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# Ethnopharmacologically important but underestimated genus *Sorbus*: a comprehensive review

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**Abstract** *Sorbus* L. sensu lato (Rosaceae family) comprises over 250 trees and shrubs growing in the Northern Hemisphere. Several *Sorbus* species have found their way into traditonal *materia medica*, as different leaf, bark or fruit preparations have a long-standing folk use. Ethnomedicine recommends their use not only in respiratory and gastrointestinal system disorders, but also in rheumatism, cancer or diabetes. Chemical composition of the genus *Sorbus* has been studied since 1960s and until now more than 250 compounds have been identified from thirty-eight species. The most thoroughly investigated substances are phenolic compounds (flavonoids and phenolic acids). Other constituents include triterpenes, sterols, carboxylic acids, coumarins and cyanogenic glycosides. Biological activity studies performed on the representatives of the genus *Sorbus* have been predominantly conducted on extracts prepared with the use of different solvents, and more rarely on isolated constituents. The majority of these studies were devoted to determination of antioxidant potential of *Sorbus* extracts. In a few cases targeted studies were conducted to confirm specific folk usage. Two of the fairly well documented medicinal uses are the antidiabetic activity of *Sorbus decora* and anti-inflammatory activity of *Sorbus commixta*.

**Keywords** *Sorbus* · Folk medicine · Phytochemistry · Biological activity

**Abbreviations**

| | |
|---|---|
| AAPH | 2,2′-Azobis-(2-amidinopropane) dihydrochloride |
| ABTS | 2,2′-Azino-bis(3-ethylbenzothioazoline-6-sulphonic acid) diammonium salt |
| ACE | Angiotensin converting enzyme |
| AChE | Acetylcholinesterase |
| ADH | Alcohol dehydrogenase |
| ALT | Alanine aminotransferase |
| AMPK | Adenosine-monophosphate-activated protein kinase |
| AST | Aspartate transaminase |
| ATO | Arsenic trioxide |
| BChE | Butyrylcholinesterase |
| CAT | Catalase |
| CD | Conjugated dienes |
| cGMP | Guanosine 3′,5′-cyclic monophosphate |
| COX-2 | Cyclooxygenase-2 |
| CYP | Cytochrome P450 |
| $DMPD^+$ | *N*,*N*-Dimethyl-*p*-phenylenediamine |
| DPPH | 2,2′-Diphenyl-1-picrylhydrazyl |
| dw | Dry weight |
| ecNOS | Endothelial cell NO synthase |
| EDTA | Ethylenediamine tetraacetic acid |

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| | |
|---|---|
| ELISA | Enzyme-linked immunosorbent assay |
| ET-1 | Endothelin-1 |
| FRAP | Ferric reducing antioxidant power |
| fw | Fresh weight |
| GAE | Gallic acid equivalents |
| GSH | Glutathione |
| HOMA | Homeostasis model assessment |
| ICAM-1 | Intercellular adhesion molecule-1 |
| IL-1$\beta$ | Interleukin-1$\beta$ |
| IL-6 | Interleukin-6 |
| i.g. | Intragastric |
| iNOS | Inducible NO synthase |
| LPS | Lipopolysaccharide |
| MAPK | Mitogen-activated protein kinase |
| MCP-1 | Monocyte chemoattractant protein-1 |
| MDA | Malondialdehyde |
| MMP-1 | Matrix metalloproteinase-1 |
| MMP-2 | Matrix metalloproteinase-2 |
| MMP-3 | Matrix metalloproteinase-3 |
| MMPs | Matrix metalloproteinases |
| $MPP^+$ | 1-Methyl-4-phenylpyridinium ion |
| MTT | Methylthiazolyldiphenyl-tetrazolium bromide |
| NBT | Nitroblue tetrazolium |
| NF-κB | Nuclear factor-κB |
| NGF | Nerve growth factor |
| NO | Nitric oxide |
| NOS | Nitric oxide synthase |
| $PGE_2$ | Prostaglandin $E_2$ |
| p.o. | Per os |
| PTP1B | Protein tyrosine phosphatase 1B |
| ROS | Reactive oxygen species |
| SOD | Superoxide dismutase |
| SPE | Solid phase extraction |
| SRB | Sulforhodamine B |
| TBARS | Thiobarbituric acid-reactive substances |
| TEAC | Trolox equivalent antioxidant capacity |
| TNF-α | Tumor necrosis factor-α |
| UVA | Ultraviolet A |
| UVB | Ultraviolet B |
| VCAM-1 | Vascular cell adhesion molecule-1 |

## Introduction

*Sorbus* L. sensu lato (Rosaceae family) comprises over 250 trees and shrubs native to eastern Asia and distributed in the Northern Hemisphere (Aldasoro et al. 1998). Genus *Sorbus* is characterized by significant diversity what inflicts taxonomic difficulties. Recent studies provide data on its polyphyletic nature. Interspecific hybridization, apomixis and polyploidy, which have contributed to diversification process, seem to play a crucial role in plant evolution (Dickinson et al. 2007; Li et al. 2017). Nevertheless, the genus *Sorbus* is currently usually divided into six subgroups: *Chamaemespilus* Medikus, *Torminalis* Medikus, *Aria* (Pers.) Host, *Micromeles* Decaisne, *Cormus* Spach and *Sorbus* sensu stricto (Li et al. 2017). All simple-leaved species are included into the first four subgroups, whereas the two latter comprise the pinnate-leaved species (Sun et al. 2018). The complicated relationships between *Sorbus* species are the subject of many current studies in the field of molecular biology. The *Sorbus* sensu stricto (88 species) is one of the most profoundly analyzed. Recent findings confirmed the existence of two major lineages, namely core *Sorbus* and Albo-carmesinae, which correspond to morphological characters such as i.a. fruit color. As confirmed by phylogenetic analyzes, the core *Sorbus* includes two clades (Aucupariae and Commixtae), whereas Albo-carmesinae comprises three clades (Tianshanicae, Discolores, Multijugae) (Li et al. 2017). The greatest diversity of *Sorbus* in Europe is seen in Britain, where in the area of Avon Gorge, among fifteen native taxa, three endemic species and four novel hybrids have been reported (Robertson et al. 2010). This interesting problem of the diversity and relationship network between different *Sorbus* species has been exhaustively discussed in a number of surveys (Chester et al. 2007; Robertson et al. 2010; Pellicer et al. 2012; Hamston et al. 2018). It is also noteworthy that the European phylogenetic checklist of *Sorbus* s.l. has been recently published (Sennikov and Kurtto 2017).

*Sorbus* species are often cultivated for ornamental purposes mainly because of the colored fruits. The berries are consumed worldwide, as raw or processed into preserves and beverages. Moreover, various parts of these valuable plants have been used as remedies for healing common ailments. Traditional medicine recommends their use not only in respiratory and

gastrointestinal system disorders, but also in rheumatism, cancer or diabetes. However, not all declared therapeutic properties seemed to be confirmed by recent phytochemical and biological studies.

Despite a large number of literature reports dedicated to phytochemistry and biological activity of various *Sorbus* species to date, to the best of our knowledge there is only one published review, which is available in Polish (Olczyk and Geszprych 2017). Thus, this paper is not accessible to a wider group of readers. Moreover, it is primarily focused on practical and nutritional value of *Sorbus* representatives. Even though chemical composition and biological activity is addressed as well, the authors had not assembled all existing data, citing only twenty-five papers devoted to phytochemical and/or biological studies on *Sorbus* species. Hence, the aim of this work was to provide the first comprehensive overview of the genus *Sorbus* in English, in which information on ethnobotanical, phytochemical and biological studies is summarized.

## Methods

The search of scientific literature was performed in various databases including Google scholar, PubMed, Scopus and Embase—using „Sorbus" as the key word. All articles published in English to date (September 2019) were collected. Those that did not concern phytochemistry, biological activity and/or ethnopharmacology of *Sorbus* species were rejected. The chemical structures of the phytoconstituents were searched in PubChem database and ChemDraw 19.0 was used to redraw selected structures.

### Ethnopharmacological studies

#### *Medicinal use*

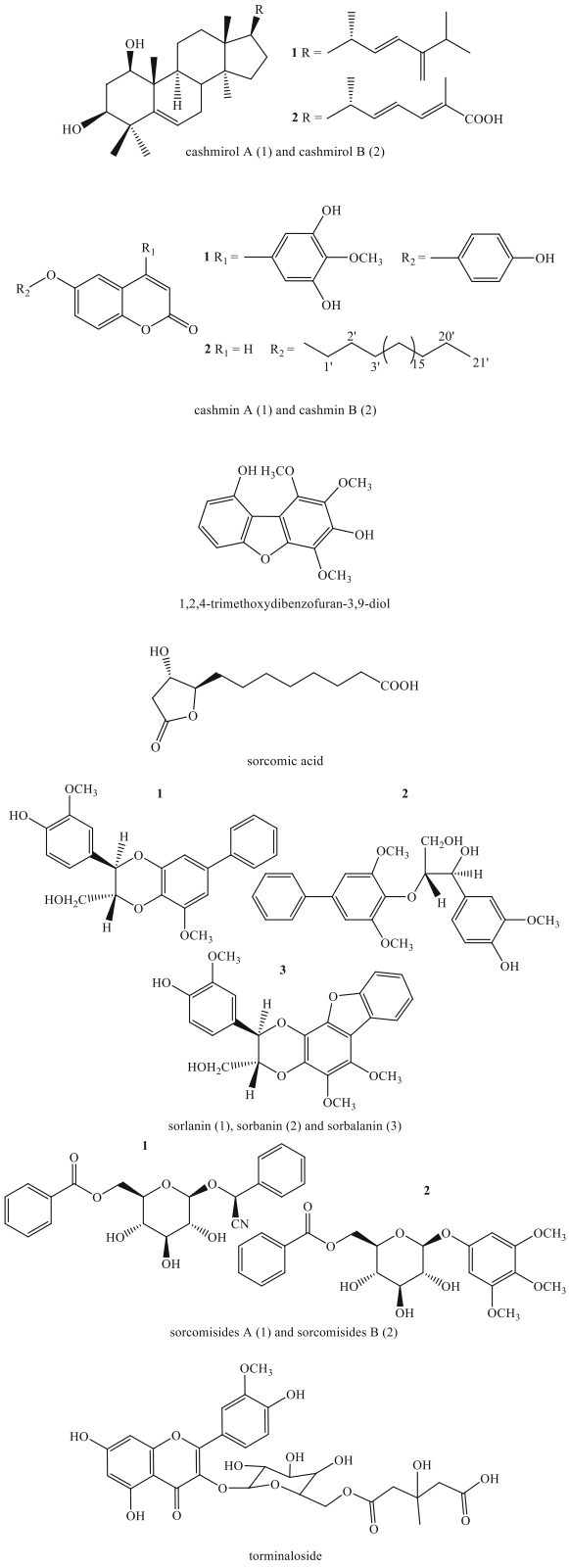
In the majority of collected reports, their authors underlined ethnopharmacological significance of investigated *Sorbus* species referring to herbal books and traditional knowledge developed over generations. Some papers however were specially devoted to this issue and revealed outcomes of in-depth interviews with local community members especially in the regions of Turkey and Korea. The available literature refers to eleven different *Sorbus* species valued worldwide as medicinal products.

##### *Asia*

*S. cashmiriana* is a tree found in Kashmir and the western Himalayas, where its bark is used in folk medicine to treat nausea and heart diseases. The berries of this plant are a remedy for scurvy (Khan et al. 2015). Another Asian species—*S. commixta*—mainly distributed in Korea, Japan and China has also a long-standing folk use. Its bark is applied in bronchitis, asthma or cough (Sohn et al. 2005b), fruits are used as gargle for throat infections or as a laxative (Lee et al. 2017) whereas stem bark is an anti-atherosclerosis and expectorant agent (Yin et al. 2005). Moreover, during analysis of ethnomedicinal practices of local communities in southern Korea, it was revealed that leaves, stem and fruits of *S. commixta* are traditionally used as a decoction or tea in liver disorders (Kim and Song 2013). People of North Jeolla Province (Korea) recommend its stem decoction in asthma and pulmonary tuberculosis. Fruits are indicated in cough and common cold (Kim and Song 2012). Apart from *S. commixta*, the bark of another species growing in Korea, namely *S. amurensis* is also used in this region as an expectorant (Kang et al. 2003). In China, two species have been valued as medicinal agents especially in the disorders of the respiratory tract. *S. tianschanica* is a traditional medicine in the treatment of asthma, dyspnea, ventricular myocytes and gastritis (Ayupbek et al. 2012). Another species which is found growing wild in Northern China—*S. pohuashanensis*—is recommended in chronic tracheitis, edema and pulmonary tuberculosis (Li et al. 2014).

##### *Europe*

Four species typical of Europe have found their way into traditonal *materia medica*. One of them is *S. domestica*, with a well documented traditional medicinal usage in the Mediterranean Basin area. This species is also a popular medicinal plant of Turkey. Kültür (2007) interviewed local communities living in Kırklareli Province and revealed that decoction of *S. domestica* leaves is used to treat prostatitis, diabetes, nephritis (infusion of the leaves is used as well), gallbladder ailments, diarrhea and kidney stones. There are also records of its cholesterol lowering and diuretic properties. What is more, bark decoction is a remedy in stomach ache or ulcers and—




◀**Fig. 1** Chemical structures of selected compounds isolated from the genus *Sorbus*

finally—fresh fruits are applied as an anti-diarrheal agent. People of Central Anatolia drink a tea of *S. domestica* leaves to treat bradyuria and kidney stones (Sezik et al. 2001). Fruits are used as astringent, diarrheic and antidiabetic agents by the people of Xanthi (Rodopi) (Termentzi et al. 2006), while in Serbia they are also used as a tonic (Jarić et al. 2015).

Another species that is a very popular natural remedy against various ailments both in Europe and Asia is *S. aucuparia*, which is commonly called rowan tree. Rowanberries are recommended in folk medicine to treat hemorrhoids, hypertension (Kültür 2007; Polat and Satıl 2012), respiratory tract infections, rheumatism and gout (Vogl et al. 2013). In Lithuania (Kaišiadorys dictrict) preparations from rowanberries were administered orally in constipation and cough, whereas bark decoction was used as a wound wash (Pranskuniene et al. 2019). Sak et al. (2014) revealed that a tea prepared from bark of *S. aucuparia* has been used in Estonia to treat cancer diseases. Preparations made from the rowan tree leaves apart from being indicated in cancer, were also used in gastrointestinal problems or prostatitis (Kültür 2007; Neves et al. 2009). Finally, the inflorescences were used as diuretic and anti-inflammatory agents (Olszewska 2011a). Two other *Sorbus* species valued in traditional medicine of Europe are *S. torminalis* and *S. aria* (whitebeam). In both cases leaves are used as a medicinal product, the decoction made from the former species is traditionally used in Turkey to treat diabetes or stomach ache (Kültür 2007), whereas the latter are used as an anti-diarrhoeal agent (Olszewska and Michel 2012).

### *North America*

The bark of *S. decora* (showy mountain ash), a species native to North America, is used to relieve symptoms related to diabetes by the Eeyou Istchee Cree First Nations of Quebec, Canada (Leduc et al. 2006; Guerrero-Analco et al. 2010). Also the bark of *S. americana* is a traditional remedy in the boreal regions of Canada, where it is recommended in the

treatment of diabetes and its complications (McCune and Johns 2002, 2003, 2007).

Food use

Berries obtained from different *Sorbus* species, apart from their medicinal use, are known for their nutritional value which is also well documented. *S. commixta* and *S. pohuashanensis* fruits are eaten in Asia as a refreshment or in preserves, the former being also used to produce country wine (Li et al. 2014; Lee et al. 2017). Rowanberries (*S. aucuparia*) are very popular edible products especially in Europe. They are often consumed raw or processed into jams, wines etc. (Tardío et al. 2006; Kalle and Sõukand 2012; Łuczaj et al. 2013; Pranskuniene et al. 2019). Fruits of *S. aucuparia*, *S. intermedia* and *S. rupicola* are bread ingredients in Estonia (Kalle and Sõukand 2012). *S. torminalis* and *S. intermedia* berries are consumed in preserves or raw, after natural fermentation or storage (Tardío et al. 2006; Łuczaj et al. 2013). *S. aria* fruits are processed into alcoholic beverages, vinegar and jams (Tardío et al. 2006; Olszewska and Michel 2012). Finally, *S. domestica* has nutritional value in Spain (Tardío et al. 2006), southern Herzegovina (Łuczaj and Dolina 2015) and Xanthi (Rodopi) (Termentzi et al. 2006).

Phytochemical studies

Chemical composition of the genus *Sorbus* has been studied since 1960s and until now more than 250 compounds have been identified from thirty-eight species. To the best of our knowledge, up to date *Sorbus* species have afforded twenty structurally new compounds, namely ten triterpenes, six phenols, two coumarins, one fatty acid and one dibenzofuran derivative. Examples of these are shown in Fig. 1. In general, the most thoroughly investigated substances are phenolic compounds. Other constituents include i.e. triterpenes, sterols, carboxylic acids, coumarins and cyanogenic glycosides.

*Phenolic compounds*

As mentioned above, the highest number of papers devoted to phytochemical analysis of various *Sorbus* species concerns flavonoids and other phenols. Common sugar-free compounds (see Table 1) such as quercetin and kaempferol are the most frequent and were detected in leaves, inflorescences and fruits of many *Sorbus* species. A more rare flavonol, namely sexangularetin was found to be characteristic of inflorescences, but its small amounts were also detected in the leaves, e.g. of *S. aria* (about 14 mg/100 g of dw), *S. domestica* and *S. intermedia* (trace levels, < LOQ) (Olszewska 2008, 2012; Olszewska and Michel 2009). Moreover, in the study of Olszewska (2012) who applied a very sensitive RP-HPLC–PDA method to the analysis of different aerial parts of *S. aria*, *S. torminalis*, *S. domestica* and *S. aucuparia*, the presence of other aglycones, i.e. limocitrin, luteolin, chrysoeriol, apigenin, was revealed. Except for limocitrin, all remaining compounds were detected solely in *S. torminalis*. What is more, isorhamnetin was confirmed in *S. aucuparia* (inflorescence).

Apart from free flavonoids also their glycosides (see Table 1) have been reported in a number of representatives of the *Sorbus* genus. Rutin, hyperoside, isoquercitrin and other quercetin derivatives are definitely the most abundant. Tian et al. (2017) underlined that quercetin 3-*O*-(6″-malonyl)-glucoside constitutes over 50% of flavonoid glycosides present in the fruit extract of *S. aucuparia* (ethanol:water:acetic acid, 70:30:1, v/v/v).

Catechins and proanthocyanidins (mainly procyanidin B1 and procyanidin B2) were found in the leaves of several *Sorbus* species (see Table 2). Futhermore, procyanidin B2 was detected in *S. aucuparia* flowers (Olszewska et al. 2019) whereas procyanidin C1 in *S. domestica* leaves (Rutkowska et al. 2019a, b). Anthocyanins, including glycosides of cyanidin, pelargonidin and delphinidin, were reported in the fruits of *S. aucuparia* (Kylli et al. 2010; Boath et al. 2012; Klensporf-Pawlik and Przybylski 2015; Veberic et al. 2015; Tian et al. 2017), *S. torminalis* (Mikulic-Petkovsek et al. 2017), *S. americana* (Klensporf-Pawlik and Przybylski 2015) and *S. discolor* (Mikulic-Petkovsek et al. 2017).

Another common group of phenolic phytoconstituents are phenolic acids (see Table 3), of which hydroxycinnamic acids, primarily chlorogenic acid and its isomer neochlorogenic acid, are widely distributed. These two caffeoylquinic acid derivatives were reported in many species of genus *Sorbus*. In *S. aucuparia* fruits they constitute almost 80% of total phenolics (Tian et al. 2017). Nevertheless,

**Table 1** Flavonoids from the genus *Sorbus*—flavone derivatives

| Species | Compounds | References |
|---|---|---|
| *S. alnifolia* | *Aglycones*<br>Quercetin (FR, L, B)<br>*Glycosides*<br>No data | Kim et al. (2010) |
| *S. americana* | *Aglycones*<br>Quercetin (L), kaempferol (L)<br>*Glycosides*<br>Rutin (FR), quercetin-3-glucoside (FR) | Olszewska et al. (2010) and Klensporf-Pawlik and Przybylski (2015) |
| *S. anglica* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercertin malonylglucoside (L), quercetin dihexoside (L), quercetin acetyl dihexoside (L) | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. aria* | *Aglycones*<br>Quercetin (FR, L, I), sexangularetin (L, I), kaempferol (FR, L, I), isorhamnetin (FR, L, I), limocitrin (I)<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercetin 3-*O*-*β*-glucopyranoside-7-*O*-α-rhamnopyranoside (L), quercetin malonylglucoside (L), quercetin dihexoside (L), quercetin acetyl dihexoside (L), astragalin (L), kaempferol 3-*O*-*β*-glucopyranoside-7-*O*-α-rhamnopyranoside (L), isorhamnetin 3-*O*-*β*-glucopyranoside (L) | Olszewska (2008, 2012), Olszewska and Michel (2009, 2012), Raudonė et al. (2015) and Šavikin et al. (2017) |
| *S. arranensis* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercetin malonylglucoside (L), quercetin dihexoside (L), quercetin acetyl dihexoside (L) | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. aucuparia* | *Aglycones*<br>Quercetin (FR, L, I, FL), sexangulaertin (I), kaempferol (FR, L, I, FL), isorhamnetin (I), limocitrin (I), apigenin (FR), amentoflavone (FR)<br>*Glycosides*<br>Rutin[a] (FR, L, I, FL), hyperoside[b] (FR, L, I, FL), isoquercitrin[c] (FR, L, I, FL), quercetin-3-*O*-rhamnoside (FR), quercetin-3-*O*-(6″-malonyl)-*β*-D-glucoside[d] (FR, L), quercetin-3-*O*-(6″-malonyl)-galactoside (FR), quercetin 3-*O*-*β*-sophoroside[e] (I, FL), quercetin derivatives[f] (FR, L, FL), astragalin (L, FL), kaempferol-3-*O*-glucoside (FR), kaempferol derivatives[g] (FR, FL), sexangularetin 3-*O*-glucopyranoside (I), sexangularetin 3-*O*-*β*-D-glucoside (FL), sexangularetin derivatives[h] (FL), baicalin (FR), scutellarin (FR), eriodictyol *O*-hexoside (FL), eriodictyol *O*-glucuronide (FL), phlorizin (FR) | Häkkinen et al. (1999), Gil-Izquierdo and Mellenthin (2001), Olszewska (2008, 2012), Olszewska and Michel (2009), Olszewska et al. (2010, 2012, 2019), Kylli et al. (2010), Boath et al. (2012), Aladedunye and Matthäus (2014), Raudonis et al. (2014), Gaivelyte et al. (2014), Raudonė et al. (2015), Klensporf-Pawlik and Przybylski (2015), Šavikin et al. (2017), Tian et al. (2017), Turumtay et al. (2017), Mrkonjić et al. (2017) and Isaikina et al. (2018) |

**Table 1** continued

| Species | Compounds | References |
|---|---|---|
| *S. austriaca* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercertin malonylglucoside (L), quercetin dihexoside (L), quercetin acetyl dihexoside (L) | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. cashmiriana* | *Aglycones*<br>Quercetin (L), kaempferol (L)<br>*Glycosides*<br>No data | Olszewska et al. (2010) |
| *S. caucasica* (var. *yaltirikii*) | *Aglycones*<br>Quercetin (FR)<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercetin malonylglucoside (L), quercetin dihexoside (L) | Raudonis et al. (2014), Raudonė et al. (2015) and Turumtay et al. (2017) |
| *S. commixta* | *Aglycones*<br>Quercetin (L, I, T), sexangularetin (I), kaempferol (L, I), sakuranetin (WP)<br>*Glycosides*<br>Rutin (FR, L, I), hyperoside (FR, L, I), isoquercitrin (FR, L, I, T), quercetin dihexoside (L), sexangularetin 3-*O*-glucopyranoside (I), neosakuranin (FR) | Bhatt et al. (2009), Olszewska et al. (2010, 2012), Gaivelyte et al. (2013), Raudonis et al. (2014), Raudonė et al. (2015), Choi (2017) and Xuan et al. (2018) |
| *S. decora* | *Aglycones*<br>Quercetin (L, I, IB), sexangularetin (I), kaempferol (L, I)<br>*Glycosides*<br>Rutin (I), hyperoside (I), isoquercitrin (I), quercetin glycoside (IB), sexangularetin 3-*O*-glucopyranoside (I) | Spoor et al. (2006) and Olszewska et al. (2010, 2012) |
| *S. discolor* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin[a] (FR, L), hyperoside[b] (FR, L), isoquercitrin[c] (FR, L), quercetin malonylglucoside (L), quercetin derivatives[i] (FR, L), kaempferol-3-glucoside (FR), kaempferol 3-rutinoside (FR), isorhamnetin rhamnoside hexoside (FR), isorhamnetyl acetyl hexoside (FR), apigenin hydroxyhexoside (FR), eriodictyol glucuronide (FR), phlorozin (FR) | Gaivelyte et al. (2013), Raudonis et al. (2014), Raudonė et al. (2015) and Mikulic-Petkovsek et al. (2017) |
| *S. domestica* | *Aglycones*<br>Quercetin (FR, L), sexangulaertin (L), kaempferol (L), isorhamnetin (L), quercetin 2-4′(-*O*-), 3,5′(-*O*-) dimmer (FR), (7-*O*-4‴, 4′-*O*-7″) quercetin dimer (FR), 7-*O*-methyl kaempferol dimer (FR), kaempferol dimer (FR)<br>*Glycosides*<br>Rutin (FR, L), hyperoside (L), isoquercitrin (L), reinutrin (L), quercitrin (L), afzelin (L), quercetin 3-*O*-(2″-*O*-*β*-D-glucopyranosyl)-α-L-rhamnopyranoside (L), quercetin 3-*O*-(2″-*O*-*β*-D-xylopyranosyl)-α-L-rhamnopyranoside (L), quercetin 3-*O*-*β*-D-glucopyranosyl (1‴→ 2″)-α-L-rhamnosyl(1′‴ → 3‴)- | Cobzac et al. (1999), Termentzi et al. (2008b, 2009), Olszewska (2012), Matczak et al. (2018) and Rutkowska et al. (2019a, b) |

**Table 1** continued

| Species | Compounds | References |
|---|---|---|
| | α-L-rhamnosyl($1'''' \rightarrow 3''''$)-α-L-arabinofuranoside (FR), quercetin 3-*O*-α-L-rhamnosyl($1''' \rightarrow 3''$)-β-D-glucopyranoside (FR), quercetin 3-*O*-birhamnoside (FR), quercetin 7-*O*-(cis-*p*-coumaroyl-) ester, 4″-*O*-rhamnoside (FR), quercetin derivatives[j] (FR, L), kaempherol 7-*O*-(rhamnosyl-) caffeoyl ester (FR), kaempferol 3-*O*-hexoside (FR), kaempherol 3-*O*-(trans-*p*-coumaroyl-) hexoside (FR), keampferol 7-*O*-dipentoside (FR), isorhamnetin 3-*O*-(*p*-coumaroyl-) hexoside (FR), isorhamnetin diglycoside (L), acacetin 7-*O*-feruloyl ester (FR), 5,7,3′,6′-tetrahydroxyflavanol 7-*O*-β-D-glucopyranoside (FR), 3′,4′,7-trimethoxy,5-hydroxy flavanone (sorbyl-) pentoside (FR) | |
| *S. gracilis* | *Aglycones*<br>Quercetin (L, I), sexangulaertin (I), kaempferol (L, I)<br>*Glycosides*<br>Rutin (FR, L, I), hyperoside (FR, L, I), isoquercitrin (FR, L, I), quercetin 3-*O*-sophoroside (L), quercetin dihexoside (L), sexangulaertin 3-*O*-glucopyranoside (I) | Olszewska et al. (2010, 2012), Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. hostii* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercertin malonylglucoside (L), quercetin dihexoside (L), quercetin acetyl dihexoside (L) | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. hybrida* (subsp. *gothlandica*, subsp. *persecta*) | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR), hyperoside (FR), isoquercitrin (FR) | Gaivelyte et al. (2013) |
| *S. intermedia* | *Aglycones*<br>Quercetin (FR, L, I), sexangulaertin (L, I), kaempferol (FR, L, I), isorhamnetin (FR, L, I)<br>*Glycosides*<br>Rutin (I), hyperoside (I), isoquercitrin (I), avicularin (I), quercetin 3-*O*-β-sophoroside (I), isorhamnetin 3-*O*-β-glucopyranoside (I), sorbaroside (I) | Olszewska (2008, 2009) and Olszewska and Michel (2009) |
| *S. koehneana* | *Aglycones*<br>Quercetin (L, I), sexangularetin (I), kaempferol (L, I)<br>*Glycosides*<br>Rutin (I), hyperoside (I), isoquercitrin (I), quercetin 3-*O*-sophoroside (I), sexangularetin 3-*O*-glucopyranoside (I) | Olszewska et al. (2010, 2012) |
| *S. lancifolia* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L) | Gaivelyte et al. (2013) |
| *S. latifolia* | *Aglycones*<br>No data<br>*Glycosides*<br>Rutin (FR), hyperoside (FR), isoquercitrin (FR) | Raudonis et al. (2014) |

**Table 1** continued

| Species | Compounds | References |
|---|---|---|
| *S. pogonopetala* | *Aglycones* | Olszewska et al. (2010, 2012) |
| | Quercetin (L), kaempferol (L) | |
| | *Glycosides* | |
| | Rutin (L), hyperoside (L), isoquercitrin (L), quercetin 3-*O*-sophoroside (L) | |
| *S. pohuashanensis* | *Aglycones* | Olszewska et al. (2010), Li et al. (2012) and Yu et al. (2017) |
| | Quercetin (FR, L, I), sexangularetin (I), kaemferol (L, I), isorhamnetin, chrysoeriol, jaceosidin | |
| | *Glycosides* | |
| | Rutin (FR), hyperoside, quercetin 3-*O*-xyloside, kaempferol 3-*O*-rhamnopyranoside-7-*O*-glucopyranoside (or its isomer), isorhamnetin 3-*O*-rutinoside, vitexin-2-*O*-rhamnoside | |
| *S. prattii* var. *prattii* | *Aglycones* | Olszewska et al. (2010) |
| | Quercetin (L), kaempferol (L) | |
| | *Glycosides* | |
| | No data | |
| *S. quercifolia* | *Aglycones* | Pavlii and Makarova (1970) |
| | No data | |
| | *Glycosides* | |
| | Rutin, hyperin, quercetin 3-$\beta$-gentiobioside, apigenin 7-glucoside | |
| *S. sambucifolia* | *Aglycones* | Olszewska et al. (2010) |
| | Quercetin (L, I), sexangularetin (I), kaempferol (L, I) | |
| | *Glycosides* | |
| | No data | |
| *S. scalaris* | *Aglycones* | Olszewska et al. (2010) |
| | Quercetin (L, I), sexangularetin (I), kaempferol (L, I) | |
| | *Glycosides* | |
| | No data | |
| *S. semi-incisa* | *Aglycones* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | No data | |
| | *Glycosides* | |
| | Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L), quercetin malonylglucoside (L) | |
| *S. setschwanensis* | *Aglycones* | Olszewska et al. (2010) |
| | Quercetin (L), kaempferol (L) | |
| | *Glycosides* | |
| | No data | |
| *S. simonkaiana* | *Aglycones* | Gaivelyte et al. (2013) and Raudonis et al. (2014) |
| | No data | |
| | *Glycosides* | |
| | Rutin (FR, L), hyperoside (FR, L), isoquercitrin (FR, L) | |

**Table 1** continued

| Species | Compounds | References |
|---|---|---|
| *S. sitchensis* | *Aglycones* | Olszewska et al. (2010) |
| | Quercetin (L, I), sexangularetin (I), kaempferol (L, I) | |
| | *Glycosides* | |
| | No data | |
| *S. subfusca* | *Aglycones* | Ekin et al. (2016) |
| | Apigenin (L) | |
| | *Glycosides* | |
| | Rutin (L) | |
| *S. tianschanica* | *Aglycones* | Zapesochnaya et al. (1969, 1973), Ayupbek et al. (2012), Gaivelyte et al. (2013), Yu et al. (2013), Raudonė et al. (2015) and Gu et al. (2016) |
| | Quercetin (L) | |
| | *Glycosides* | |
| | Rutin (L), hyperoside[b] (FR, L, B), isoquercitrin[c] (L, FL), quercetin-3-*O*-(6″-*O*-malonyl)-*β*-D-glucoside[d] (L), quercetin dihexoside (L), astragalin (L), kaempferol-3-*O*-(6″-*O*-malonyl)-*β*-D-glucopyranoside (L), kaempferol-3-*O*-*β*-D-glucoside (L), hesperidin (L) | |
| *S. torminalis* (f. *torminalis*, f. *semitorminalis*) | *Aglycones* | Olszewska and Roj (2011), Olszewska (2012), Mikulic-Petkovsek et al. (2017) and Mrkonjić et al. (2017) |
| | Quercetin (FR, L, I), sexangularetin (I), kampferol (L, I), isorhamnetin (FR, L, I), limocitrin (I), luteolin (FR, L, I), chrysoeriol (FR, L, I), apigenin (FR, L, I), amentoflavone (FR) | |
| | *Glycosides* | |
| | Quercetin 3-rutinoside (FR), hyperoside[b] (FR, I), isoquercitrin[c] (FR, I), quercitrin (FR), quercetin 3-glucuronide (FR), quercetin-dihexoside (FR), quercetin ramnoside hexoside (FR), kaempferol-3-*O*-glucoside (FR), kaempferol 3-rutinoside (FR), kaempferol 3-glucuronide (FR), isorhamnetin hexoside-pentoside (FR), isorhamnetin rhamnoside hexoside (FR), isorhamnetin hexoside (FR), 3,5,7,4′-tetrahydroxy-8,3′-dimethoxyflavone-3-*O*-*β*-D-glucopyranoside (I), 3,5,7,4′-tetrahydroxy-8-methoxyflavone-3-*O*-*β*-D-glucopyranoside (I), 3,5,7,4′-tetrahydroxy-3′-methoxyflavone-3-*O*-*β*-D-galactopyranoside (I), 3,5,7,4′-tetrahydroxy-3′-methoxyflavone-3-*O*-*β*-D-glucopyranoside (I), 5,7,4′-trihydroxy-3′-methoxyflavone-7-*O*-*β*-D-glucopyranoside (I), laricitrin hexoside (FR), torminaloside (I), apigenin glucuronide (FR), eriodictyol hexoside (FR) | |
| *S. umbellata* (var. *umbellata*) | *Aglycones* | Ekin et al. (2016), Kavak and Akdeniz (2019) |
| | Quercetin (L), apigenin (L) | |
| | *Glycosides* | |
| | Rutin (L) | |

**Table 1** continued

| Species | Compounds | References |
|---|---|---|
| *S. wilfordii* | *Aglycones*<br>Quercetin (L), kaempferol (L)<br>*Glycosides*<br>Rutin (L), isoquercitrin (L), quercetin 3-*O*-sophoroside (L) | Olszewska et al. (2010, 2012) |

*B* branch, *FL* flower, *FR* fruit, *I* inflorescence, *IB* inner bark, *L* leaf, *T* twig, *WP* whole plant. Synonyms and/or compounds which are not listed in table: [a]quercetin 3-rutinoside, quercetin 3-*O*-rutinoside [b]quercetin 3-galactoside, quercetin 3-*O*-galactoside, hyperin, [c]quercetin 3-*O*-glucoside, quercetin 3-glucoside, hirsutrin, [d]quercetin malonylglucoside, [e]quercetin 3-*O*-sophoroside, [f]quercetin pentoside, quercetin 3-hexoside, quercetin *O*-dihexoside, quercetin dihexoside, quercetin 3-*O*-hexose-hexoside, quercetin hexose-pentoside, quercetin pentose-hexoside, quercetin hexoside-pentoside, quercetin *O*-pentosylhexoside, quercetin *O*-hexosylpentoside, quercetin *O*-rhamosylhexoside, quercetin acetylhexoside, quercetin *O*-acetylhexoside, quercetin acetyl dihexoside, [g]kaempferol *O*-dihexoside, kaempferol hexose-hexoside, kaempferol *O*-rhamosylhexoside, kaempferol *O*-hexoside, kaempferol *O*-acetylhexoside, [h]sexangularetin di-*O*-hexoside, sexangularetin *O*-dihexoside, sexangularetin *O*-rhamosylhexoside, sexangularetin *O*-acetylhexoside, [i]quercetin dihexoside, quercetin acetyl dihexoside, quercetin-malonyl-hexoside, quercetin glucuronide hexoside, quercetin hexoside-pentoside, [j]quercetin rhamnoside-hexoside, quercetin hexoside-rhamnoside, pentoside-rhamnoside, quercetin 7-*O*-hexoside, quercetin (3,7)-*O*-biglycoside (rhamnose, pentose), quercetin 3-*O*-(hexosyl-) caffeoyl ester, quercetin 3-*O*-(sorbyl-) hexoside, quercetin 3-*O*-(benzoyl-, acetyl-) hexoside, qurcetin 3-*O*-(*p*-methoxycinnamoyl-) pentoside

hydroxybenzoic acids, such as protocatechuic acid and *p*-hydroxybenzoic acid, were also detected in *Sorbus* genus. Other phenolics present in *Sorbus* species are listed in Table 4.

### *Triterpenoids*

Up till now, thirty-three triterpenes have been identified in seven *Sorbus* species (see Table 5). These included already known structures as well as rare compounds that were identified exclusively within this genus. The levels of triterpenoids, especially in fruits, constitute a substantial part of crude plant material. Yin et al. (2019) obtained a triterpenoid fraction after four times repeated recrystallization from ethyl acetate extract of *S. pohuashanensis* fruits. The Vanillin-glacial acetic acid-perchloric acid colorimetric method confirmed that triterpenes constitute 64.6% of the total. Moreover, ursolic acid was found to be the main component. This triterpene was also reported in *S. aucuparia* fruits together with squalene, $\beta$-amyrin, $\alpha$-amyrin, cycloartenol, betulin and oleanolic acid (Klavins et al. 2016). It is noteworthy that apart from these fairly common triterpenes some *Sorbus* species provided structurally novel compounds. For instance, *S. cashmiriana* (the whole plant) afforded lanosta-5,22,24(28)-triene-1$\beta$,3$\beta$-diol, (22*E*,24*E*)-1$\beta$,3$\beta$-dihydroxylanosta-5,22,24-triene-27-oic acid, 5,12(13),15 ursatriene-1$\beta$,3$\beta$,23$\alpha$-triol, 5,12,19 lupatriene-1$\alpha$,3$\beta$,12$\alpha$,28$\beta$-tetraol, 3$\beta$,23-dihydroxylupa-1,20(29)-dien-28-oic acid as well as 3$\beta$-hydroxy-23-methoxylupa-1,20(29)-dien-28-oic acid, which were named cashmirol A, cashmirol B, sorbinol A, sorbinol B, sorbicin A and sorbicin B, respectively (Kazmi et al. 2007, 2009, 2011). Another lupane-type triterpene—sorbanolic acid—identified as 2$\alpha$,3$\beta$,23-trihydroxy-lup-20(29)en-28-oic acid-23-caffeate was obtained from the stem wood of *S. lanata* (Latif et al. 2014), while 23,28-dihydroxyursan-12-ene-3$\beta$-caffeate, 23,28-dihydroxylupan-20(29)-ene-3$\beta$-caffeate and 3$\beta$,23,28-trihydroxy-12-ursene were isolated from stem bark of *S. decora* (Guerrero-Analco et al. 2010).

### *Carboxylic acids, alcohols, sugars and other compounds*

Some *Sorbus* species were analyzed for the presence of fatty acids. Johansson et al. (1997) identified these compounds in the seeds of *S. aucuparia* with the largest amount of linoleic acid. The presence of fatty acids was also confirmed in rowanberries, in which the dominant acids namely linoleic, oleic and palmitic amounted to 18,841.0, 11,201.0, 5149.7 mg/kg of air-

dried raw material, respectively. Palmitic acid was most abundant in leaves (3793.5 mg/kg). In turn, the leaves of *S. aria* afforded mainly palmitic and linolenic acids (Krivoruchko et al. 2013). A new fatty acid named sorcomic acid was isolated from the bark of *Sorbus commixta* (Kim et al. 2016). Simple organic acids, primarily malic, citric and oxalic were reported in the leaves of *S. aria* and *S. aucuparia* (Krivoruchko et al. 2013). The fruits of the latter species as well as of *S. torminalis* and *S. doscolor* yielded citric, malic, tartaric and fumaric acids (Mikulic-Petkovsek et al. 2012, 2017).

Other phytoconstituents reported in the *Sorbus* genus include alkanes (heptacosane, nonacosane), fatty alcohols (1-docosanol, 1-tricosanol, 1-tetracosanol, 1-pentacosanol, 1-hexacosanol, 1-octacosanol) and some monoglycerides (α-monopalmitin, α-monostearin), all of which were detected in *S. aucuparia* fruits (Klavins et al. 2016) Among sugars, the most common were sorbitol, glucose and fructose. In *S. aucuparia* fruits the levels of sorbitol and glucose reached 134.1 g/kg fw and 52.9 g/kg fw, respectively (Mikulic-Petkovsek et al. 2012), whereas for *S. torminalis* fruits the highest amounts were seen for glucose and fructose (98.88 and 80.67 g/kg fw, respectively). In turn, the contents of glucose, fructose and sorbitol in the fruits of another species—*S. discolor*—were comparable. Sucrose generally was found in small amounts, and was detected in the fruits of *S. discolor*, wild S. *aucuparia* as well as its cultivars. These compounds are listed in Table 6.

## Nutritional value of *Sorbus* berries

Apart from sugars, fatty acids and simple organic acids, which are characterized in detail above (and listed in Table 6), the fruits of different *Sorbus* species seem also to be a good source of vitamin C, minerals, pigments and tocopherols (Häkkinen et al. 1999; Aslantas et al. 2007; Egea et al. 2010; Mlcek et al. 2014; Klavins et al. 2016; Mrkonjić et al. 2017; Šavikin et al. 2017). Although, the presence of toxic parasorbic acid should be also underlined, this compound degrades during fruit processing and does not pose a health risk (Mlcek et al. 2014).

It is also noteworthy that various *Sorbus* cultivars have been bred mostly to intensify the sweet flavor and improve organoleptic properties of fruits. Indeed, a comparison of the sugars/organic acids ratios of twenty *Sorbus* clones indicated significant differences (Zymone et al. 2018). Other phytochemical studies revealed that also flavonoid, phenolic acid, anthocyanin and carotenoid contents of various *Sorbus* cultivars varied distinctly (Hukkanen et al. 2006; Kylli et al. 2010; Mikulic-Petkovsek et al. 2017; Zymone et al. 2018). Nevertheless, the fruits of both *Sorbus* species and their varieties constitute a valuable contribution to daily diet.

## Biological studies

Biological activity studies performed on the representatives of the genus *Sorbus* have been predominantly conducted on extracts prepared with the use of different solvents, and more rarely on isolated constituents. Although extracts from all parts of the plant were investigated, the majority of data refer to fruits, leaves and bark. Taking into account the high number of phenolic compounds that have been detected in various *Sorbus* species, the majority of biological activity studies were focused on the determination of their antioxidant potential. Interestingly, a large number of data is however available on the cytotoxic activity of *Sorbus* extracts.

## Antioxidant activity

It should be underlined that the vast majority of antioxidant activity studies were performed using chemical methods. In fact, the ability of different *Sorbus* extracts (or isolates) to scavenge radicals in vitro was predominantly determined. It however does not provide information on the real antioxidant effects in a human body. Although chemical models dominate, several studies using cellular systems have also been conducted.

### *Antiradical activity in chemical models*

Antioxidant properties of various fruits were often studied because they constitute a substantial part of human diet. This activity was also confirmed for *Sorbus* berries, especially those derived from *S. domestica*, *S. aucuparia* and *S. torminalis*. Termentzi et al. (2006) examined methanol extracts from fruits of *S. domestica* which differed in the maturity stage and found that unripe yellow fruits and fruit pulp were most effective. Moreover, these methanol extracts

were next partitioned with dichloromethane, diethyl ether, ethyl acetate, butanol and water. The first three fractions showed significant radical-scavenging activity in the chemiluminescence method (greater than trolox). In another study, fruits of *S. domestica* (extracted with phosphate buffer) showed poor ability to scavenge $ABTS^{\cdot-}$ (TEAC value of 0.466 ± 0.14 μmol trolox/g fw) and $H_2O_2$ (3.63 ± 2.29% of inhibition at 5 mg/mL), however generation of $OH^{\cdot}$ radicals was found to be suppressed. Nevertheless, in the absence of ascorbic acid in the reaction mixture, inhibition of hydroxyl radicals decreased from 68.30% to 59.05%. Thus, the authors underlined that the antioxidant activity of *S. domestica* may be in part related to direct scavenging of radicals as well as avoiding ascorbate oxidation (Egea et al. 2010). In turn, methanol extracts from the fruits of *S. aucuparia* as well as *S. caucasica* var. *yaltirikii* had $SC_{50}$ values of 0.366 ± 0.009 mg/mL and 0.520 ± 0.023 mg/mL in DPPH test, respectively. The results were compared to these of gallic acid ($SC_{50}$ = 0.002 ± 0.000 mg/mL), chlorogenic acid ($SC_{50}$ = 0.006 ± 0.000 mg/mL) and quercetin ($SC_{50}$ = 0.003 ± 0.000 mg/mL) (Turumtay et al. 2017). Antioxidant activity of rowanberries (*S. aucuparia*) was also confirmed by Kähkönen et al. (1999, 2001), Ganhão et al. (2010), Aladedunye and Matthäus (2014) and Aladedunye et al. (2015). Moreover, rapeseed oil fortified with polyphenolic fractions of *Sorbus* extract displayed lower thermooxidative degradation (Aladedunye and Matthäus 2014). The fruits of *S. aucuparia* exerted antiradical properties towards various particles. The methanol extract showed an ability to scavenge hydroxyl radicals (16.33 ± 0.96%, percentage of inhibition), nitric oxides (25.17 ± 1.72%) and superoxide anions (26.74 ± 1.75%) (Mlcek et al. 2014). These findings were confirmed by Mrkonjić et al. (2017), who also studied two forms of *S. torminalis* (*torminalis* and *semitorminalis*). In another study, water and ethyl acetate extracts from *S. torminalis* fruits showed higher antioxidant activity than adequate acetone and methanol (the lowest activity) extracts. For instance, $EC_{50}$ values for water extract were 5.30 ± 0.166, 5.69 ± 0.364 and 9.01 ± 1.025 mg/mL in ABTS, DPPH and NBT assays, respectively. However, the results were still lower than those of reference standards, i.e. quercetin and α-tocopherol (Hasbal et al. 2015). Scientific literature reports on antioxidant potential of other *Sorbus* berries, like those of *S. hajastana* or *S. sambusifgolia* (Lapinskii and Gorbachev 2006; Manukyan et al. 2019). DPPH and hydrogen peroxide scavenging activity as well as metal-chelating activity were also measured for methanol–water extract from *S. umbellata* (Desf.) Fritsch var. *umbellata* (we can only assume that the fruit extract was examined as the plant material was not defined). Its antioxidant activity was significant but not so high as that observed for *Rosa canina* or *Rosa hemisphaerica* extracts (Serteser et al. 2008). Acetone extract from fruits of *S. pohuashanensis* reached $EC_{50}$ values of 60.3 ± 2.11 and 23.8 ± 0.74 μM trolox/g of fw in ABTS and DPPH assays, respectively (Fan et al. 2011). Finally, ethyl acetate fraction of methanol extract from *S. americana* fruits had $IC_{50}$ value of 113.96 ± 5.48 μg/mL in DPPH test and displayed low activity in comparison to other edible American plants (Acuña et al. 2002).

Apart from fruits also *Sorbus* leaves are a source of antioxidant compounds. Olszewska and Michel (2012) partitioned methanol–water extract of *S. aria* leaves (pre-extracted with chloroform) with diethyl ether, ethyl acetate, n-butanol and water, and observed the best radical-scavenging activity in the DPPH test for the ethyl acetate fraction ($EC_{50}$ = 2.99 ± 0.11 mg/L). Further analysis revealed that its main constituents are isoquercitrin, astragalin and chlorogenic acid. In turn, *S. domestica* leaf extracts were potent antioxidants in DPPH, FRAP, TBARS tests, especially ethyl acetate and diethyl ether fractions. Moreover, antioxidant activity correlated with the total polyphenol content. As was confirmed by Matczak et al. (2018), the defatted *S. domestica* methanol leaf extract (0.427 g trolox/g dw) appeared to have stronger activity than methanol extracts from the fruits (0.009–0.122 g trolox/g dw) (Termentzi et al. 2006; Matczak et al. 2018). More in-depth analysis of the leaf extract revealed nine predominant polyphenols, namely (–)-epicatechin, procyanidin B2, procyanidin C1, rutin, quercitrin, quercetin, quercetin 3-*O*-(2″-*O*-*β*-D-glucopyranosyl)-α-L-rhamnopyranoside, quercetin 3-*O*-(2″-*O*-*β*-D-xylopyranosyl)-α-L-rhamnopyranoside and chlorogenic acid (Rutkowska et al. 2019b). Successively, the scavenging activity of these compounds (against $O_2^{\cdot-}$, $OH^{\cdot}$, $NO^{\cdot}$, $H_2O_2$, $ONOO^{-}$, HClO) was assessed using suitable fluorimetric and spectrophotometric methods. The most potent were quercetin, (–)-epicatechin and procyanidins (3.94–24.16 μmol

**Table 2** Flavonoids from the genus *Sorbus*—flavane derivatives

| Species | Compounds | References |
|---|---|---|
| *S. americana* | Cyanidin 3-galactoside (FR), cyanidin 3-arabinoside (FR), cyanidin 3-glucoside (FR), cyanidin 3-xyloside (FR), cyanidin 3,5-diglucoside (FR), pelargonidin 3-glucoside (FR), delphinidin 3-glucoside (FR) | Klensporf-Pawlik and Przybylski (2015) |
| *S. anglica* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. aria* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. arranensis* | (−)-Epicatechin (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. aucuparia* | (−)-Epicatechin[a] (FR, L, FL), (+)-catechin (FL), catechin derivatives[b] (FR, FL), procyanidin B1 (L), procyanidin B2 (L, FL), procyanidin derivatives (FR), cyanidin 3-*O*-galactoside[c] (FR), cyanidin 3-*O*-arabinoside[d] (FR), cyanidin 3-glucoside (FR), cyanidin 3-rutinoside (FR), cyanidin 3-xyloside (FR), cyanidin 3,5-diglucoside (FR), pelargonidin 3-glucoside (FR), delphinidin 3-glucoside (FR) | Kylli et al. (2010), Boath et al. (2012), Aladedunye and Matthäus (2014), Gaivelyte et al. (2014), Klensporf-Pawlik and Przybylski (2015), Raudonė et al. (2015), Veberic et al. (2015), Tian et al. (2017) and Olszewska et al. (2019) |
| *S. austriaca* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. caucasica* (var. *yaltirikii*) | (−)-Epicatechin (L), procyanidin B2 (L), anthocyanin derivative (FR) | Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. commixta* | catechin-7-*O*-*β*-D-xylopyranoside (SB), catechin-7-*O*-*β*-D-apiofuranoside (SB), epicatechin (T), procyanidin B1 (L), procyanidin dimer (T) | Na et al. (2002a, b), Raudonė et al. (2015) and Xuan et al. (2018) |
| *S. decora* | (−)-Epicatechin (SB), (+)-catechin (SB) | Guerrero-Analco et al. (2010) |
| *S. discolor* | (−)-Epicatechin[a] (FR, L), procyanidin derivatives (FR), cyanidin 3-galactoside (FR), cyanidin 3-arabinoside (FR) | Raudonė et al. (2015) and Mikulic-Petkovsek et al. (2017) |
| *S. domestica* | (−)-Epicatechin (L), (+)-catechin (L), procyanidin B2 (L), procyanidin C1 (L), procyanidin derivatives (L) | Matczak et al. (2018) and Rutkowska et al. (2019a, b) |
| *S. gracilis* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L), anthocyanin derivative (FR) | Raudonis et al. (2014) and Raudonė et al. (2015) |
| *S. hostii* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. pohuashanensis* | Delphinidin, methylanthocyanidin | Yu et al. (2017) |
| *S. semi-incisa* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. tianschanica* | (−)-Epicatechin (L), procyanidin B1 (L), procyanidin B2 (L) | Raudonė et al. (2015) |
| *S. torminalis* (f. *torminalis*, f. *semitorminalis*) | Epicatechin (FR), catechin (FR), procyanidin derivatives (FR), cyanidin 3-galactoside (FR), peonidin 3-galactoside (FR) | Mikulic-Petkovsek et al. (2017), Mrkonjić et al. (2017) |
| *S. umbellata* var. *umbellate* | Epicatechin (L), catechin (L) | Kavak and Akdeniz (2019) |

*FL* flower, *FR* fruit, *L* leaf, *SB* stem bark, *T* twig. Synonyms and/or compounds which are not listed in table: [a]epicatechin, [b](epi)catechin-B-(epi)catechin, (epi)catechin derivative, catechin monomer, [c]cyanidin 3-galactoside, [d]cyanidin 3-arabinoside

**Table 3** Phenolic acids from the genus *Sorbus*

| Species | Compounds | References |
|---|---|---|
| *S. alnifolia* | *Hydroxycinnamic acid derivatives* | Kim et al. (2010) |
| | Chlorogenic acid (FR, L, B), caffeic acid (FR, L, B), *p*-coumaric acid (FR, L, B) | |
| | *Hydroxybenzoic acid derivatives* | |
| | Protocatechuic acid (FR, L, B) | |
| *S. americana* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) and Becerra-Herrera et al. (2015) |
| | Chlorogenic acid[a] (FR, L), neochlorogenic acid[b] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. anglica* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. aria* | *Hydroxycinnamic acid derivatives* | Olszewska and Michel (2009, 2012), Krivoruchko et al. (2013), Raudonė et al. (2015) and Šavikin et al. (2017) |
| | Chlorogenic acid (FR, L, I), neochlorogenic acid (FR, L, I), ferulic acid (L), caffeoylshikimic acid (L), other hydroxycinnamic acids[c] (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | vanillic acid (L) | |
| *S. arranensis* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. aucuparia* | *Hydroxycinnamic acid derivatives* | Gil-Izquierdo and Mellenthin (2001), Olszewska and Michel (2009), Olszewska et al. (2010, 2012, 2019), Kylli et al. (2010), Boath et al. (2012), Mikulic-Petkovsek et al. (2012), Krivoruchko et al. (2013), Aladedunye and Matthäus (2014), Raudonis et al. (2014), Gaivelyte et al. (2014), Aladedunye et al. (2015), Raudonė et al. (2015), Klavins et al. (2016), Mrkonjić et al. (2017), Šavikin et al. (2017), Tian et al. (2017), Turumtay et al. (2017) and Isaikina et al. (2018) |
| | Chlorogenic acid[a] (FR, L, I, FL), neochlorogenic acid[b] (FR, L, I, FL), 3,5-*O*-dicaffeoylquinic acid (FL), 4,5-*O*-dicaffeoylquinic acid (FL), cryptochlorogenic acid (I, FL), caffeic acid and derivatives (FR, L, I, FL), coumaric acid and derivatives (FR, L, I, FL), 5-*O*-*p*-coumaroylquinic acid (FL), 3-*O*-caffeoyl-4-*O*-*p*-coumaroilquinic acid (FL), ferulic acid (FR, L, FL), 3-*O*-caffeoyl-5-*O*-feruloylquinic acid (FL), 3-*O*-feruloyl-5-*O*-caffeoylquinic acid (FL), 4-*O*-feruloylquinic acid (FL), 5-*O*-caffeoylshikimic acid (FL), other hydroxycinnamic acids[d] (FR, L, FL) | |
| | *Hydroxybenzoic acid derivatives* | |
| | vanillic acid (FL), protocatechuic acid (FR, I, FL), *p*-hydroxybenzoic acid (I, FL), *m*-hydroxybenzoic acid (FR), salicylic acid (FR, L), *p*-salicylic acid (FR), shikimic acid (FR) | |
| *S. austriaca* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), caffeoylshikimic acid (L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |

**Table 3** continued

| Species | Compounds | References |
|---|---|---|
| *S. cashmiriana* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L), neochlorogenic acid (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. caucasica* (var. *yaltirikii*) | *Hydroxycinnamic acid derivatives* | Raudonis et al. (2014), Raudonė et al. (2015) and Turumtay et al. (2017) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), caffeic acid and derivative (L), coumaric acid derivatives (FR, L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. commixta* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012), Gaivelyte et al. (2013), Raudonis et al. (2014), Raudonė et al. (2015), Kim et al. (2018) and Xuan et al. (2018) |
| | Chlorogenic acid (FR, L, I), neochlorogenic acid (FR, L, I), cryptochlorogenic acid (I), caffeic acid and derivatives (I, T), coumaric acid and derivatives (I), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | methyl syringate α-L-rhamnoside (SB), protocatechuic acid (I), *p*-hydroxybenzoic acid (I) | |
| *S. decora* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I), cryptochlorogenic acid (I), caffeic acid and derivatives (I), coumaric acid derivatives (I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (I), *p*-hydroxybenzoic acid (I) | |
| *S. discolor* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014), Raudonė et al. (2015) and Mikulic-Petkovsek et al. (2017) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), 4-caffeoylquinic acid (FR), caffeic acid derivative (FR), coumaric acid derivative (FR), 3-*p*-coumaroylquinic acid (FR), 5-*p*-coumaroylquinic acids (FR), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | Shikimic acid (FR) | |
| *S. domestica* | *Hydroxycinnamic acid derivatives* | Termentzi et al. (2008b, 2009), Matczak et al. (2018) and Rutkowska et al. (2019a, b) |
| | Chlorogenic acid[a] (FR, L), neochlorogenic acid[b] (L), 3,5-dicaffeoylquinic acid (L), 4-*O*-caffeoylquinic acid (L), caffeic acid and derivatives (FR, L), hydrocaffeic acid derivative (FR), dihydrocaffeic acid derivative (FR), coumaric acid and derivatives (FR, L), 3-*O*-caffeoyl shikimic acid[e] (L), other hydroxycinnamic acids[f] (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | Syringic acid (FR), vannilic acid 4-*O*-α-L-rhamnoside (FR), trivanilloyl-(1,3,4-trihydroxybenzol) ester (FR), vanillic acid and derivatives (FR), protocatechuic acid and derivatives (FR, L), *p*-hydroxybenzoic acid and derivatives (FR, L), dihdroxybenzoic acid derivative (L), qallic acid (FR) | |

**Table 3** continued

| Species | Compounds | References |
|---|---|---|
| *S. gracilis* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L, I), neochlorogenic acid (FR, L, I), cryptochlorogenic acid (L, I), caffeic acid and derivatives (L, I), coumaric acid and derivatives (L, I), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (L, I), *p*-hydroxybenzoic acid (L, I) | |
| *S. hostii* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), caffeoylshikimic acid (L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. hybrida* (*subsp. gothlandica*, *subsp. persecta*) | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013) |
| | Chlorogenic acid (FR), neochlorogenic acid (FR) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. intermedia* | *Hydroxycinnamic acid derivatives* | Olszewska and Michel (2009) |
| | Chlorogenic acid (FR, L, I), neochlorogenic acid (FR, L, I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. koehneana* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I), cryptochlorogenic acid (I), caffeic acid and derivatives (I), coumaric acid and derivatives (I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (I), *p*-hydroxybenzoic acid (I) | |
| *S. lanata* | *Hydroxycinnamic acid derivatives* | Uddin et al. (2013) |
| | Tetracosyl-3-(3,4-dihydroxyphenyl)acrylate (SW) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. lancifolia* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. latifolia* | *Hydroxycinnamic acid derivatives* | Raudonis et al. (2014) |
| | Chlorogenic acid (FR), neochlorogenic acid (FR), other hydroxycinnamic acids (FR) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. pogonopetala* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012) |
| | Chlorogenic acid (L), neochlorogenic acid (L), cryptochlorogenic acid (L), caffeic acid and derivatives (L), coumaric acid and derivatives (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (L), *p*-hydroxybenzoic acid (L) | |

**Table 3** continued

| Species | Compounds | References |
|---|---|---|
| *S. pohuashanensis* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) and Li et al. (2012) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I), 1-caffeoylquinic acid (FR) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. prattii* var. *prattii* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L), neochlorogenic acid (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. quercifolia* | *Hydroxycinnamic acid derivatives* | Pavlii and Makarova (1970) |
| | Chlorogenic acid, neochlorogenic acid, caffeic acid | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. sambucifolia* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. scalaris* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. semi-incisa* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013), Raudonis et al. (2014) and Raudonė et al. (2015) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), caffeoylshikimic acid (L), other hydroxycinnamic acids[c] (FR, L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. setschwanensis* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L), neochlorogenic acid (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. simonkaiana* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013) and Raudonis et al. (2014) |
| | Chlorogenic acid (FR, L), neochlorogenic acid (FR, L), other hydroxycinnamic acids (FR) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. sitchensis* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010) |
| | Chlorogenic acid (L, I), neochlorogenic acid (L, I) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. subfusca* | *Hydroxycinnamic acid derivatives* | Ekin et al. (2016) |
| | Chlorogenic acid (L), ferulic acid (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |

**Table 3** continued

| Species | Compounds | References |
|---|---|---|
| *S. tianschanica* | *Hydroxycinnamic acid derivatives* | Gaivelyte et al. (2013) and Raudonė et al. (2015) |
| | Chlorogenic acid (L), neochlorogenic acid (L), caffeoylshikimic acid (L), other hydroxycinnamic acids[c] (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. torminalis* (f. *torminalis*, f. *semitorminalis*) | *Hydroxycinnamic acid derivatives* | Olszewska and Roj (2011), Mikulic-Petkovsek et al. (2017) and Mrkonjić et al. (2017) |
| | Chlorogenic acid (FR, I), neochlorogenic acid (I), caffeic acid derivative (FR), ferulic acid and derivatives (FR) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (FR), gallic acid (FR), shikimic acid (FR) | |
| *S. umbellata* (var. *umbellata*) | *Hydroxycinnamic acid derivatives* | Ekin et al. (2016) and Kavak and Akdeniz (2019) |
| | Chlorogenic acid (L), caffeic acid (L), *p*-coumaric acid (L), ferulic acid (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | No data | |
| *S. wilfordii* | *Hydroxycinnamic acid derivatives* | Olszewska et al. (2010, 2012) |
| | Chlorogenic acid (L), neochlorogenic acid (L), cryptochlorogenic acid (L), caffeic acid and derivatives (L), coumaric acid and derivatives (L) | |
| | *Hydroxybenzoic acid derivatives* | |
| | protocatechuic acid (L), *p*-hydroxybenzoic acid (L) | |

*B* branch, *FL* flower, *FR* fruit, *I* inflorescence, *L* leaf, *SB* stem bark, *SW* stem wood, *T* twig. Synonyms and/or compounds which are not listed in table: [a]5-*O*-caffeoylquinic acid [b]3-*O*-caffeoylquinic acid, [c]caffeoylquinic acid, dicaffeoylquinic acid, [d]tricoumaroyl spermidine isomer, dicoumaroyl-caffeoyl spermidine isomer, caffeoylquinic acid, dicaffeoylquinic acid, feruloylquinic acid, caffeoyl glucoside, caffeoyl glucose, coumaroylguinic acid, [e]caffeoyl shikimic acid isomer, [f]caffeoylquinic acid, caffeoylquinic acid hexoside, caffeoyl-(dimethylether quinic acid) derivative, feruloylquinic acid, bi(*p*-methoxycinnamoyl)-caffeic acid biester, *p*-coumaroyl-,caffeoyl-quinic acid biester, cis-*p*-coumaroyl, hydrosinapic acid derivative, trans-*p*-coumaroyl, hydrosinapic acid derivative, caffeoyl-ferulic acid, caffeoyl-, (methylether-, acetyl-) quinic acid, trihydroxycinnamic acid derivative, trans-*p*-coumaric acid derivative

ascorbic acid/mg). In the same study, antiradical activities of the diethyl ether and ethyl acetate fractions were confirmed what correlates with previous reports (Rutkowska et al. 2019a). Methanol extracts from the leaves as well as fruits of *S. aucuparia* and *S. caucasica* var. *yaltirikii* were tested for their DPPH radical scavenging activity. The most potent were leaf extracts (containing primarily rutin derivatives) with $SC_{50}$ values of 0.036 ± 0.001 mg/mL and 0.045 ± 0.000 mg/mL, respectively (Turumtay et al. 2017). Finally, the differences in antioxidant capacity of extracts from *S. aucuparia* leaves collected during the whole vegetation season were confirmed (Olszewska 2011a).

Antioxidant activity of other plant organs was also documented. Ethanol extracts from bark (collected twice in 2003 and 2004) and stem of *S. decora* were assessed using DPPH, CD and TBARS assays. Strong scavenging activity was noted with $IC_{50}$ values ranging from 19.63 ± 0.57 to 48.95 ± 2.49 ppm in the DPPH test (ascorbic acid with $IC_{50}$ = 3.84 ± 0.01 ppm). What is noteworthy, bark collection from 2003 displayed weaker activity (Fraser et al. 2007). DPPH radical scavenging activity of *S. decora* inner bark (80% ethanol extract) was

**Table 4** Other phenolics from the genus *Sorbus*

| Species | Compounds | References |
|---|---|---|
| *S. aucuparia* | *Lignans* | Erdtman et al. (1963), Chizzali and Beerhues (2012) and Olszewska et al. (2019) |
| | Cinchonain I isomer (FL) | |
| | *Other phenolics* | |
| | Aucuparin (HW), 2′-methoxyaucuparin (HW), 4′-methoxyaucuparin, noraucuparin, isoaucuparin, 2′-hydroxyaucuparin | |
| *S. cahmiriana* | *Other phenolics* | Khan et al. (2015) |
| | Cashmin A (WP), cashmin B (WP) | |
| *S. commixta* | *Lignans* | Na et al. (2002b), Liu et al. (2015) and Kim et al. (2018) |
| | Lyoniresinol 3*a*-*O*-*β*-D-xylopyranoside[a] (S, SB), (+)-lyoniresinol (SB), lyoniside (SB), tiliamurosides A (SB), nudiposide (SB), ssioriside (SB), prupaside (SB), (7*S*,8*R*)-dihydrodehydrodiconiferyl alcohol 9-*O*-α-L-rhamnoside (SB) | |
| | *Other phenolics* | |
| | Sorcomisides B (SB), 2,3-dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone (SB) | |
| *S. decora* | *Lignans* | Narasimhachari and von Rudloff (1962) |
| | (+)-dimethoxyisolariciresinol xyloside (W) | |
| | *Other phenolics* | |
| | Aucuparin (W), methoxyaucuparin (W) | |
| *S. domestica* | *Other phenolics* | Termentzi et al. (2009) |
| | 3-{4-(bis[4-hydroxy-3-(5-hydroxypentanoyloxy)phenyl)methoxy]-3,5-dihydroxy phenyl} propanoic acid (FR), [2,2′-dihydroxy,4-(propionic acid hexyl ester),4′-(propionic acid heptyl ester)] biphenyl (FR), [2,6,2′,6′-tetrahydroxy,4,4′-bis-(propionic acid hexyl ester)] biphenyl (FR) | |
| *S. lanata* | *Lignans* | Uddin et al. (2013) and Latif et al. (2014) |
| | Lyoniside (SW), polystachyol (SW), isolariciresinol (SW), dihydrodehydrodiconiferyl alcohol (SW), tuberculatin (SW), ovafolinin E (SW) | |
| | *Other phenolics* | |
| | Sorlanin (SW), sorbanin (SW), sorbalanin (SW), aucuparin (SW), 2′-methoxyaucuparin (SW) | |
| *S. pohuashanensis* | *Other phenolics* | Li et al. (2012) |
| | Phenylmethanol α-L-arabinofuranosyl(1 → 6)-*β*-D-glucopyranoside (FR) | |
| *S. torminalis* f. *semitorminalis* | *Other phenolics* | Mrkonjić et al. (2017) |
| | Aesculetin (FR) | |

*FL* flower, *FR* fruit, *HW* heartwood, *S* stem, *SB* stem bark, *SW* stem wood, *W* wood, *WP* whole plant. Synonyms: [a](−)-lyoniresinol 3*a*-*O*-*β*-D-xylopyranoside

confirmed as well (Spoor et al. 2006). The bark of *S. americana* (methanol extract) had $IC_{50}$ value of 15.80 ± 1.91 ppm in DPPH assay (McCune and Johns 2002). Methanol extract from *S. amurensis* bark was partitioned between n-hexane, ethyl acetate, butanol and water and next all fractions were examined for their scavenging effects on superoxide and hydroxyl radicals. Among the tested extracts,

**Table 5** Triterpenoids and steroids from the genus *Sorbus*

| Species | Compounds | References |
|---|---|---|
| *S. aucuparia* | *Triterpenes* | Shavva et al. (1969), Deren'ko and Suprunov (1979), Dehaen et al. (2011) and Klavins et al. (2016) |
| | α-amyrin (FR), ursolic acid (FR, L, S), β-amyrin (FR), oleanolic acid (FR), betulin (FR), 23-hydroxybetulin (BA), cycloartenol (FR), squalene (FR) | |
| | *Steroids* | |
| | β-sitosterol (FR) | |
| *S. cashmiriana* | *Triterpenes* | Kazmi et al. (2007, 2009, 2011) |
| | Ursolic acid (WP), sorbinol A (WP), sorbinol B (WP), sorbicin A (WP), sorbicin B (WP), cashmirol A (WP), cashmirol B (WP), taraxerol (WP) | |
| | *Steroids* | |
| | β-sitosterol (WP) | |
| *S. commixta* | *Triterpenes* | Na et al. (2002b, 2009), Yang and An (2014), Choi et al. (2018) and Kim et al. (2018) |
| | Ursolic acid (SB,BA), 3β-acetoxy ursolic acid (SB), betulin (BA), betulinic acid (BA), lupenone (SB), lupeol (SB,BA), cecropiacic acid (SB) | |
| | *Steroids* | |
| | β-sitosterol (SB,BA), β-sitosteryl-3-*O*-β-glucopyranoside (BA) | |
| *S. decora* | *Triterpenes* | Narasimhachari and von Rudloff (1962) and Guerrero-Analco et al. (2010) |
| | α-amyrin (SB), 23,28-dihydroxyursan-12-ene-3β-caffeate (SB), 3β,23,28-trihydroxy-12-ursene (SB), uvaol (SB), betulin (SB), 23-hydroxybetulin (SB), betulinic acid (SB), 23,28-dihydroxylupan-20(29)-ene-3β-caffeate (SB) | |
| | *Steroids* | |
| | β-sitosterol (W) | |
| *S. lanata* | *Triterpenes* | Latif et al. (2014) |
| | Sorbanolic acid (SW), 3β,23-dihydroxy-lup-20(29)ene-28-oic acid-23-caffeate (SW), 3β,23-dihydroxy-lup-20(29)ene-28-oic acid-3β-caffeate (SW) | |
| *S. pohuashanensis* | *Triterpenes* | Li et al. (2012) and Yin et al. (2019) |
| | Ursolic acid (FR), ursolaldehyde (FR), 3β-acetoxyurs-11-en-28,13-olide (FR), 3β-acetoxy-urs-12-ene-28-oic acid (FR), euscaphic acid (FR), pomolic acid (FR), pomolic acid-3β-acetate (FR), oleanolic acid (FR), betulinic acid (FR) | |
| | *Steroids* | |
| | Stigma-5-en-3-*O*-β-glucoside (FR) | |
| *S. tianschanica* | *Triterpenes* | Ayupbek et al. (2012) |
| | ursolic acid (L) | |

*BA* bark, *FR* fruit, *L* leaf, *S* stem, *SB* stem bark, *SW* stem wood, *W* wood, *WP* whole plant

n-butanol extract exhibited the highest activity (Kang et al. 2003). Bae et al. (2007) assessed antioxidant activity of 70% ethanol extract from *S. commixta* cortex and revealed that the extract had $IC_{50}$ = 14.2 ± 0.8 μg/mL and $IC_{50}$ = 18.0 ± 0.2 μg/mL in NBT and DPPH assays, respectively. In a different study, DPPH radical scavenging activity of *S. commixta* (70% ethanol extract, however plant organ was not mentioned, thus we can only assume that the extract was derived from cortex as well) was confirmed (Yu et al. 2009). Also Liu et al. (2015) revealed that ethanol (30%) extract from stem of *S. commixta*

**Table 6** Other compounds from the genus *Sorbus*

| Species | Compounds | References |
|---|---|---|
| *S. aria* | *Carboxylic acids* | Krivoruchko et al. (2013) |
| | Oxalic acid (L), malonic acid (L), succinic acid (L), fumaric acid (L), malic acid (L), 3-hydroxy-2-methylglutaric acid (L), citric acid (L), isocitric acid (L), azelaic acid (L), benzoic acid (L), caproic acid (L), 2-hexenoic acid (L), 3-hexenoic acid (L), lauric acid (L), myristic acid (L), pentadecanoic acid (L), palmitic acid (L), palmitoleic acid (L), margaric acid (L), stearic acid (L), oleic acid (L), linoleic acid (L), linolenic acid (L), arachic acid (L), behenic acid (L), lignocerinic acid (L) | |
| *S. aucuparia* | *Carboxylic acids* | Johansson et al. (1997), Chizzali and Beerhues (2012), Mikulic-Petkovsek et al. (2012), Krivoruchko et al. (2013), Klavins et al. (2016) and Isaikina et al. (2018) |
| | Phosphoric acid (FR), oxalic acid (FR, L), malonic acid (FR, L), lactic acid (FR), succinic acid[a] (FR, L), methoxysuccinic acid (FR), tartaric acid (FR), fumaric acid (FR, L), malic acid (FR, L), citric acid (FR, L), azelaic acid (FR, L), benzoic acid (FR, L), cinnamic acid (FR), phenylacetic acid (FR, L), *o*-Toluic acid (FR), caproic acid[b] (FR, L), 3-hexenoic acid (L), heptanoic acid (FR), caprylic acid[c] (FR, L), pelargonic acid[d] (FR, L), capric acid[e] (FR), undecanoic acid (FR), 10-undecenoic acid (FR), lauric acid[f] (FR, L), *n*-tridecanoic acid (FR), myristic acid[g] (FR, L), pentadecanoic acid (FR, L), palmitic acid[h] (FR, L, SE), palmitoleic acid (FR, L, SE), margaric acid[i] (FR, L), stearic acid[j] (FR, L, SE), oleic acid (FR, L, SE), linoleic acid (FR, L, SE), linolenic acid (FR, L), α-linolenic acid (SE), vaccenic acid[k] (FR, L, SE), 9,12-octadecadienoic acid (FR), trans-9-octadecenoic acid (FR), nonadecanoic acid (FR), arachic acid[l] (FR, L, SE), 11,13-eicosadienoic acid (FR), 11-eicosenoic acid[m] (FR, SE), heneicosanoic acid (FR, L), behenic acid[n] (FR, L, SE), erucic acid (FR), lignocerinic acid[o] (FR, L, SE), kerotinic acid (L) | |
| | *Fatty alcohols* | |
| | 1-Docosanol (FR), 1-tricosanol (FR), 1-tetracosanol (FR), 1-pentacosanol (FR), 1-hexacosanol (FR), 1-octacosanol (FR) | |
| | *Monoglycerides* | |
| | α-monopalmitin (FR), α-monostearin (FR), | |
| | *Alcanes* | |
| | Heptacosane (FR), nonacosane (FR) | |
| | *Other compounds* | |
| | Eriobofuran, noreriobofuran | |
| *S. chamaemespilus* | *Other compounds* | Chizzali and Beerhues (2012) |
| | γ-cotonefuran | |

**Table 6** continued

| Species | Compounds | References |
|---|---|---|
| *S. commixta* | *Carboxylic acids* | Takaishi et al. (1977), Kim et al. (2016, 2018), Lee et al. (2017) and Choi et al. (2018) |
| | Azelaic acid (SB), monomethyl azelate (SB), methyl (3*S*,5*S*)-3,5-dihydroxyhexanoate (SB), 3(*R*)-hydroxyoctanoic acid (SB), 9-hydroxynonanoic acid (SB), methyl 9-hydroxynonanoate (SB), (*S*)-(*E*)-4-hydroxy-2-nonenoic acid (SB), sorcomic acid (SB), (9*S*,12*S*,13*R*)-(*E*)-9,12,13-trihydroxy-10-octadecaenoic acid (SB), (9*S*,12*R*,13*R*)-(*E*)-9,12,13-trihydroxy-10-octadecaenoic acid (SB) | |
| | *Cyanogenic glycosides* | |
| | Sorcomisides A* (SB), prunasin (FR, L, BA, W, SE etc.), amygdalin (L, BA, W, SE etc.), sambunigrin (FR) | |
| | *Other compounds* | |
| | 1,2,4-trimethoxydibenzofuran-3,9-diol (BA), *β*-pyrufuran (BA), benzyl *β*-D-glucopyranoside (FR) | |
| *S. discolor* | *Carboxylic acids* | Mikulic-Petkovsek et al. (2017) |
| | Tartaric acid (FR), fumaric acid (FR), malic acid (FR), citric acid (FR) | |
| *S. domestica* | *Other compounds* | Chizzali and Beerhues (2012) |
| | γ-cotonefuran | |
| *S. gracilis* | *Cyanogenic glycosides* | Takaishi et al. (1977) |
| | Prunasin (L, BA, W), amygdalin (L, BA, W) | |
| *S. matsumurana* | *Cyanogenic glycosides* | Takaishi et al. (1977) |
| | Prunasin (L, BA, W), amygdalin (L, BA, W) | |
| *S. pohuashanensis* | *Carboxylic acids* | Li et al. (2012) |
| | Butanedioic acid (FR), (3*S*,5*S*)-3-(*β*-D-glucopyranosyloxy)-5-hydroxyhexonic acid ethyl ester (FR), 1-glyceryl linolate (FR) | |
| | *Cyanogenic glycosides* | |
| | prunasin (FR), amygdalin (FR) | |
| | *Other compounds* | |
| | parasorboside (FR) | |
| *S. sambusifolia* | *Cyanogenic glycosides* | Takaishi et al. (1977) |
| | prunasin (L, BA, W), amygdalin (L, BA, W) | |
| *S. tianschanica* | *Carboxylic acids* | Ayupbek et al. (2012) |
| | Hexacosanoic acid (L) | |
| | *Cyanogenic glycosides* | |
| | Prunasin (L), amygdalin (L) | |
| *S. tormnalis* | *Carboxylic acids* | Mikulic-Petkovsek et al. (2017) |
| | Tartaric acid (FR), fumaric acid (FR), malic acid (FR), citric acid (FR) | |

*BA* bark, *FR* fruit, *L* leaf, *SE* seed, *SB* stem bark, *W* wood. *Classified as phenol by the authors. Synonyms: [a]butanedioic acid, [b]hexanoic acid, [c]octanoic acid, [d]nonanoic acid, [e]decanoic acid, [f]dodecanoic acid, [g]tetradecanoic acid, [h]hexadecanoic acid, [i]heptadecanoic acid, [j]octadecanoic acid, [k]11-octadecenoic acid/trans-11-octadecenoic acid, [l]eicosanoic acid, [m]11-eicosenic acid, [n]docosanoic acid, [o]tetracosanoic acid

had $IC_{50}$ value of 23.4 μg/mL in DPPH test. Moreover, catechin-7-*O*-*β*-D-xylopyranoside and catechin-7-*O*-*β*-D-apiofuranoside, isolated from stem bark of *S. commixta*, showed significant antioxidant activity (Na et al. 2002a).

Several authors performed comparative analysis of different *Sorbus* extracts. 70% methanol extracts from various aerial parts (and in one case also their diethyl ether, ethyl acetate, n-butanol and water fractions) of *S. aucuparia*, *S. aria*, *S. intermedia*, *S. commixta*, *S. decora*, *S. gracilis*, *S. koehneana*, *S. pogonopetala*, *S. wilfordii*, *S. pohuashanensis*, *S. scalaris*, *S. prattii* var. *prattii*, *S. americana*, *S. sambucifolia*, *S. sitchensis*, *S. cashmiriana*, *S. setschwanensis* were screened for antioxidant activity using different models e.g. FRAP, DPPH, TEAC and AAPH-induced linoleic acid peroxidation tests. One of the most promising seems to be *S. aucuparia* inflorescence next to *S. wilfordii* leaves as well as *S. decora* and *S. koehneana* inflorescences (Olszewska and Michel 2009; Olszewska et al. 2010, 2012). Indeed, diethyl ether, ethyl acetate, and n-butanol fractions of water–methanol flower extract of *S. aucuparia* showed significant radical-scavenging activity (especially towards $OH^{\cdot}$, $ONOO^{-}$, HClO, and $O2^{\cdot-}$) (Olszewska et al. 2019). Olszewska (2011b) compared the activity of 70% methanol extracts from the leaves, fruits and inflorescences of *S. torminalis* with those of *S. aucuparia* using DPPH, ABTS and the AAPH-induced linoleic acid peroxidation test. *S. torminalis* extracts expressed antiradical activity towards DPPH, with TEAA values from 62.0 to 244.1 μmol trolox/g dw. Still, plant extracts derived from this species possessed weaker ability to scavenge radicals than those obtained from *S. aucuparia*. Ekin et al. (2016) underlined that among all tested thirty-four Rosaceae samples (therein ten *Sorbus* species from different localities), the best values in FRAP and DMPD tests were obtained in case of 75% ethanol extract of *S. umbellata* and *S. subfusca* leaves, respectively. In turn, *S. kusnetzovii* leaf extract exerted the strongest metal-chelating capacity (27.13 ± 2.01% at 2000 μg/mL), however still not so high as EDTA (97.66 ± 0.12% at 2000 μg/mL).

Although, the antioxidant activities of *S. lanata* and *S. cashmiriana* have not been investigated, there are three papers referring to the activity of their constituents. The former afforded three new phenols (sorlanin, sorbanin and sorbalanin) and a new triterpene—sorbanolic acid. In the latter two new coumarins, cashmin A and cashmin B, were found. Sorbanolic acid showed significant activity in DPPH assay ($IC_{50}$ = 24.2 μM), whereas sorlanin, sorbanin and sorbalanin had poor $IC_{50}$ values of 192.2 ± 2.9, 90.7 ± 0.5 and 445.9 ± 4.0 μM, respectively (ascorbic acid, $IC_{50}$ = 33.9 μM) (Uddin et al. 2013; Latif et al. 2014). Cashmin A and cashmin B showed significant antioxidant activity in DPPH and ABTS assays. Their $Fe^{+3}$ reducing and hydrogen peroxide scavenging activities were confirmed as well (Khan et al. 2015).

### *Antioxidant activity in cellular models*

Antioxidant activity of *S. domestica*, *S. aucuparia* and *S. hajastana* were assayed using human plasma model. The water–methanol flower extract of *S. aucuparia* and its fractions effectively protected human plasma exposed to oxidative/nitrative stress. Not only the levels of the oxidative stress biomarkers (3-nitrotyrosine, lipid hydroperoxides and thiobarbituric acid-reactive substances) were found to be decreased, but also the non-enzymatic antioxidant capacity of blood plasma was enhanced (Olszewska et al. 2019). Likewise, the defatted *S. domestica* leaf extract (methanol), at the concentration range of 1–50 μg/mL, decreased 3-nitrotyrosine, lipid hydroperoxides and thiobarbituric acid-reactive substances levels in human plasma (Matczak et al. 2018). Moreover, nine predominant polyphenols ((–)-epicatechin, procyanidin B2, procyanidin C1, rutin, quercitrin, quercetin, quercetin 3-*O*-(2″-*O*-*β*-D-glucopyranosyl)-α-L-rhamnopyranoside, quercetin 3-*O*-(2″-*O*-*β*-D-xylopyranosyl)-α-L-rhamnopyranoside and chlorogenic acid)—present in the leaf extract—significantly reduced lipid peroxidation and protein nitration as well as enhanced/normalized the non-enzymatic antioxidant capacity of blood plasma in the FRAP test (Rutkowska et al. 2019b). Finally, *S. hajastana* reduced lipid peroxidation in human plasma (Manukyan et al. 2019).

In another study, inhibitory effects of *S. amurensis* bark on lipid peroxidation in brain homogenates and erythrocyte hemolysis were assayed. The biological material, both erythrocytes and brains, were obtained from Sprague–Dawley rats. Here, n-butanol fraction of *S. amurensis* methanol extract was found to be active. Erythrocyte hemolysis decreased by 64.6 ± 2.0% and 78.9 ± 2.1% after incubation with

the extract at the concentration of 100 and 200 μg/mL, respectively. In turn, lipid peroxide generation was reduced by 90.7 ± 0.7% at 200 μg/mL (Kang et al. 2003). In another study, methanol extract from the fruits of *S. aucuparia* moderately (8.21 ± 0.64%) prevented lipid peroxidation (homogenized rat liver) (Mlcek et al. 2014).

## Antidiabetic activity

Among all *Sorbus* species, *S. decora* is most studied for potential antidiabetic activity as its bark was traditionally used to treat symptoms of diabetes. Therefore, surveys have appeared describing activity of the bark (or inner bark) extracts both in vitro and in vivo. Spoor et al. (2006) revealed that the ethanol extract from inner bark enhanced glucose uptake in C2C12 cells. Moreover, after 18–21 h incubation with the plant extract, the effect was comparable to that of a positive control (metformin in dose 400 μmol/L). What is noteworthy, no influence on basal or glucose-stimulated insulin secretion was observed in INS832/13 rat insulinoma cells, what suggests that antidiabetic effects were not related to affecting *β*-cells. Likewise, no glitazone-like activity was seen as triglyceride accumulation was not increased in differentiating 3T3-L1 adipocytes treated with the plant extract. Nevertheless, *S. decora* notably protected PC12-AC cells against glucose toxicity under high glucose conditions. Indeed, in another study, the ethanol extract at the concentration of 15 μg/mL increased glucose uptake in C2C12 cells after 18 h of incubation and inhibited glucose-6-phosphatase enzyme activity in H4IIE liver cells (Shang et al. 2015). Next, Martineau et al. (2010) studied mechanisms of glucose uptake improvement in C2C12 myoblasts by extracts from several Canadian species. The results indicate, that extracts, including that from the inner bark of *S. decora*, act through metformin-like mechanism, where the AMPK pathway is activated. We would like to underline, that also a pure compound isolated from stem bark of *S. decora*, namely 23,28-dihydroxylupan-20(29)-ene-3*β*-caffeate, significantly potentiated glucose uptake in C2C12 skeletal muscle cells with $EC_{50}$ = 1.47 μM (Guerrero-Analco et al. 2010). Finally, this very promising plant was examined in vivo using genetic KK-$A^y$ Type 2 diabetic mice, male Sprague–Dawley rats with streptozotocin-induced type 1 diabetes and insulin resistant rats treated for that purpose with 10% glucose water for 6 weeks. Ethanol extract from *S. decora* significantly decreased glycemia in model of Type 1 diabetes and the effect was observed after just a single dose (200 mg/kg, i.g.). Furthermore, the increasing intensity of peak decreases in glycemia observed during the experiment suggests a cumulative effect. Nevertheless, the effectiveness of the extract was not so high as that of the reference drug (metformin, 500 mg/kg, i.g.). On the other hand, modest hyperglycemia and hyperinsulinemia, observed in insulin-resistant model, were normalized when rats received *S. decora* extract (200 mg/kg/day, i.g.). Also, the HOMA insulin resistance parameter was reduced and the extract was as effective as metformin. In KK-$A^y$ Type 2 diabetic mice, the glycemia decreased by 15% after 7 days of treatment with the extract in dose 200 mg/kg/day (incorporated into food to avoid stressing animals) (Vianna et al. 2011).

Reports on the antidiabetic potential of *Sorbus* berries can also be found in the scientific literature. The diethyl ether and ethyl acetate fractions derived from methanol extracts of *S. domestica* fruits (differing in maturity stage) showed strong aldose reductase activity ranging from 72 to 93% at the concentration of 50 μg/mL (Termentzi et al. 2008a). Also a component of *S. domestica* fruits—(1*S*,3*R*,4*S*,5*R*)5-*O*-caffeoylquinic acid—showed an ability to reduce glucose uptake by HepG2 cells. This isomer of chlorogenic acid exerted hypolipidemic properties as well (Forino et al. 2015). In turn, Boath et al. (2012) revealed that polyphenol-rich extract of *S. aucuparia* inhibited α-glucosidase with $IC_{50}$ = 30 μg GAE/mL, which was comparable to acarbose.

It is probable that in the case of *S. commixta* bark and *S. pohuashanensis* fruits, triterpene constituents may at least in part contribute to the observed effects of extracts. Lupenone and lupeol (present in stem bark of *S. commixta*) inhibited noncompetitively PTP1B with $IC_{50}$ = 13.7 ± 2.1 and 5.6 ± 0.9 μM (Na et al. 2009). Also, 3*β*-acetoxy-urs-12-ene-28-oic acid, pomolic acid-3*β*-acetate and betulinic acid from *S. pohuashanensis* fruits had $IC_{50}$ values of 4.8 ± 0.5, 6.1 ± 0.3 and 3.5 ± 0.1 μM, respectively. Ursolic acid, a common triterpene in many *Sorbus* species (see Table 5) which was used as the positive control in this study, is a known PTP1B inhibitor ($IC_{50}$ = 3.4 ± 0.1 μM) (Li et al. 2014).

## Anti-inflammatory activity

Anti-inflammatory activity of *S. commixta* was confirmed both in vitro and in vivo. Regarding in vitro studies on LPS-stressed RAW 264.7 macrophages, 70% ethanol extract from *S. commixta* effectively inhibited NO and $PGE_2$ production (no effect on TNF-α) with concomitant influence on iNOS and COX-2 mRNA levels (Yu et al. 2009). Dose-dependent suppression at the transcriptional level of NO and $PGE_2$ production in LPS-induced RAW 264.7 cells was also observed for water extract from inner stem bark. Moreover, the extract was next tested in vivo and caused a significant reduction in arachidonic acid-induced ear edema in mice (pre-treated for 7 days by orally administered extract at the dose of 100 mg/kg or indomethacin 1 mg/kg) (Yu et al. 2011). What is noteworthy, *β*-sitosteryl-3-*O*-*β*-glucopyranoside, the main component of the bark of *S. commixta*, showed anti-inflammatory activity both in vitro and in vivo. The compound reduced NO, $PGE_2$, TNF-α, IL-1*β* and IL-6 production (together with iNOS and COX-2 expressions) and suppressed NF-kB activation in LPS-induced RAW 264.7 cells. Regarding the results of in vivo study in a carrageenan-induced mouse paw edema model, the edema rate was decreased by 63.2% and 32.4% after 3 h of *β*-sitosteryl-3-*O*-*β*-glucopyranoside administration at the dose of 25 mg/kg (p.o) and 100 mg/kg (p.o), respectively. The results were compared to ibuprofen (100 mg/kg, p.o.), which was used as drug reference and at that time reduced the edema rate by 50.4% (Yang and An 2014). Another isolate of *S. commixta* bark, namely (9*S*,12*R*,13*R*)-(*E*)-9,12,13-trihydroxy-10-octadecaenoic acid, reduced NO production in LPS-stimulated BV-2 cells with an $IC_{50}$ = 71.25 μM (Kim et al. 2016). Contrary to *S. commixta*, *S. alnifolia* (ethanol–water extract from leaves, branches and fruits) showed poor inhibitory effect on NO production in activated RAW 264.7 macrophages with $IC_{50}$ value > 500 μg/mL (Kim et al. 2010).

Some authors determined inhibitory activity of *Sorbus* species on lipoxygenase and hyaluronidase. Matczak et al. (2018) examined defatted (pre-extracted with chloroform) water–methanol extract from *S. domestica* leaves. The influence of both the extract and its fractions was analyzed and compared. The results showed that the most potent lipoxygenase inhibitor was ethyl acetate fraction with $IC_{50}$ value 115.54 ± 4.99 μg/mL (which was comparable to indomethacin, $IC_{50}$ = 92.60 ± 3.71 μg/mL) and the most active towards hyaluronidase was n-butanol fraction with $IC_{50}$ = 11.06 ± 0.30 μg/mL (indomethacin: $IC_{50}$ = 12.77 ± 0.91 μg/mL). Indeed, subsequent studies confirmed the inhibitory activity of extract components against the tested enzymes (Rutkowska et al. 2019b). Also, n-butanol fraction of *S. aucuparia* water–methanol flower extract revealed strong anti-hyaluronidase activity (even stronger than indomethacin), whereas its ethyl acetate and diethyl ether fractions were potent lipoxygenase inhibitors. All extracts expressed no influence on xanthine oxidase (Olszewska et al. 2019). One paper refers to the activity of cashmirol A and cashmirol B, two new triterpenes from *S. cashmiriana*. These compounds were found to be moderate lipoxygenase inhibitors in in vitro assay with $IC_{50}$ values 90.2 and 74.9 μM, respectively (baicalein was used as positive control, $IC_{50}$ = 8.0 μM) (Kazmi et al. 2009).

## Antimicrobial activity

The majority of papers referring to antimicrobial activity of *Sorbus* species provide data on the extracts from *S. aucuparia* fruits. Aqueous and 50% ethanol extracts inhibited the growth of *Bacillus cereus* MSCL 330, *Staphylococcus aureus* MSCL 334 and *Pseudomonas aeruginosa* MSCL 331 (against the latter, only extracts from fresh fruits were active) but no effects on *Escherichia coli* MSCL 332 and *Candida albicans* MSCL 378 were observed (Liepiņa et al. 2013). In another study, phenolic-rich fractions (SPE-purified acetone extracts) of wild *S. aucuparia* and its cultivars (Burka, Zoltaja, Titan, Granatnaja) showed a weak bacteriostatic activity against *Staphylococcus aureus* VTT E-70045. Zoltaja and Granatnaja inhibited weakly growth of *Escherichia coli* VTT E-94564T and Zoltaja slightly retarded *Salmonella enterica* sv. Typhimurium VTT E-981151 growth. In addition, extracts from wild *S. aucuparia* and the Burka cultivar affected M hemagglutinin-mediated hemagglutination of *E. coli* HB101 (pRR7) at concentrations of 1–2 μg and 0.5–1 μg of total phenolics/mL, respectively (Kylli et al. 2010). Krisch et al. (2008) screened antibacterial activity of juices as well as water and methanol pomace extracts from various berries against *Bacillus subtilis* ssp. *subtilis* BD 170, *B. cereus* var. *mycoides* ATCC 9634, *Escherichia coli*

SZMC 0582 and *Serratia marcescens* SZMC 0567. In general, *S. aucuparia* next to *Ribes nigrum* and *Cornus mas* exhibited the best inhibition capacity. Nohynek et al. (2006) examined polyphenolic-rich fraction of *S. aucuparia* towards *Clostridium perfringens* E-861$^T$, *Campylobacter jejuni* E-1008$^T$, *Bacillus cereus* E-727, *Staphylococcus aureus* E-045 and *Candida albicans* NCPF 3179, however *S. aucuparia* exhibited poor antimicrobial activity towards all tested strains with the exception of *Bacillus cereus* E-727. In a different study *S. aucuparia* fruit extracts (water and methanol) moderately affected the growth of *Escherichia coli* ATCC 25922 and *Staphylococcus aureus* ATCC 25923. Slightly better effects were seen in case of adequate extracts from fruits of *S. torminalis* f. *torminalis* and *S. torminalis* f. *semitorminalis* (Mrkonjić et al. 2017). Despite all above-mentioned studies, the antimicrobial activity of rowan fruits is still poorly argued and seems to be quite weak.

Kavak and Akdeniz (2019) examined antimicrobial activity of the leaf extract of *Sorbus umbellata* (Desf.) Fritsch var. *umbellata*. The extract suppressed the growth of *Staphylococcus aureus* ATCC29213 and *Escherichia coli* ATCC25922, but displayed no effect on *Bacillus cereus* ATCC7064, *Bacillus subtilis* ATCC 6633, *Pseudomonas aeruginosa* ATCC27853 and *Listeria monocytogen* ATCC 7644 (ampicillin and gentamicin used as controls). Moreover, the extract inhibited the bacterial $\beta$-glucuronidase with $IC_{50}$ = 117.9 μg/mL.

In turn, Turumtay et al. (2017) compared activity of fruit and leaf DMSO extracts from *S. aucuparia* as well as *S. caucasica* var. *yaltiriki* against Gram-negative (*Escherichia coli* ATCC25922, *Pseudomonas aeruginosa* ATCC 27853, *Salmonella typhimurium* ATTC14028) and Gram-positive bacteria (*Staphylococcus aureus* ATCC25923, *Bacillus subtilis* ATCC6633, *Enterococcus faecalis* ATTC29212). Although the activity of the extracts varied, they were all inactive against Gram-positive bacteria and active against *P. aeruginosa*. In the same study, the effects of methanol extracts on both non-replicative (Klenow Fragment-KF and Bacillus Large Fragment-BLF) and replicative (DnaE and PolC) bacterial DNA polymerases were measured. *S. aucuparia* fruit extract inhibited all replicative and non-replicative DNA polymerases, whereas leaf extract was able to affect only the two replicative ones. In turn, leaf extract of *S. caucasica* var. *yaltirikii* showed activity against KF (strong inhibitory effect), DnaE and polC, while fruit extract inhibited only KF and DnaE.

## Cytotoxic activity

Many authors performed cytotoxicity studies on *Sorbus* species to confirm cellular safety or potential anticancer activity of investigated analytes. Scientific literature provides information on cytotoxicity of extracts derived from various *Sorbus* berries. Fairly well documented is the activity of *S. aucuparia* fruits, which were examined both in vitro and in vivo. Boncler et al. (2017) used a screening assay for the assessment of cytotoxicity of various agents towards HepG2, Caco-2, A549, HMEC-1 and 3T3 cells. Three key cell indicators were measured: cell membrane integrity, mitochondrial membrane potential and nuclear size. *S. aucuparia* fruit extract exerted relatively high toxicity especially where the nuclear area was concerned. In another study, a polyphenol-rich extract from rowanberries reduced the viability of HeLa cells to about 50% at 50 μg of GAE/mL (McDougall et al. 2008). Also methylene chloride fraction of ethanol extract from *S. aucuparia* reduced the viability of HeLa cells in MTT assay with $IC_{50}$ = 15 ± 03 μg/mL (plant organ not mentioned) (Bozkurt-Guzel et al. 2018). Goun et al. (2002) tested not only methylene chloride, but also methanol extracts (extraction in sequence) towards mouse leukemia cells (ATCC L1210) and only the first one was active (likewise, plant organ not mentioned). Mrkonjić et al. (2017) observed poor cytotoxic activity of water and methanol extracts from fruits of *S. aucuparia* (fruit jam was studied as well, but it was totally inactive). Cytotoxicity studies were performed towards HeLa, HT-29, MCF7 and normal MRC-5 cells in comparison to podophyllotoxin using the SRB assay. The $IC_{50}$ values of all extracts ranged from 414 ± 12.5 to 965 ± 27.9 μg/mL and no selectivity of action was noted (podophyllotoxin, $IC_{50}$ values from $(1.30 \pm 0.20) \times 10^{-3}$ to $(4.70 \pm 0.80) \times 10^{-3}$). Razina et al. (2016) examined in vivo antitumor activity of acidified 95% ethanol extract from *S. aucuparia* fruits standardized on anthocyanins. This extract was given to female C57BL/6 mice with intramuscularly transplanted melanoma B-16 and Lewis lung carcinoma cells ($5 \times 10^6$ cells/0.1 mL saline). Therapy with the extract alone or in combination with cyclophosphamide markedly decreased the tumor

growth in both cases. Similarly, Isaikina et al. (2018) revealed a potential antitumor activity of acidified 95% ethanol extract from rowanberries in C57BL/6 female mice with transferred Lewis lung carcinoma.

As regards reports on cytotoxicity of berries of other *Sorbus* species, ethanol extract from *S. sambucifolia* fruits at the dose of $5 \times 10^3$ μg/mL decreased HL-60 leukemic cells proliferation by 51% in Alamar Blue method. Also differentiation-inducing effects were observed (Yoshizawa et al. 2000). *S. pohuashanensis* fruits were tested against HT-29 and HepG2 cells and significant dose-dependent inhibition of cell proliferation was observed (Fan et al. 2011). Cytotoxicity of water–methanol extract from *S. commixta* fruits was evaluated on A549, H1264, H1299 and Calu-6 cells differing in p53 gene status with the help of WST-1 assay. The extract induced apoptotic process and this effect was independent of cellular p53 status (Lee et al. 2017). Finally, percent of HepG2 cells viability was 78.13% after incubation with *S. hajastana* extract at the concentration of 200 μg/mL (Alamar Blue assay) (Manukyan et al. 2019).

Even though reports on cytotoxic activity of extracts from plant parts other than fruits are definitely less numerous, some of them provided interesting results. Water extract from *S. commixta* stem and bark showed significant effects in Hep3B (from 250 μg/mL of the extract), HepG2 HCC cells (from 200 μg/mL), Chang liver cells (at 500 μg/mL) and HCT116 colon cancer cells (from 100 μg/mL). Moreover, the anti-invasive and anti-migration potential of this extract was confirmed. In metastatic Hep3B cells the matrix metalloproteinase-9 activity and expression was decreased, likewise the expression of the chemokine receptors. What is more, actin fiber arrangement was found to be suppressed (Park et al. 2017). Results from another study showed that the water extract (*S. commixta* stem and bark) inhibited cell viability in several liver and colon cancer cells, i.e. Hep3B, HepG2 and HCT116 cells with $IC_{50}$ values of 300.1, 237.8 and 77.7 μg/mL, respectively. Further analysis on HCT116 cells revealed that this extract caused apoptosis via the ROS-mediated mitochondrial pathway (Moon et al. 2018). What is noteworthy, not only *S. commixta* extracts were examined, but also its components. Kim et al. (2016, 2018) and Choi et al. (2018) tested several isolates from the bark of *S. commixta*, including four new structures, namely 1,2,4-trimethoxydibenzofuran-3,9-diol, sorcomic acid, sorcomisides A and sorcomisides B, however these compounds were found to be inactive.

Ethanol–water leaf extract from *Sorbus umbellata* (Desf.) Fritsch var. *umbellata* displayed cytotoxic activity towards A549 and MCF-7 cells in MTT assay with the highest inhibition of cell proliferation observed for A549 cells (71.8% at 150 μg/mL) (Kavak and Akdeniz 2019).

## Neuroprotective activity

Ethanol extract from the stem of *S. commixta* showed neuroprotective activity against A$\beta$42 toxicity both in vitro and in vivo. In case of in vivo study, *Drosophila* models were employed, where A$\beta$42-expressing flies showed Alzheimer's disease-like phenotypes, including decreased survival rate and motility, malformation of the eye as well as increased cell death in the larval brain and increased ROS levels in the eye imaginal discs. The extract ameliorated such phenotypes and its neuroprotective activity was confirmed in vitro using A$\beta$-treated SH-SY5Y cells (Liu et al. 2015). It is also interesting to note that sorcomic acid, a new fatty acid from the bark of *S. commixta*, was itself tested for potential neuroprotective activity, which was assessed in vitro using an ELISA development kit. Sorcomic acid significantly induced NGF secretion in C6 glioma cells (233.40 ± 12.82%, percentage of the untreated control group) in comparison to a positive control, 6-shogaol (168.58 ± 7.16%) (Kim et al. 2016).

Cheon et al. (2017) tested whether methanol extract from stem and twigs of *S. alnifolia* has protective effects on $MPP^+$-induced dopaminergic neurodegeneration. It was shown that the extract protected $MPP^+$-treated PC12 cells with the viability values 63.61 ± 11.76, 79.93 ± 9.22 and 85.83 ± 8.74% (% of control) at 125, 250 and 500 μg/mL, respectively. Furthermore, several in vivo tests were performed using *Caenorhabditis elegans*. *S. alnifolia* extract restored the loss of viability of $MPP^+$-treated worms by 10.62%, 21.85%, and 54.93% at 62.5, 125, and 250 μg/mL, respectively. Moreover, both chemically- and genetically-induced dopaminergic neurodegeneration were reduced (BZ555 and UA57 strains were used). Food-sensing assay showed that dopaminergic specific behavioural deficit was rescued in worms fed with *S. alnifolia* extract. Also, the influence of the extract on α-synuclein aggregation in

*C. elegans* (transgenic strain NL5901) was evaluated, but no significant effect was observed.

Some *Sorbus* species were found to have an ability to inhibit AChE and/or BuChE. Methanol extracts (75%) from the leaves of several *Sorbus* species, namely *S. aucuparia*, *S. caucasica*, *S. caucasica* var. *yaltrikii*, *S. kusnetzovii*, *S. persica*, *S. roopiana*, *S. subfusca*, *S. torminalis* and *S. umbellata*, were examined for possible AChE and BChE inhibitory activities. All samples were tested at the concentrations of 200 μg/mL and compared to the reference drug (galanthamine, 100 μg/mL). The strongest inhibition of AChE was observed for *S. umbellata* extract (58.18 ± 3.77%, $IC_{50}$ = 177.8 μg/mL), however this was a weak effect when compared to the reference compound galanthamine ($IC_{50}$ = 1.78 μg/mL). Among all tested *Sorbus* species, *S. subfusca* reached the highest percent of BChE inhibition with 43.11 ± 3.24% (Ekin et al. 2016). Previously, Hasbal et al. (2015) observed moderate antiacetylcholinesterase activity of *S. torminalis* fruits water extract. Interestingly, in the study of Mrkonjić et al. (2017), neither of extracts from *S. torminalis* f. *torminalis* and f. *semitorminalis* was active (the authors tested water and methanol extracts as well as fruit jams). Nevertheless, the anti-AChE activity of adequate *S. aucuparia* extracts was noted ($IC_{50}$ values ranging from $(2.02 \pm 0.02) \times 10^3$ to $(3.81 \pm 0.21) \times 10^3$ μg/mL; galanthamine, $IC_{50}$ = 0.39 ± 0.01 μg/mL).

## Hepatoprotective activity

Triterpenoid fraction obtained from *S. pohuashanensis* fruits was tested for potential hepatoprotective effect in animal model of APAP-induced liver injury (male ICR mice). Not only the levels of AST, ALT, TNF-α, IL-1β, IL-6, MDA, SOD, GSH, CAT were normalized after treatment, but also hepatic tissues necrosis, hemorrhage and infiltration of inflammatory cell were inhibited. Moreover, western-blot and RT-PCR analysis revealed suppressive effect on iNOS and COX-2 over-expressions. Finally, triterpenoid fraction reduced APAP-induced phosphorylation of MAPK family signals (Yin et al. 2019).

Lee et al. (2006) extracted *S. commixta* bark with 80% aqueous methanol and then partitioned the extract with n-hexane, chloroform, ethyl acetate n-butanol and water. Methanol extract and its fractions were than administered to alcohol-treated Sprague–Dawley rats (alcohol intake 3.0 g/kg). Significant decrease in blood alcohol concentration was observed when rats were treated with methanol extract at doses higher than 200 mg/kg. The highest activity were observed for the ethyl acetate fraction (rich in phenolics), which caused about 46% decrease 2 h post alcohol administration at the dose of 150 mg/kg. Moreover, increased MDA levels and decreased catalase activity were reversed by the ethyl acetate fraction but no statistically significant influence on ADH, ALT, AST, GSH levels or SOD activity was observed (however the last two markers were not affected by the alcohol treatment itself).

## Cardioprotective activity

*S. pohuashanensis* flavonoid fraction showed a protective effect against ATO-induced cardiotoxicity in male BALB/c mice and H9c2 cells. ATO-induced apoptosis and oxidative stress were suppressed both in vivo and in vitro. Moreover, alterations of cardiac tissue such as myofibrillar loss, cytoplasmic vacuolization and cardiomyocyte necrosis were observed in the hearts of ATO-treated mice. Pretreatment with *S. pohuashanensis* flavonoids (20 mg/kg, intraperitoneal injection) alleviated these abnormalities. Also, the levels of creatine kinase, creatine kinase-MB, lactate dehydrogenase and glutamic oxaloacetic transaminase were found to be significantly reduced. (Yu et al. 2017).

## Vasorelaxant and anti-atherogenic activities

To the best of our knowledge, only *S. commixta* bark extracts were tested for potential vasorelaxant and anti-atherogenic activities. Anti-atherogenic effects of methanol extract were assessed by Sohn et al. (2005a, b) using two rat models. In one case, atherosclerosis in male Sprague–Dawley rats was induced by administration of $N^G$-nitro-L-arginine methyl ester, which inhibited NO production and led to inflammation. Over-expressions of MCP-1, NF-κB p65, adhesion molecules (including ICAM-1, VCAM-1, E-selectin), ET-1 and ACE as well as decreased ecNOS expression in aorta were observed. All these abnormalities were ameliorated by chronic treatment with the extract in doses 100 mg/kg/day and 200 mg/kg/day (Sohn et al. 2005a). In the second model male

Sprague–Dawley rats were fed an atherogenic-diet. Likewise, increases in the expression of ET-1, NF-kB p65, E-selectin, ICAM-1 and VCAM-1 were reversed. Moreover, the extract (in dose 100 mg/kg/day and 200 mg/kg/day) improved aortic NOS/NO system dysfunction (Sohn et al. 2005b).

Regarding a potential vasorelaxant activity, n-butanol fraction of S. *commixta* stem bark methanol extract was tested using aortic rings isolated from healthy male Sprague–Dawley rats. First, the aortic tissues were contracted with phenylephrine ($3 \times 10^{-6}$ M). The extract at the concentration of 100 μg/mL caused 92.9 ± 1.9% relaxation. What is more, when $N^G$-nitro-L-arginine methyl ester (NOS inhibitor) was added or functional endothelium was removed, the activity disappeared suggesting that vasorelaxant effect may be associated with endothelial NO signaling pathway (Yin et al. 2005). These findings were also confirmed by Kang et al. (2005). Here, methanol extract induced relaxant response of the phenylephrine-contracted aorta obtained from male Sprague–Dawley rats. Likewise, the endothelium-denuded aortic tissues were insensitive. Pretreatment with $N^G$-nitro-L-arginine methyl ester or soluble guanylyl cyclase inhibitors (methylene blue and 1*H*-[1,2,4]-oxadiazole-[4,3-α]-quinoxalin-1-one) blocked the extract-induced relaxation. Moreover, cGMP production in the carotid artery and human umbilical vein endothelial cells was found to be increased after incubation with *S. commixta* extract. These findings suggest involvement of endothelium-dependent NO-cGMP signaling pathway.

Other activities

Exposure of human dermal fibroblasts to UVA radiation (6.3 J/cm$^2$) caused increase in MMP-1 expression by approximately 41%, which led to degradation of collagen, gelatin etc. Ethanol extract from *S. commixta* bark affected MMP-1 expression in UVA-irradiated cells and showed photoprotective activity. Moreover, enzymatic conversion of crude extract enhanced this inhibitory effect. Thus, *β*-glucanase-treated extract at concentrations of 2.5, 5, 10, and 20 μg/mL reduced the expression level of MMP-1 by 7.4, 16.5, 32.4, and 55.9% respectively (Bae et al. 2007). In turn, Xuan et al. (2018) investigated the effect of *S. commixta* twig ethanol extract on MMPs levels in UVB-irradiated human dermal fibroblasts (80 mJ/cm$^2$). The extract at concentrations of 12.5–50 μg/mL notably decreased UVB-induced MMP-1, MMP-2, MMP-3 and c-Fos expressions (no effect on c-Jun phosphorylation) as well as suppressed the intracellular ROS generation. These results suggest involvement of MAPK pathway.

Ethanol extracts from stem and leaves of *S. commixta* showed anti-lipase and anti-phosphodiesterase activity ($IC_{50}$ values of 29.6 μg/mL and 20.08 μg/mL, respectively), however it was not so effective as the reference drug orlistat ($IC_{50}$ = 0.076 μg/mL). Phosphodiesterase activity was evaluated using the PDE-GloTM phosphodiesterase activity kit whereas pancreatic lipase inhibitory activity was assayed by measuring the hydrolysis of p-nitrophenyl butyrate to p-nitrophenol (Lee et al. 2012).

Goun et al. (2002) revealed that methanol extract of *S. aucuparia* showed weak antithrombin activity (plant organ not mentioned), whereas Tam et al. (2009) and Cieniak et al. (2013) have found that *S. decora* ethanol extract (we can only assume that the extract was derived from the bark) may affect CYP-mediated metabolism of other drugs.

It is noteworthy that sorbicin A and sorbicin B, new triterpenes isolated from *S. cashmiriana*, inhibited urease as well as α-chymotrypsin in vitro. In urease inhibitory assay both compounds displayed inhibitory potential with $IC_{50}$ values 85.2 ± 0.28 and 17.8 ± 0.12 μM, whereas thiourea—positive control—had an $IC_{50}$ value of 21.6 ± 0.18 μM. Also, both compounds inhibited α-chymotrypsin with $IC_{50}$ values 23.2 ± 0.09 and 22.7 ± 0.12 μM (positive control—chymostatin, $IC_{50}$ = 7.2 ± 0.26 μM) (Kazmi et al. 2011).

## Conclusions

As presented in this work, many *Sorbus* species have an established position in folk medicine. However, not all ethnomedical applications have been confirmed by scientific studies. Even though many species showed antioxidant activity, which can support their value in the treatment of many diseases, only in a few cases more targeted studies were conducted to confirm specific folk usage. One of the fairly well documented medicinal uses is the antidiabetic activity of the bark of *S. decora*. It is noteworthy that in this case not only in vitro tests were performed, but also in vivo studies

in three animal models of insulin resistance and diabetes. Although reports indicate that *S. domestica* berries were also applied as antidiabetic remedies, their therapeutic properties do not have much support in scientific data. However, their aldose reductase activity was observed, which could help to prevent retinopathy and neuropathy in people with diabetes. On the other hand, hypoglycemic potential of (1*S*,3*R*,4*S*,5*R*)5-*O*-caffeoylquinic acid, which is a component of *S. domestica* fruits, seems to be noteworthy. *S. commixta* is another *Sorbus* species, the traditional medicinal usage of which seems to be explained by recent scientific findings. Its bark preparations have been used to treat diseases related to inflammation like asthma or bronchitis. Indeed, the anti-inflammatory effect of aqueous extracts was confirmed both in vitro and in vivo. Moreover, one in vivo study proved the efficacy of the bark of *S. commixta* in atherosclerosis. Nevertheless, most folk applications of *Sorbus* preparations are not supported by scientific evidence thus attempts should be made to confirm their effectiveness.

As mentioned above, biological studies have been conducted primarily on plant extracts. However, only in some papers (mainly those published in recent years) their chemical constituents were determined. More often, the authors measured the total phenolic content, but it still does not explain which compounds are responsible for the activity of whole extracts. A small share of in vivo as well as safety studies is also noticeable, which extends the area of potential additional analyzes.

Regarding phytochemical studies, they all revolved around a few most commonly found species. Thus, a large number of *Sorbus* representatives have not been studied as thoroughly, or at all. Moreover, an overwhelming amount of papers was devoted to identification of phenolic compounds, which means, that *Sorbus* species are worthwhile to further investigate phytochemically.



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