids* (mg/100 g): β-carotene (3.95); α-carotene (0.80); lutein (1.55); zeaxanthin (0.23); *cis*-lycopene (0.55); *trans*-lycopene (1.59)	
		Titration		*Ascorbic acid*: 385.82 mg/100 g	
	Seed	HPLC	Methanol	*Phenolic acids* (mg/100 g): gallic acid (88.69); chlorogenic acid (45.83); caffeic acid (12.73); *p*-coumaric acid (22.04); ferulic acid (4.83) *Flavonoids* (mg/100 g): rutin (19.11); kaempferol-3-*O*-glucoside (5.29); luteolin (1.89); quercetin (2.87); quercetin-3-*O*-glucoside (3.02)	

			n-Hexane	*Carotenoids* (mg/100 g): β-carotene (0.58); zeaxanthin (0.21); *cis*-lycopene (0.13); *trans*-lycopene (0.24)	
		Titration		*Ascorbic acid*: 22.99 mg/100 g	
Spain	Fruit	HPLC	Acetone/water (4:1)	*Phenolic acids* (mg/g): vanillic acid (0.26); caffeic acid (0.002); syringic (0.11); gallic acid (0.298); ellagic acid (0.080); protocatechuic acid (0.21) *Flavonoids* (mg/g): myricetin (5.4); rutin (22); catechin (11.9); quercetin (1.5) *Vitamin C*: 101 μg/g	Jiménez et al. (2017)
Portugal	Fruit	HPLC-DAD-ESI/MS	Methanol/water (4:1)	*Flavone/flavonols* (mg/100 g): quercetin glucuronide 0.24); quercetin rhamnoside (0.46); quercetin 3-*O*-rutinoside (0.47); taxifolin pentoside (1.18); eriodictyol hexoside (0.50) *Flavans* (mg/100 g): catechin (3.59) *Procyanidins* (mg/100 g): procyanidin dimer B1 (1.68); procyanidin dimer B3 (1.50) *Anthocyanins* (mg/100 g): cyanidin 3-*O*-glucoside (0.68)	Guimaraes et al. (2013)
Greece	Fruit	UPLC-MS-MS	Methanol	*Phenolic acids* (μg/g): gallic acid (2.12); protocatechuic acid (2.09); *p*-coumaric acid (2.44) *Flavonoids* (μg/g): catechin (134.75); epicatechin (120.99); hyperoside (308.11); rutin (25.64); astragalin (172.48); phloridzin (3.41); quercetin (0.67); kaempferol (0.46) *Organic acids* (μg/g): quinic acid (1102.59 ± 38.91) *Triterpenoids* (μg/g): betulinic acid (0.47); ursolic acid (138.23)	Kerasioti et al. (2019)
Poland	Fruit	LC-DAD/ESI/MS	Water	*Phenolic acids* (μg/g): gallic acid (2.08); protocatechuic acid (1.07); vanillic acid (2.35); chlorogenic acid (1.45); syringic acid (1.11); *p*-coumaric acid (9.05); ferulic acid (0.93); sinapic acid (1.54); rosmarinic acid (0.62); cinnamic acid (9.53) *Flavonoids* (μg/g): rutin (3.04); quercetin (7.64)	Polumackanycz et al. (2020)
			Methanol/water (4:1)	*Phenolic acids* (μg/g): gallic acid (8.77); protocatechuic acid (2.60); vanillic acid (0.08); chlorogenic acid (0.16); cinnamic acid (0.11) *Flavonoids* (μg/g): rutin (0.33); quercetin (0.18)	

(continued)

Table 3.3 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compound(s)	References
	Leaf		Water	*Phenolic acids* (µg/g): gallic acid (7.65); protocatechuic acid (5.52); vanillic acid (2.58); chlorogenic acid (9.52); syringic acid (6.75); *p*-coumaric acid (3.56); ferulic acid (1.46); sinapic acid (2.51); rosmarinic acid (0.65); cinnamic acid (10.53 ± 1.65) *Flavonoids* (mg/g): rutin (5.68); quercetin (6.82)	
			Methanol/water (4:1)	*Phenolic acids* (µg/g): gallic acid (8.92); vanillic acid (9.61); chlorogenic acid (4.74); cinnamic acid (9.03) *Flavonoids* (mg/g): rutin (3.13); quercetin (0.63)	
Turkey	Seed	UV/Vis	2% metaphosphoric acid	*Vitamin C*: 1793 µg/g	Ilyasoğlu (2014)
		GC	Chloroform	*Fatty acids* (%): palmitic (3.34); stearic (1.69); oleic (19.50); linoleic (54.05); α-linolenic (19.37); arachidic (1.00) *Sterols* (mg/100 g): campesterol (23.3); stigmasterol (18.9); clerosterol (1.4); β-sitosterol (544); 5-avenasterol (31.6); 7-stigmastenol (41.1); 7-avenasterol (1.9)	

Table 3.4 Chemical composition of hawthorn (*Crataegus monogyna*)

Country of origin	Plant part	Analytical technique	Type of extract	Compounds	References
Serbia (Belgrade)	Fruit	UHPLC-DAD-ESI-MS/MS	70% methanol	*Phenolic acids* mg/kg): protocatechuic acid (0.78); *p*-hydroxybenzoic acid (1.56); 5-*O*-caffeoylquinic acid (4.36); caffeic acid (1.35); vanillic acid (6.66); *p*-coumaric acid (0.56); ellagic acid (2.49); ferulic acid (0.52) *Flavonoids* (mg/kg): rutin (30.92); quercetin 3-*O*-galactoside (77.31); phlorizin (0.32); kaempferol (0.59); aesculin (3.79)	Natić et al. (2019)
Western Serbia				*Phenolic acids* (mg/kg): 5-*O*-caffeoylquinic acid (20.71); caffeic acid (0.61); *p*-coumaric acid (0.14); ellagic acid (0.63); ferulic acid (0.11) *Flavonoids* (mg/kg): arbutin (12.28); catechin (3.29); rutin (66.54); quercetin 3-*O*-galactoside (117.35); naringin (0.41); kaempferol 3-*O*-glucoside (29.49); phlorizin (3.91); kaempferol (0.25); aesculin (14.69)	Natić et al. (2019)
Poland	Fruit	HPLC-ESI-Q-TOF-MS and HRMS/MS	Ethanol/water (1:1)	*Phenolic acids* (mg/g): protocatechuic acid (0.035); chlorogenic acid (0.326); sinapinic acid (0.363) *Flavonoids* (mg/g): quercetin (0.4907); quercitrin (0.0385); rutin (0.368); quercetin 3-galactoside (0.6428) *Anthocyanin* (mg/g): cyanidin-3-glucoside (0.5357)	Bekbolatova et al. (2018)
			96% ethanol	*Phenolic acids* (mg/g): sinapinic acid (0.1208); chlorogenic acid (0.279); *p*-coumaric acid (0.022); *m*-coumaric acid (0.0229); *o*-coumaric acid (0.018) *Flavonoids* (mg/g): quercetin (0.392); quercitrin (0.0451); rutin (0.103); quercetin 3-galactoside (0.1709) *Anthocyanins* (mg/g): cyanidin-3-glucoside (0.721)	
	Flower		Ethanol/water (1:1)	*Phenolic acids* (mg/g): gentisic acid (0.086); sinapinic acid (0.057); chlorogenic acid (1.496); *p*-coumaric acid (0.0359); *o*-coumaric acid (0.027); caffeic acid 3-glucoside (0.0046) *Flavonoids* (mg/g): quercetin (0.572); quercitrin (0.5117); rutin (0.73); quercetin 3-galactoside (3.712)	

(continued)

Table 3.4 (continued)

Country of origin	Plant part	Analytical technique	Type of extract	Compounds	References
			96% ethanol	*Phenolic acids* (mg/g): gentisic acid (0.095); chlorogenic acid (0.749); *p*-coumaric acid (0.044); *m*-coumaric acid (0.0399); *o*-coumaric acid (0.031); caffeic acid 3-glucoside (0.0011), caffeic acid (0.0076) *Flavonoids* (mg/g): quercetin (0.1234); quercitrin (0.26); rutin (0.563); quercetin 3-galactoside (0.105) *Anthocyanins* (mg/g): cyanidin-3-glucoside (0.0052)	
	Leaf		Ethanol/water (1:1)	*Phenolic acids* (mg/g): gentisic acid (0.0422); chlorogenic acid (0.479); protocatechuic acid (0.0126); *m*-coumaric acid (0.0139); *o*-coumaric acid (0.01) *Flavonoids* (mg/g): quercetin (1.094); quercitrin (0.83); epigallocatechin (0.0006); rutin (0.427); quercetin 3-galactoside (2.671) *Anthocyanins* (mg/g): cyanidin-3-glucoside (0.0026)	
			96% ethanol	*Phenolic acids* (mg/g): sinapinic acid (0.0389); chlorogenic acid (0.6087) *Flavonoids* (mg/g): quercetin (0.2024); quercitrin (0.1603); catechin (0.0036); epigallocatechin (0.0009); rutin (0.372); quercetin 3-galactoside (1.6328)	
China	Fruit	HPLC	Methanol	*Phenolic acids* (mg/100 g): chlorogenic acid (84.2); *p*-coumaric acid (24.9) *Flavonoids* (mg/100 g): catechin (27.1); epicatechin (281.6); quercetin (78.4); isoquercitrin (9.6) *Procyanidins* (mg/100 g): procyanidin B2 (243.5)	Zhang et al. (2020)
Iran	Fruit	HPLC	Methanol/ water (4:1)	*Phenolic acids* (mg/g): chlorogenic acid (0.40) *Flavonoids* (mg/g): vitexin (0.18); hyperoside (1.15); isoquercetin (0.68); quercetin (0.05)	Alirezalu et al. (2020)

Finland	Fruit	HPLC-DAD-ESI-MS	Methanol	*Phenolic acids*: chlorogenic acid; neochlorogenic acid *Procyanidins*: procyanidin B2; procyanidin B5 *Flavonols*: hyperoside; quercetin-pentosides; quercetin-hexoside acetate; quercetin-rhamnosylhexoside; epicatechin *Flavones*: luteolin-*C*-hexoside; methyl luteolin-*C*-hexoside	Liu et al. (2011)
	Leaf			*Phenolic acid*: chlorogenic acid *Procyanidins*: procyanidin B2; procyanidin B5 *Flavonols*: hyperoside; quercetin-pentosides; quercetin-hexoside acetate; quercetin-rhamnosylhexoside; epicatechin *Flavones*: luteolin-*C*-hexoside; methyl luteolin-*C*-hexoside	
Turkey	Seed	GC-MS	Hexane	*Fatty acids* (%): palmitic (5.61–6.76); palmitoleic (0.07–0.13); stearic (1.43–1.91); oleic (33.48–39.36); linoleic (50.53–52.51); γ-linolenic (1.26–1.47); eicosenoic (0.40–0.45); tricosanoic (0.64–0.89); docosadienoic (0.25–0.29)	Özderin et al. (2016)

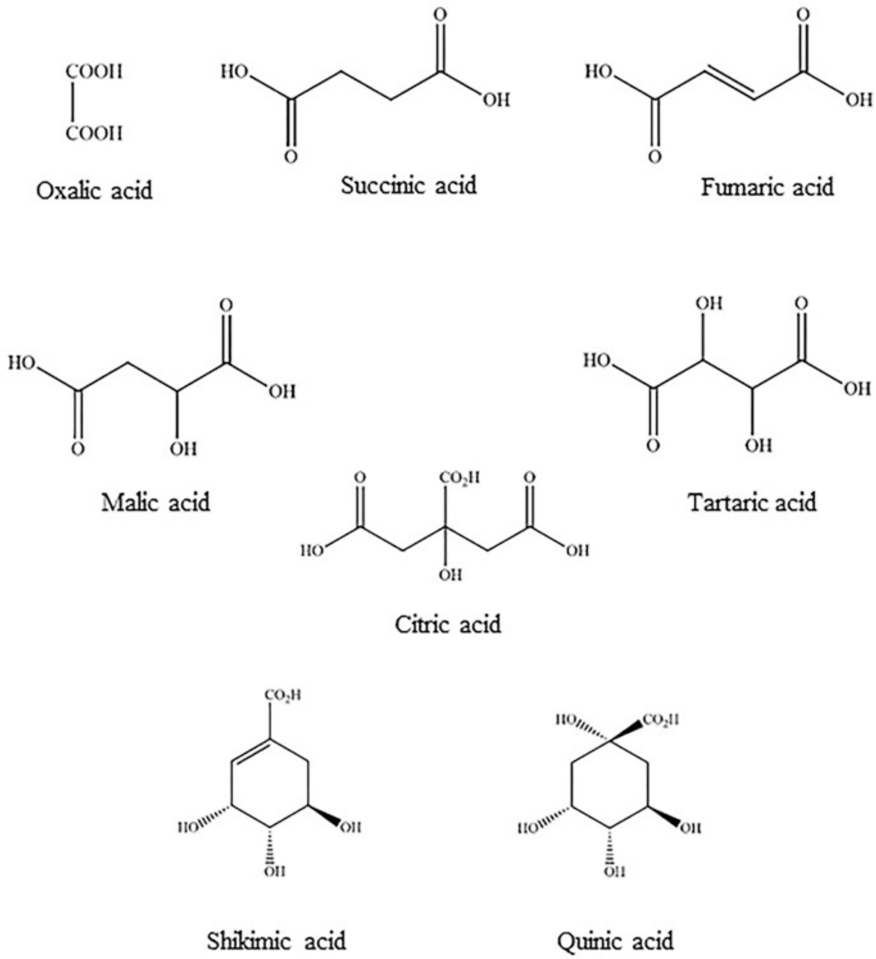


Fig. 3.1 Chemical structures of organic acids isolated from selected wild plants

3.4 Biological Activity and Medicinal Application of Selected Plants

Blackthorn (*Prunus spinosa* L.) is used in the traditional medicine of many European countries, and it is native in West Asia and Northwest Africa as well (Marchelak et al. 2017). In Europe and Near East countries, the blackthorn fruits have been used since prehistoric times (Balta et al. 2020). Blackthorn fruits, despite their pungent acid taste, were dominantly used as phytotherapeutics in the treatment of diseases of the circulatory system, based on their anti-inflammatory, diuretic, laxative, and astringent characteristics, but also for curing coughs (Marchelak et al.

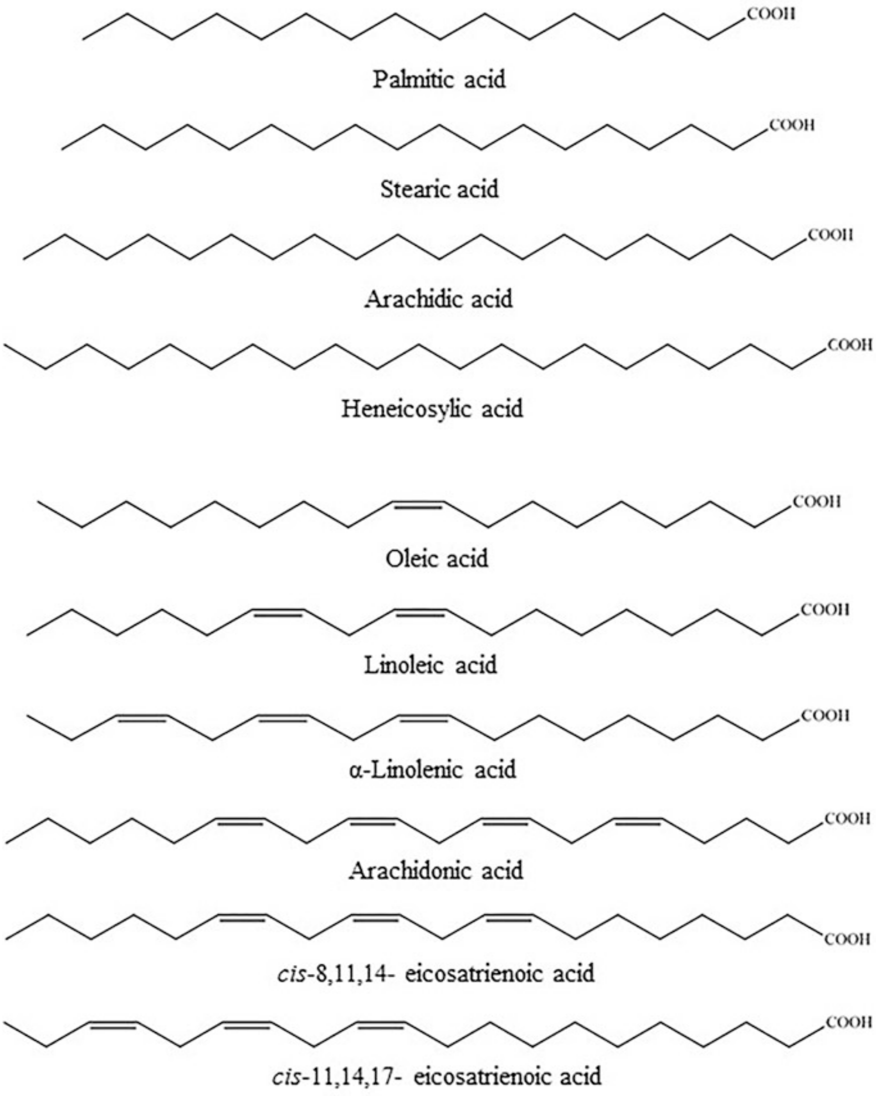


Fig. 3.2 Chemical structures of the most represented saturated and unsaturated fatty acids (FAs) of selected wild plants

2017; Sabatini et al. 2020). Fruits also possess heart-strengthening properties and are used in the treatment of myocarditis, cardiac neurosis, and atherosclerosis (Jarić et al. 2015).

The other parts of the plant (e.g., roots, flowers, and laxative and bark) have similar effects (laxative and diuretic) (Balta et al. 2020). Flowers showed many beneficial properties, such as detoxifying, anti-inflammatory, vasoprotective, and

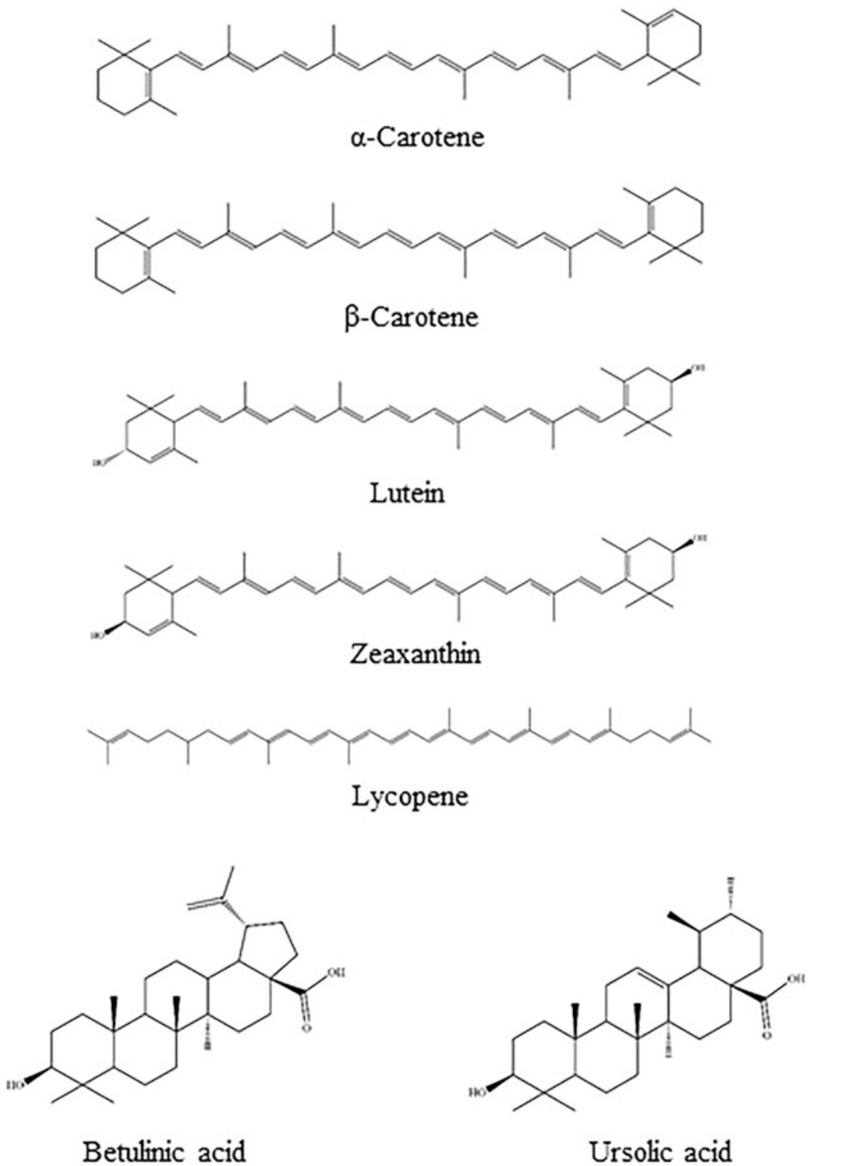


Fig. 3.3 Chemical structures of carotenoids and triterpenoid acids (betulinic and ursolic) isolated from selected wild plants

spasmolytic actions, and may be used for various disorders of the respiratory tract and intestinal problems, but also in the treatment of cardiovascular diseases (Marchelak et al. 2021).

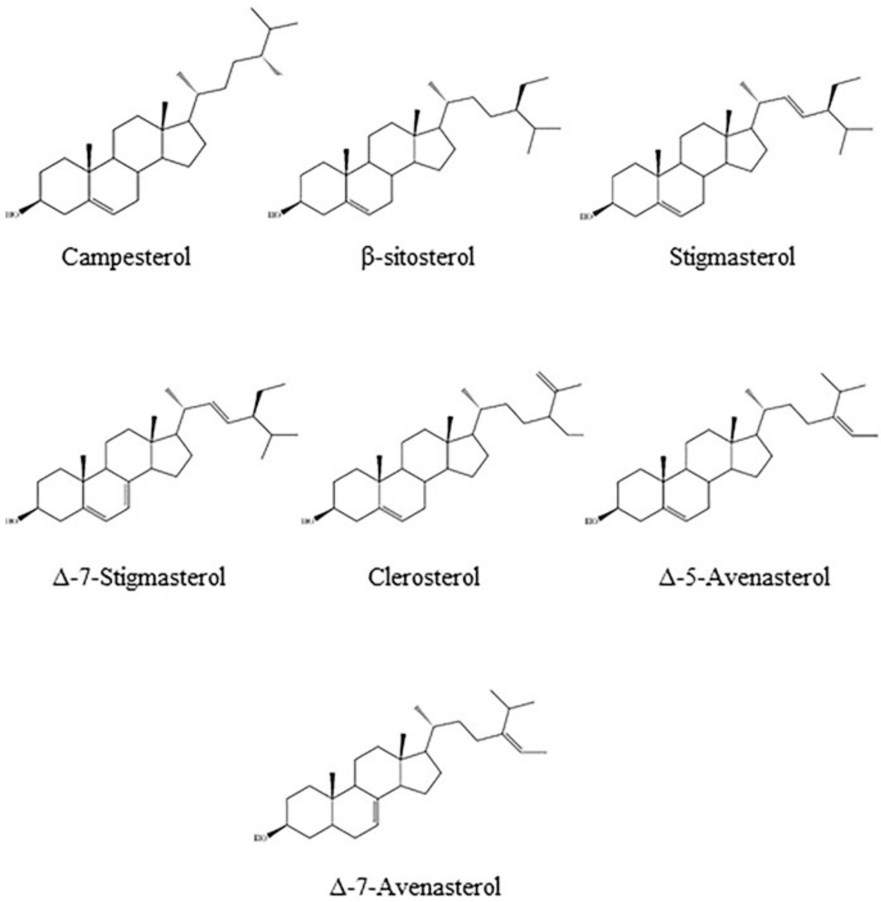
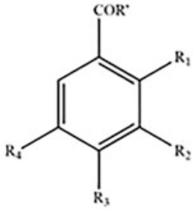


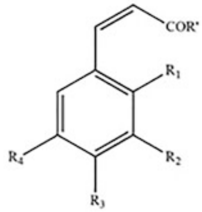
Fig. 3.4 Chemical structures of phytosterols isolated from selected wild plants

Although the astringent *P. spinosa* fruits have many benefits for human health, their consumption is limited to the prepared product such as teas, juices, wines, liqueurs, jams, and compote, because heat treatment contributes to the richness of taste (Balta et al. 2020; Sabatini et al. 2020).

Main compounds that are associated with blackthorn pharmacological potential are several classes of polyphenols – anthocyanins, A-type proanthocyanidins, tannins, flavonoids, and phenolic acids (Marchelak et al. 2017). All these phytochemicals are well-known for their significant activities in terms of antioxidant defense, anti-inflammatory, and antimicrobial effects (Katanić et al. 2015a, 2016), and many compounds, including anthocyanins, showed excellent cardioprotective properties (Di Lorenzo et al. 2021; Najjar and Feresin 2021; Verediano et al. 2021). Various biological activities of many plants from Rosaceae family containing anthocyanins, hydroxycinnamic acids, flavonoids, and tannins are well-known, not just the species



Benzoic dervatives



Cinnamic derivatives

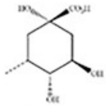
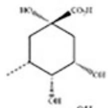
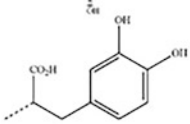
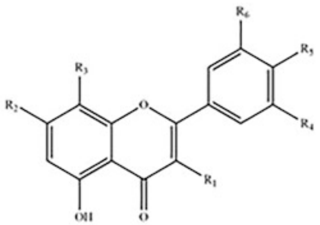
Benzoic dervatives	R'	R_1	R_2	R_3	R_4	Cinnamic derivatives
Benzoic acid	OH	H	H	H	H	Cinnamic acid
p-hydroxybenzoic	OH	H	H	OH	H	*p*-Coumaric acid
Salicylic acid	OH	OH	H	H	H	*o*-Coumaric acid
α-Resorcylic acid	OH	H	OH	H	H	*m*-Coumaric acid
Protocatechuic acid	OH	H	OH	OH	H	Caffeic acid
Gentisic acid	OH	OH	H	H	H	
Gallic acid	OH	H	OH	OH	OH	
Vanillic acid	OH	H	OCH_3	OH	H	Ferulic acid
Syringic acid	OH	H	OCH_3	OH	OCH_3	Sinapic acid
Gentisic acid	OH	OH	H	H	OH	
		H	OH	OH	H	Chlorogenic acid
		H	OH	OH	H	Neochlorogenic acid
		H	OH	OH	H	Rosmarinic acid

Fig. 3.5 Chemical structures of most represented phenolic acids in selected wild plants

with edible fruits (Mihailović et al. 2018, 2019) but also the aerial parts, flowers, and roots of herbaceous Rosaceae plants (Katanić et al. 2015a, b; Boroja et al. 2018).

The antioxidant activity of blackthorn fruits was assessed in vitro by many research groups in the last decade, starting with Barros et al. (2010), who showed significant amount of tocopherols and vitamin C in blackthorn fruit extract, but also interesting free radical scavenging properties, especially in terms of lipid peroxidation inhibition. This was also confirmed by Morales et al. (2013). The antioxidant action of aqueous *P. spinosa* fruit extract toward DPPH radical was shown by Gegiu et al. (2020) as well as by Sabatini et al. (2020) who demonstrated concentration-dependent antioxidant potential as well as antimicrobial and anti-inflammatory



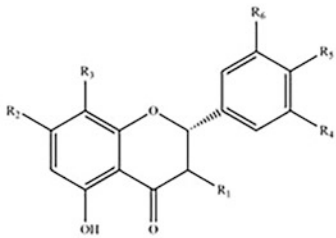
Flavonols and flavones

Compound	R1	R2	R3	R4	R5	R6
Kaempferol	OH	OH	H	H	OH	H
Kaempferol-3-*O*-glucoside	*O*-β-Glu	OH	H	H	OH	H
Kaempferol-7-*O*-glucoside	OH	*O*-β-Glu	H	H	OH	H
Kaempferol-3-*O*-rhamnoside	*O*-α-Rha	OH	H	H	OH	H
Quercetin	OH	OH	H	H	OH	OH
Quercetin-3-*O*-glucoside	*O*-β-Glu	OH	H	H	OH	OH
Quercetin-7-*O*-glucoside	OH	*O*-β-Glu	H	H	OH	OH
Quercetin-3-*O*-rhamnoside	*O*-α-Rha	OH	H	H	OH	OH
Apigenin	H	OH	H	H	OH	H
Myricetin	OH	OH	H	OH	OH	OH
Hyperside	*O*-β-Gal	OH	H	OH	OH	H
Vitexin	H	OH	*O*-β-Glu	H	OH	H
Luteolin	H	OH	H	H	OH	OH
Rutin	*O*-β-Glu-(6→1)-α-Rha	OH	H	OH	OH	H

Fig. 3.6 Chemical structures of flavonoids (flavonols and flavones) isolated from selected wild plants

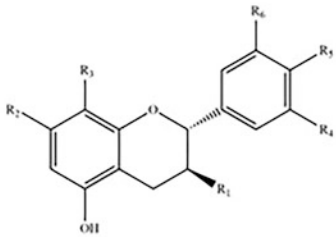
properties. The antimicrobial effects of *P. spinosa* fruit from Italy showed antibacterial potential against both Gram+ and Gram− bacteria, e.g., *E. coli*, *S. typhimurium*, *E. aerogenes*, *E. faecalis*, and *S. aureus* (Pozzo et al. 2020), along with in vitro antioxidant properties and against in vivo streptozotocin-induced oxidative stress in liver and brain tissues.

Many Serbian authors confirmed antioxidant properties of blackthorn fruit, predominantly used in Serbia as an infusion or alcoholic extract in the treatment of heart problems and for reducing high blood cholesterol and triglyceride levels (Šavikin et al. 2013). Mitic et al. (2014) reported high antioxidant potential of blackthorn extract in FRAP, DPPH, and ABTS assays compared with blackberries, raspberries, and cherries from southern Serbia, which correlated with the content of anthocyanins. Blackthorn fruits from the region of Southeast Serbia were also tested for antioxidant activity as well as antimicrobial potential toward *E. coli*, *P. aeruginosa*, *S. aureus*, and *C. albicans* (Veličković et al. 2014). Blackthorn fruits from Central Serbia showed a high antioxidant potential in DPPH and nitric oxide scavenging activity, ferro-chelating capacity, and ferric-reducing capacity assays (Natić et al. 2019). The study of ultrasonic blackthorn fruit extracts showed that 45% propylene glycol extract had the highest antioxidant activity against DPPH radicals, nitric oxide radical scavenging, and non-site-specific hydroxyl radical scavenging activity, along with tyrosinase inhibitory potential (Stanković et al. 2019). *P. spinosa* fruit extracts



Flavanones

Compound	R_1	R_2	R_3	R_4	R_5	R_6
Epicatechin	OH	OH	H	H	OH	OH
Naringenin	H	OH	H	H	OH	H
Taxifolin	OH	OH	H	H	OH	OH
Hesperidin	H	*O*-α-Rha-(1→6)-β-Glu	H	H	OCH_3	OH



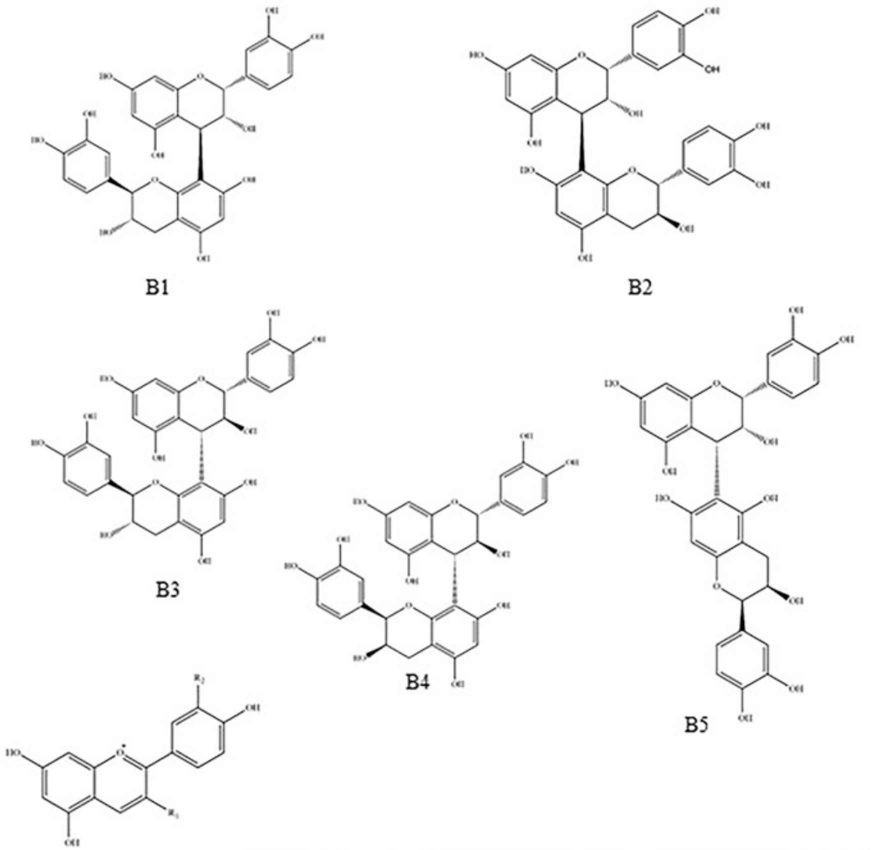
Flavans

Compound	R_1	R_2	R_3	R_4	R_5	R_6
Catechin	OH	OH	H	H	OH	OH
Catechin-3-*O*-gallate	OH	OH	H	H	OH	*O*-galloyl

Fig. 3.7 Chemical structures of flavonoids (flavanones and flavans) isolated from selected wild plants

collected in north Serbia demonstrated FRAP and DPPH antioxidant potential ranging from 7.06 to 25.27 mg ascorbic acid equivalents/g and IC_{50} values from 0.62 to 3.46 mg/mL, respectively, with significant positive correlation with total phenolic content (Popović et al. 2020). The same extracts showed antidiabetic potential toward inhibition of α-amylase and α-glucosidase enzymatic activity with strong positive correlation with total content of phenolics and individual polyphenols. The antiproliferative effects of tested fruit samples were demonstrated on HT29 cell line, with the most pronounced potential of samples from Beška (Popović et al. 2020).

Other parts of *P. spinosa* plant are also interesting given the biological activities they exerted. It was reported that the extracts of *P. spinosa* branches showed high DPPH scavenging capacity and that simulated in vitro digestion lead to the alteration



Anthocyanidins

Compound	R1	R2
Cyanidin	OH	OH
Cyanidin-3-*O*-glucoside	*O*-β-Glu	OH
Cyanidin-3-*O*-rutinoside	*O*-β-Glu-(6→1)-α-Rha	OH
Peonidin	OH	OCH_3
Peonidin-3-*O*-glucoside	*O*-β-Glu	OCH_3
Peonidin-3-*O*-rutinoside	*O*-β-Glu-(6→1)-α-Rha	OCH_3

Fig. 3.8 Chemical structures of procyanidins (B1-B5) and anthocyanidins from wild plant extracts

of phenolic compounds but with no significant changes in the total content of polyphenolics (Pinacho et al. 2015). The flowers of *P. spinosa* demonstrated significant antioxidant potential, pro-inflammatory enzymes' (lipoxygenase and hyaluronidase) inhibitory activity, with the protection of human plasma components against peroxynitrite-induced damage (Marchelak et al. 2017). The flower extracts showed scavenging effects toward harmful reactive oxygen species such as $OH^{\cdot}$, O_2^{-}, H_2O_2, $NO^{\bullet}$, $ONOO^{-}$, and HOCl, along with their phenolic metabolites (Marchelak et al. 2019). Regarding the antioxidant mechanism of action of *P. spinosa* flower extracts and phenolic metabolites, the same research group recently reported the amelioration of fibrinogen changes under peroxynitrite-induced oxidative stress (Marchelak et al. 2021). They showed that low molecular weight blackthorn polyphenolic compounds were the most responsible for the protection of fibrinogen and other plasma components.

It was recently reported that *P. spinosa* leaf extracts (aqueous and ethanol) showed prominent antioxidant, antimicrobial, and cytotoxic properties on malignant cell lines: HeLa, K562, and MDA-MB-453 (Veličković et al. 2021). In addition to this, they exerted significant inhibition of α-amylase and α-glucosidase enzymes showing the potential antidiabetic activity. The cytotoxic effects of blackthorn flower extract were proven by Murati et al. (2019) in non-neoplastic hepatocytes and hepatoblastoma cells with cell death primarily through necrosis. The *P. spinosa* drupes also showed cytotoxic activity against in vitro 3D and in vivo colon cancer models. Flower extract also showed significant amelioration in oxidative status of C57/BL6 mice in an in vivo experiment (Balta et al. 2020) affecting the levels of internal antioxidants such as catalase, superoxide dismutase, reduced glutathione, and levels of tissue lipid oxidation.

The biological benefits of blackthorn branch extract were applied in the gel emulsion for the incorporation in beef patties (Alejandre et al. 2019). The extract enhanced the antioxidant benefits, and it was able to inhibit lipid peroxidation in beef patties. Moreover, Gironés-Vilaplana et al. (2012) tested adding lyophilized blackthorn fruits to lemon juice toward DPPH, superoxide radical, hydroxyl radical, and hypochlorous acid scavenging activity and additionally on AChE and BChE inhibition. It showed high activity considering a significant level of bioactive anthocyanins as well as other important polyphenolics quantified in blackthorn fruits. Modern aspects of application of *P. spinosa* fruits may be based on the use of biomimetic nanoparticles loaded with the extract (Tiboni et al. 2021). Multiple benefits of nanoparticle synthesis are reflected, not only in increased bioavailability and biocompatibility but also in the potential to be accumulated in specific tissue exerting their biological activity. Tiboni et al. (2021) recently showed excellent properties of *P. spinosa* fruit nanoparticles in wound-healing activity accompanied by increased anti-inflammatory effects. Although there are numerous data regarding the positive effects of blackthorn on human health, there is still enough space to evaluate its most efficient form, to expand research in many directions, and especially to consider new ways of application for better utilization and higher bioactivity. The overview of major chemical constituents, secondary metabolites, and bioactivity of blackthorn is presented in Fig. 3.9.

***Cornelian cherry* (*Cornus mas* L.)** ethnomedicinal use has been well-known for more than 1000 years in different regions of Europe and Asia. The most used preparations in traditional medicine from *C. mas* are made from fruits, but there are also some galenic formulations prepared from flowers, leaves, and fruit stones of *C. mas* (Dinda et al. 2016; Przybylska et al. 2020). In ethnobotanical studies, Cornelian cherry is reported as the most commonly used medicine for gastrointestinal disorders in many countries. Especially the preparations made from Cornelian cherry are reported to act against diarrhea and colitis (Dinda et al. 2016; Süntar et al. 2020). There are also some traditional medicines prepared from *C. mas* for

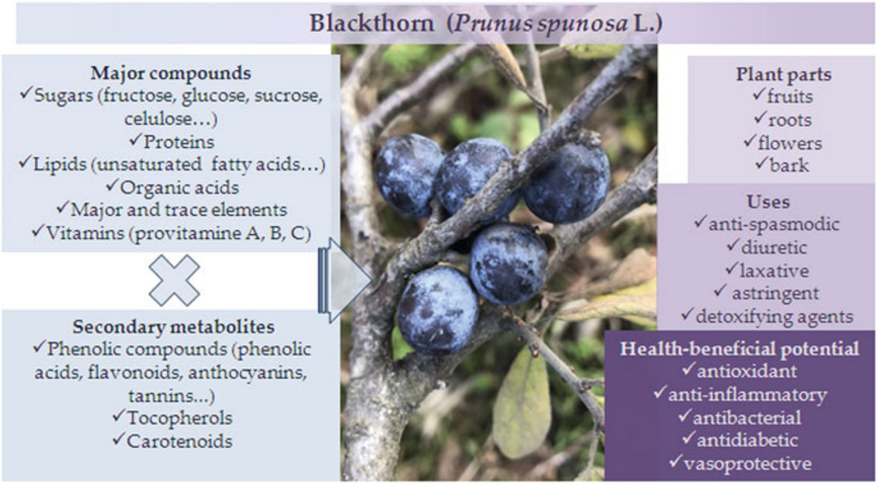


Fig. 3.9 Chemical composition and health-promoting properties of blackthorn

inflammatory bowel disease, sore throats, wound healing, stomach ulcers, fever, malaria, and kidney stones (Dinda et al. 2016). According to literature reports, Cornelian cherry fruit has exhibited anti-inflammatory, antimicrobial, antioxidant, antidiabetic, and nephron-, hepato-, cardio-, and neuroprotective activities in pharmacological studies (Bayram and Arda Ozturkcan 2020; Süntar et al. 2020; Nowak et al. 2021). Considering the wide range of traditional use and abundant evidence for pharmacological effects of *C. mas* fruits, there are also researches based on their application as ingredients of some functional foods (Szczepaniak et al. 2019). The literature search about biological properties of *C. mas* showed a thorough evaluation of different preparations (whole fruits, extracts, juice, or isolated compounds) from *C. mas* in in vitro, in vivo, toxicological, and clinical studies, as well as nanotechnological application.

The most studied biological activity of *C. mas* is its antioxidant potential using different in vitro methods including free radical scavenging activities, reducing antioxidant capacity, β-carotene bleaching properties, and antioxidant activity in the lipid system (Dinda et al. 2016; Szczepaniak et al. 2019; Tiptiri-Kourpeti et al. 2019; Bayram and Arda Ozturkcan 2020; Przybylska et al. 2020; Moussouni et al. 2020; Blagojević et al. 2021). The fruit extracts were the subject of the largest number of studies dealing with antioxidant potential of *C. mas* and showed remarkable antioxidant characteristics of this fruit from different areas of Europe and Asia. Some fruit extracts of *C. mas* showed antioxidant activity comparable to activities of synthetic standard antioxidants, butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) (Szczepaniak et al. 2019; Bayram and Arda Ozturkcan 2020). This property of Cornelian cherry is related to high phenolic and vitamin C content in the studied extracts (Dinda et al. 2016; Szczepaniak et al. 2019; Blagojević et al. 2021; Mishra et al. 2017). In addition to the antioxidant activity of the fruit, it has also been found that *C. mas* leaves (Dinda et al. 2016; Szczepaniak et al. 2019; Grygorieva et al. 2020; Efenberger-Szmechtyk et al. 2021a, b) and stones (Przybylska et al. 2020) possess antioxidant properties.

Among in vitro studies conducted to determine the biological properties of *C. mas*, some researches focused on its antimicrobial properties. The extracts from fruit and leaves of *C. mas* showed the potential to inhibit the growth of different pathogenic bacteria and fungi (Dinda et al. 2016; Szczepaniak et al. 2019; Bayram and Arda Ozturkcan 2020; Efenberger-Szmechtyk et al. 2020a; Savaş et al. 2020; Efenberger-Szmechtyk et al. 2021a, b). Recent study showed that *C. mas* leaf extract possessed the most potent antimicrobial activities compared with *Aronia melanocarpa* (black chokeberry) and *Chaenomeles superba* leaf extracts (Efenberger-Szmechtyk et al. 2020a). The Cornelian cherry leaf extract also showed potential for use as a natural preservative in pork meat products extending their shelf life (Efenberger-Szmechtyk et al. 2021a, b).

The extracts of different parts of *C. mas* displayed cytotoxic activity toward some cancer cell lines (Dinda et al. 2016; Tiptiri-Kourpeti et al. 2019; Bayram and Arda Ozturkcan 2020). For example, *C. mas* leaf aqueous extract caused morphological changes and DNA damage in the Caco-2 cells with an IC_{50} value of 0.6% (Efenberger-Szmechtyk et al. 2020b). In another study, *C. mas* juice showed pronounced antiproliferative activity against HepG2 human cancer cells (IC_{50} 0.08%) (Tiptiri-Kourpeti et al. 2019). The study conducted by Popović et al. (2021) showed low cytotoxicity of 50% ethanol *C. mas* fruit extract. Cornelian cherry fruit extract was successfully applied for green synthesis of gold nanoparticles with low cytotoxic activity against human skin (Perde-Schrepler et al. 2016), while biosynthesized gold and silver nanoparticles using fruit extract showed non-cytotoxicity to normal oral cells, but induced cell death of dysplastic cells (Baldea et al. 2019). Gold nanoparticles synthesized using Cornelian cherry fruit extract and luteolin, in a study published by Domsa et al. (2020), showed possibility to modulate oxidative stress and inflammation process on Caco-2 cells treated with gliadin simulating celiac disease. This use of *C. mas* in the preparation of nanomaterials also shows the possibility of its application in an environmentally friendly synthesis and production of nanoparticles with capping molecules that make them less toxic to normal cells.

Cornelian cherry extracts were evaluated as potential inhibitors of some enzymes in vitro. The fruit extract showed the ability to inhibit α-glucosidase suggesting its potential application in the prevention and treatment of type 2 diabetes (Blagojević et al. 2021; Szczepaniak et al. 2021a). Also, *C. mas* flower infusion possesses an inhibitory effect of aldose reductase which reduces glucose to sorbitol under hyperglycemic conditions contributing to the development of chronic diabetic complications (Forman et al. 2020). Fruit extract was described as an arginase inhibitor which has an important role in normal vascular function (Bujor et al. 2019). It has also been proven that Cornelian cherry fruit extract may inhibit the TAS2R3 and TAS2R13 bitter taste receptors and can be effectively applied for masking the bitter taste of probiotic dark chocolate (Szczepaniak et al. 2021b).

Aside from in vitro studies, there are in vivo, clinical, and toxicological studies, as well as studies about justification of ethnomedicinal uses of *C. mas*. The latest results showed that various preparations from *C. mas* or its extracts may reduce oxidative stress in mice with tumor developed by Ehrlich ascites tumor cell injection (Yilmaz et al. 2020a, b) and in rats treated with a chemotherapeutic agent (Zarei and Shahrooz 2019; Mesgari Abbasi et al. 2020). There is also evidence for Cornelian cherry influence on tumor proliferation in mice (Yilmaz et al. 2020a, b). As in vitro studies showed the potential of Cornelian cherry type 2 diabetes treatment, in vivo studies demonstrated antidiabetic effects of Cornelian cherries' extracts and improvement of diabetes manifestations (Capcarova et al. 2019; Dzydzan et al. 2019, 2020; Omelka et al. 2020). A recent study justified the ethnomedical use of Cornelian cherry for the treatment of ulcerative colitis (Süntar et al. 2020). *C. mas* extracts were also reported to possess anti-inflammatory effects (Szczepaniak et al. 2019; Bayram and Arda Ozturkcan 2020), positive influence on hypercholesterolemia (Nowak et al. 2021), and atherosclerosis (Lietava et al. 2019) in some in vivo studies.

Only a few clinical studies have included *C. mas* supplements. Human clinical studies showed that consumption of Cornelian cherry fruits may prevent hyperlipidemia (Asgary et al. 2013) and hyperglycemia in humans (Soltani et al. 2015). A randomized clinical trial that included effects of *C. mas* extract supplementation (900 mg daily) in postmenopausal women showed that this extract may improve some aspects of postmenopausal complications (bone resorption, osteoporosis, lipid profile, and glycemic indices) (Gholamrezayi et al. 2019; Aryaeian et al. 2021).

According to all literature data about *C. mas* biological activities and potential use, there is a need for further research for its application as a food supplement or raw material for the pharmaceutical industry, especially clinical trials. Also, it seems that more research should be directed toward the use of waste products which remain after *C. mas* fruit exploitation. The overview of major chemical constituents, secondary metabolites, and bioactivity of Cornelian cherry is presented in Fig. 3.10.

***Dog rose* (*Rosa canina* L.)** is a wild plant, well-known as a component of traditional medicine in Europe, Asia, and North America. The pseudo fruits of *R. canina* (the rose hips) are often used as food or medicine in many countries. The health benefit of the rose hip is attributed to its high vitamin C and polyphenolic content (Fan et al. 2014; Patel et al. 2017). Usually, decoctions of *R. canina* hips are used as remedies for the treatment and prevention of cold and flu, as well as for infectious diseases, inflammation, stomach disorders, arthritis, and rheumatoid disorders in traditional folk medicine (Chrubasik et al. 2008; Patel 2013; Živković et al. 2020, 2021). *R. canina* hip seeds are a valuable source of oil popular in natural skin care products. Rose hip seed oil is used in cosmetic preparation as a skin vitalizing agent, usually for reducing scars, wrinkles, and pigmentation on the skin. There are several commercial products based on dog rose hips on the market such as supplements, rose hip tea bags, or cosmetic preparations (Patel 2013). The biological activities of *R. canina* reported so far included antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and osteoarthritis treatments, as well as the use for

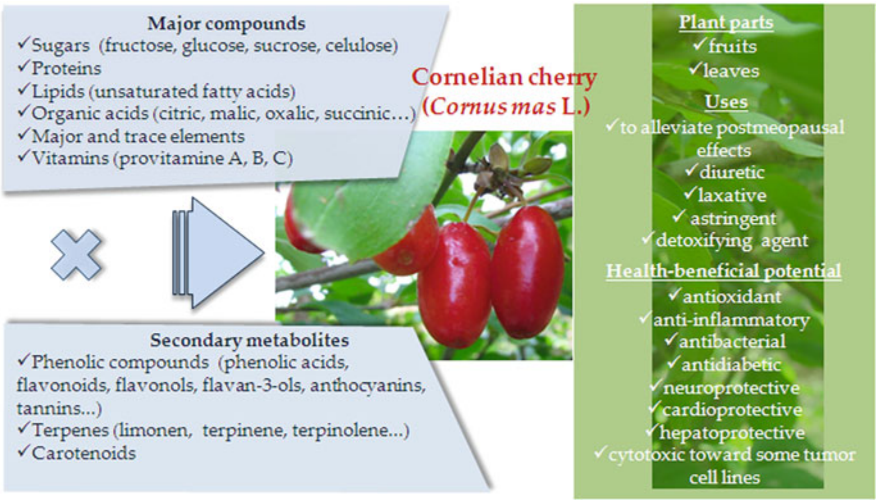


Fig. 3.10 Chemical composition and health-promoting properties of Cornelian cherry

immunomodulation, and in cosmetics (Chrubasik et al. 2008; Patel 2013, 2017; Gruenwald et al. 2019).

R. canina hips displayed strong antioxidant activity in vitro in radical scavenging methods similar to the antioxidant activity of well-known antioxidants, quercetin and Trolox (Fetni et al. 2020a, b; Rovná et al. 2020). The dog rose hips in comparative studies proved to be one of the most potent antioxidants among different wild fruits and berries (Ungurianu et al. 2019; Hendrich et al. 2020; Ouerghemmi et al. 2020; Smanalieva et al. 2020; Tabaszewska and Najgebauer-Lejko 2020; Moldovan et al. 2021). The animal study also showed the antioxidant potential of dog rose hips lowering oxidative manifestations on vancomycin-induced nephrotoxicity in rats (Sadeghi et al. 2021). The antioxidant potential in vitro also showed pasteurized dog rose nectar (Atalar et al. 2020) and flower extract (Demasi et al. 2021), while *R. canina* distilled water improved antioxidant and biochemical parameters in tamoxifen-treated male Wistar rats (Karimimojahed et al. 2020). Interestingly, dog rose hip powder showed the possibility to improve oxidative and microbiological stability of gingerbread (Ghendov-Mosanu et al. 2020). *R. canina* hip extracts showed moderate antimicrobial properties in different studies especially against *E. coli* growth (Hendrich et al. 2020; Rovná et al. 2020). The extracts of dog rose hips showed no cytotoxicity to some carcinoma cells in concentrations up to 400 μg/mL, as well as inhibition of NO production in mouse macrophage-like cell line RAW 264.7 (Moldovan et al. 2021). Fetni et al. (2020a) reported that methanolic extract of dog rose hips applied at a concentration of 250 μg/mL significantly reduced the growth of HepG2 and SH-SY5Y cancer cells. The determination of biological activities of *R. canina* hips in vitro demonstrated that hip extract possessed inhibitory activity of α-glucosidase (IC_{50} 0.54 mg/mL) (Moldovan et al. 2021) and lipoxygenase (Hendrich et al. 2020).

In recent studies, *R. canina* hip extracts were described as agents for the biosynthesis of metal nanoparticles. Green synthesized nanoparticles obtained using *R. canina* were utilized for different applications, e.g., palladium and copper oxide nanoparticles were successfully applied as recyclable nano-catalysts in organic synthesis reactions (Hekmati 2019; Hemmati et al. 2019), and silver and gold nanoparticles showed antimicrobial activity (Gulbagca et al. 2019; Cardoso-Avila et al. 2021), catalytic degradation potential (Cardoso-Avila et al. 2021), and antioxidant potential (Gulbagca et al. 2019).

One of the newest studies demonstrated that methanol extract of dog rose hips is nontoxic in subchronic intraperitoneal toxicity examination on female Wistar albino rats. The methanol extract possessed $LD_{50} > 5000$ mg/kg of body weight, and that result classified this extract as nontoxic. Also, there were no statistically significant differences in biochemical and hematological parameters between the groups treated with different doses of this extract and the untreated group (Fetni et al. 2020a).

Several recent studies demonstrated the positive influence of dog rose hips on diabetic management. Sajadimajd et al. (2020) proved that oligosaccharides from *R. canina* hips improved streptozotocin (STZ)-induced diabetic condition with an increase in the expression of autophagy markers in rat pancreatic Rin-5F cells in vitro. Also, in vivo studies showed significant effects of oligosaccharides from *R. canina* hips on lowering the glucose levels in SZT-induced diabetic rats (Bahrami et al. 2020a, b; Rahimi et al. 2020). One of the most studied biological activities of dog rose in in vivo and clinical studies is its use in osteoarthritis treatment. Several clinical studies showed that dog rose hips (5 g of powder/day) successfully reduced pain associated with osteoarthritis. This beneficial effect of dog rose on osteoarthritis can be attributed to its powerful antioxidant and anti-inflammatory effects (Patel 2013; Cheng et al. 2016; Gruenwald et al. 2019). *R. canina* hip extract has potential for application in cosmetics and dermatology. It has been demonstrated that dog rose hip extract inhibited melanogenesis and reduced skin pigmentation (Patel 2013, 2017).

R. canina has great potential for the development of food supplements and pharmaceutical products, but additional research is needed, especially in vivo studies and randomized controlled clinical trials for more evidence about its biological activities determined in in vitro and animal studies. The most important compounds and bioactivity of rose dog are summarized in Fig. 3.11.

Hawthorn (*Crataegus monogyna* Jacq.) has been continuously used in traditional medicine for centuries. The first written mention of hawthorn was in Dioscorides *De Materia Medica* in the first century where it was described to be used against cardiac disorders (Nabavi et al. 2015). The beneficial effects of hawthorn leaves, flowers, and fruits in the prevention and treatment of heart diseases are mainly due to their hypotensive, antispasmodic, cardiotonic, anti-hyperlipidemic, and anti-atherosclerotic activities (Pawlaczyk-Graja 2018). It was used for relieving symptoms of arrhythmia and hypertension; to treat chronic heart failure, angina pectoris, and myocardial injuries; and to improve blood circulation (Abuashwashi et al. 2016; Bardakci et al. 2019). Abuashwashi et al. (2016) reported that in recent

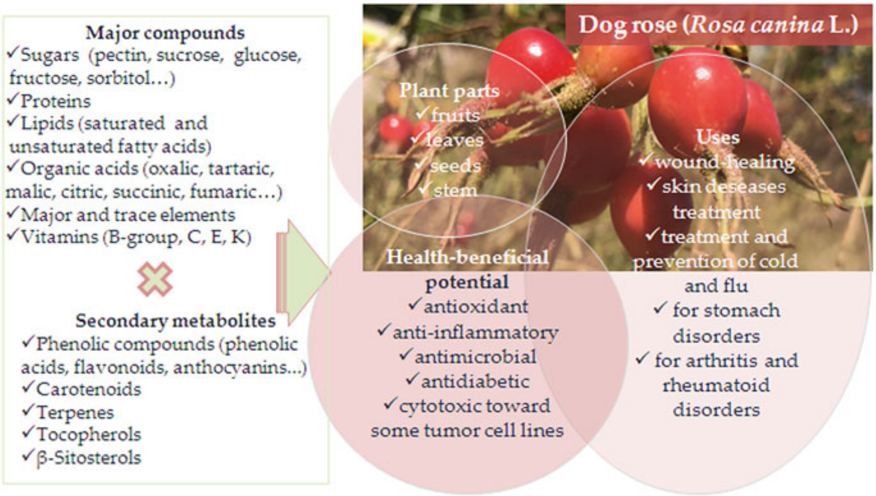


Fig. 3.11 Chemical composition and health-promoting properties of dog rose

years arose a novel use of hawthorn in the treatment of temporary nervous cardiac complaint symptoms.

Besides hawthorn's cardioprotective properties, it also finds a role in the treatment of arthritis, insomnia, gall bladder disease, and diarrhea (Barros et al. 2011; Pawlaczyk-Graja 2018). The hawthorn was traditionally used in the treatment of respiratory tract disorders as well as for relieving the symptoms of menopause (Barros et al. 2011).

The nutritious benefits of hawthorn fruits (berries) made its use as a source of vitamins and minerals even more worthwhile for improving general health. In that sense, the berries were and still are the constituents of numerous food products, such as jams, jellies, different drinks, and wine, or in the form of canned fruit (Barros et al. 2011; Nabavi et al. 2015).

The fruits are also used in the treatment of gout, depression, kidney stones, and intestinal problems, as a diuretic, and for the stimulation of digestion (Keating et al. 2014; Nabavi et al. 2015; Bardakci et al. 2019).

The exact active compounds in *C. monogyna* have not been elucidated with certainty so far. Most likely it could be simultaneous beneficial effects on cardiovascular system of the mixture of many different phytochemicals, including polyphenolic compounds (flavonoids) and triterpenoids from hawthorn leaves and flowers (Momekov and Benbassat 2013). The studies revealed that hawthorn possesses a positive inotropic effect, cardioprotective effects, and an antiarrhythmic effect; it increases coronary blood flow, etc. Many of these pharmacologically important activities are directly dependent on the action of flavonoids, particularly the inhibition of Na^+/K^+ adenosine triphosphatase (Na^+/K^+ pump) that leads to the positive inotropic effect (Momekov and Benbassat 2013). Moreover, the antioxidant activity of hawthorn's constituents can have profound impact on the body and vital effect on the cardiovascular system.

Barros et al. (2011) explored the antioxidant properties of *C. monogyna* flower buds, flowers, and fruits (unripe, ripened, and overripened) by radical scavenging effects (DPPH), reducing power, and inhibition of lipid peroxidation assays. The unripe fruits were the most active compared to other extracts, especially compared to the overripened fruits with the lowest antioxidant potential. Generally, the higher production of phenolic compounds in unripe fruits due to plant stress response can be connected to the higher bioactivity of the fruit extract in this stage of fruit maturity (Barros et al. 2011).

The methanolic extract of *C. monogyna* aerial parts and its fractions were tested in DPPH, and β-carotene bleaching assay showed strong antioxidant activity (Coimbra et al. 2020). The detection of quercetin and vitexin derivatives, along with phenolic acids and procyanidin polymers with high antioxidant level in tested material, contributed to overall bioactivity. Leaves of *C. monogyna* also showed significant ORAC, TRAP, and HORAC antioxidant activity (1405 μmol TE/g, 1301 μmol TE/g, and 882 μmol GAE/g, respectively), but lower compared to other Rosacea plants tested in this study (Denev et al. 2014).

The *C. monogyna* fruit extracts showed the highest antioxidant activity (using DPPH, FRAP, CUPRAC, and total antioxidant capacity tests) compared to four other *Crataegus* species from Turkey (*C. rhipidophylla*, *C. pontica*, *C. orientalis*, and *C. turcicus*) (Bardakci et al. 2019). Since the *C. monogyna* contained the highest total proanthocyanidin, hyperoside, and chlorogenic acid content, all polyphenolic compounds with various mechanisms of reaction with free radicals, no wonder it has pronounced antioxidant potential. Abuashwashi et al. (2016) showed that samples of *C. monogyna* from different geographical origins in Spain demonstrated significant antioxidant activity in ORAC (1.32–2.76 μmol TE/mg) and DPPH (IC_{50} 2.67–3.76 μg/mL) assays with positive correlation between antioxidant activity and phenolic content. Flavonoids and phenolic acids detected in *C. monogyna*, like kaempferol, quercitrin, rutin, hesperetin, arbutin gentisic acid, and chlorogenic acid, significantly contributed to general antioxidant potential of *C. monogyna* aerial part extracts from Spain (Abuashwashi et al. 2016). The extracts from buds and sprouts of *C. monogyna* from various locations in Italy also exerted antioxidant activity in ABTS radical cation assay with values ranging from 31.48 to 147.25 mg Trolox eq./kg (Ferioli et al. 2020). The phenolic composition of those hawthorn bud and sprout samples showed high content of phenolic acids, with prevalence of caffeic and neochlorogenic acid, and flavonoids, of which dominant were vitexin and its derivative vitexin-2″-*O*-(4‴-*O*-acetyl)-rhamnoside, and lower amount of flavonols where the most abundant were hyperoside and isoquercitrin (Ferioli et al. 2020); all of them are scientifically proven antioxidants with various modes of action (Heim et al. 2002; Taofiq et al. 2017).

In addition to the antioxidant activity of hawthorn, the effect of the digestive process on its antioxidant capacity was also reported. Keating et al. (2014) evaluated the influence of simulated digestion on the antioxidant activity of hawthorn preparations (infusion, decoction, berry tincture, and leaf and flower tincture) and phenolic standards commonly present in hawthorn. They showed that total phenolic content after exposure to simulated gastrointestinal fluid decreased only in infusions, but decoction showed the lowest antioxidant potential after digestion. In other preparations, activity decreased, but not significantly. On the other hand, based on the previous reports that hawthorn had extract poor bioavailability after oral administration regarding the low water solubility of flavonoids, Lucconi et al. (2014) had a goal to prepare the microparticulate delivery system of hawthorn methanolic extracts (fruits and flowering tops) with intestinal delivery for oral formations. The microencapsulated and microparticulated systems obtained from hawthorn flowers showed preservation of antioxidant activity during in vitro digestion and in intestinal conditions.

Hendrich et al. (2020) recently reported a high antioxidant potential of hawthorn fruit methanol and water extracts from Poland and showed their effectiveness in Trolox equivalent antioxidant activity (TEAA), DPPH, and ABTS assays, but also the inhibition of lipid peroxidation and lipoxygenase-1 (LOX-1) activity. The capacity of hawthorn to inhibit the process of lipid oxidation was used to prevent increasing of TBARS and volatile carbonyl concentration and odor in pork patties (Akcan et al. 2017). Also, the hawthorn extracts were added to prevent lipid oxidation and oxymyoglobin oxidation in bovine muscle homogenates (Shortle et al. 2014). In both cases, hawthorn showed significant potential against lipid oxidation in meat and proved its use as an antioxidant ingredient for the manufacturing of high-quality meat products with prolonged shelf life.

Another possible benefit of hawthorn extracts is their antimicrobial potential. Hawthorn leaves showed moderate antibacterial effects against *Staphylococcus aureus* (Denev et al. 2014), *Bacillus cereus*, and *Acinetobacter baumannii* (Coimbra et al. 2020), while it was much more efficient against different *Candida* spp. (Coimbra et al. 2020). Nunes et al. (2017), besides antioxidant properties of hawthorn extracts, evaluated also their antimicrobial and cytotoxic properties. The extracts were able to highly inhibit the growth of *Listeria monocytogenes* and in moderate manner *S. aureus*. Nevertheless, *C. monogyna* extracts had protective effect on normal fibroblasts, which can be associated with the high content of zinc along with the presence of phenolic compounds, like chlorogenic and neochlorogenic acids, quercetin, and vitexin. The effects of hawthorn flower buds and fruit extracts (unripened, ripened, and overripened) were tested on human tumor cell lines (MCF7, breast carcinoma; NCI-H460, non-small lung cancer; HeLa, cervical carcinoma; $HepG_2$, hepatocellular carcinoma) (Rodrigues et al. 2012). It was shown that the most active extracts on all cell lines were those of flower buds and unripened fruit of hawthorn, connecting their activity to the chemical composition. In flower buds, the most dominant were phenolic acids 3-*O*- and 5-*O*-caffeoylquinic acids, derivatives of quercetin and apigenin, and (-)-epicatechin, while in fruits, besides mentioned compounds, procyanidin polymers were the most abundant. Sahin-Yaglıoglu et al. (2016) also confirmed the antiproliferative effects of hawthorn flowers against rat brain tumor (C6) and human cervical cancer (HeLa) cell lines. The silver and gold nanoparticles were synthesized with *C. monogyna* leaf extract, and particularly AgNP showed significant antimicrobial activity against a panel of pathogenic microorganisms, e.g., *E. faecalis*, *A. baumannii*, *P. aeruginosa*, *P. mirabilis*, *S. aureus*, *E. coli*, and *K. pneumoniae* (Shirzadi-Ahodashti et al. 2020). Both AgNP and AuNP displayed cytotoxic properties against AGS and MCF-7 cells via apoptotic mechanism with increased ROS production.

The anticoagulant activity of hawthorn flower and fruit extracts was analyzed using activated partial thromboplastin time (aPTT) and prothrombin time (PT) bioassays in vitro. The extracts showed quite high anticoagulant activity with prolongation of the plasma coagulation process (Pawlaczyk-Graja 2018). Those results were another proof that hawthorn can be recommended for the prevention and treatment of cardiovascular diseases. The antithrombotic activity of hawthorn ethanolic extract was demonstrated in vivo in carrageenan-induced tail thrombosis model by Arslan et al. (2015). The activity was ascribed to the high content of proanthocyanidins which exert antithrombotic effects and promote vascular function. Another in vivo experiment showed hyperglycemic activity of hawthorn fruit extract with alleviation of oxidative stress and protection of pancreatic tissue in streptozotocin-induced diabetic rats (Chahardahcharic and Setorki 2018). The immunomodulatory effects of *C. monogyna* extract were also demonstrated in vivo in BALB/c mice (Lis et al. 2020), whereby the authors came to a conclusion that hawthorn modulates the lymphocyte subsets and stimulates the humoral immune response so it can be used as an immunomodulator. The predominant compounds and bioactivity of hawthorn are summarized in Fig. 3.12.

Wild fruits are part of both tradition and religion and are closely connected with the customs of many people. Ever-increasing interest for high-quality food products associated with health-beneficial effects highly encourages researchers to intensively study natural products. Wild-growing fruit plants contain a wide assortment of

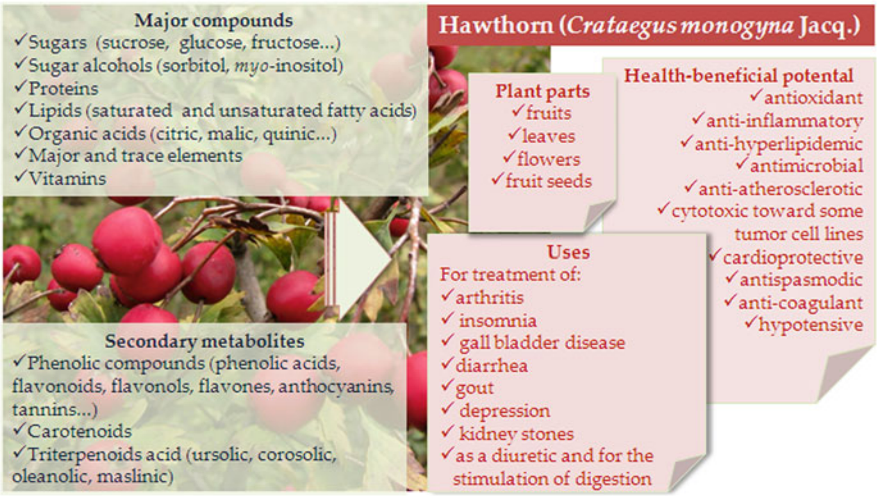


Fig. 3.12 Chemical composition and health-promoting properties of hawthorn

nutritional and health-promoting compounds that are important in the pharmaceutical industry. Local, traditional, healthy, and functional foods are just some attributes that attract consumers when purchasing food. Recently, originality and authenticity of food products became highly important categories to consumers as well as producers. In addition, the interest in collection of the fruits of wild plants is gaining attention from the economic aspects.

3.5 Conclusion

Due to the powerful health-promoting properties of wild fruits, blackthorn, Cornelian cherry, dog rose, and hawthorn are well-known in traditional medicine of many European and Asian countries. The plants are a good source of nutritionally valuable and health-beneficial compounds. Among them, secondary metabolites, especially polyphenolic compounds, mostly contribute to the bioactivity of fruits, leaves, flowers, and twig extracts of these plants, which is reflected in the anti-inflammatory, antimicrobial, antioxidant, antidiabetic, neuroprotective, and other activities. In traditional folk medicine, these plants are used as remedies for the prevention of colds and the flu, as well as for the treatment of various health disorders. But, in the light of climate change, wild fruits will be endangered in the future, because, first of all, their habitat will experience a decrease. Climate change can diminish wild fruit fields or shift them to other locations which can influence local populations. Changing flora can lead to the appearance of invasive species which can influence the pollination of the native wild fruit-producing plants.

Acknowledgments Authors thank to Professor M. Fotirić Akšić and N. Mićanović for providing original photos. This work was supported by the Ministry of Education, Science, and Technological Development of the Republic of Serbia (Grants Nos. 451-03-9/2021-14/200026, 451-03-9/2021-14/200378, 451-03-68/2021-14/200122).

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