Flavonoids of the Caryophyllaceae

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Abstract The plant family Caryophyllaceae, commonly known as the pink family, is divided into 3 subfamilies and contains over 80 genera with more than 2600 species that are widely distributed in temperate climate zones. Plants belonging to this family produce a variety of secondary metabolites important in an ecological context; however, some of these metabolites also show health-promoting activities. The most important classes of phytochemicals include saponins, phytoecdysteroids, other sterols, flavonoids, lignans, other polyphenols, essential oils, and N-containing compounds such as vitamins, alkaloids or cyclopeptides. Flavonoids are polyphenolic compounds that remain one of the most extensively studied constituents of the Caryophyllaceae family. Numerous structurally diverse aglycones, including flavones, flavonols, flavonones (dihydroflavones), flavonols, isoflavones, and their O- or C-glycosides, exhibit multiple interesting biological and pharmacological activities, such as antioxidant, anti-inflammatory, anti-oedemic, antimicrobial, and immunomodulatory effects. Thus, this review analysed the flavonoid composition of 26 different genera and more than 120 species of Caryophyllaceae for the first time.

Keywords Caryophyllaceae · Phytochemistry · Flavonoids · Secondary metabolites

Introduction

The Caryophyllaceae family, commonly known as the pink family, contains over 80 genera with more than 2600 species. The pink family is divided into 3 subfamilies, Paronychioideae, Alsinoideae, and Caryophylloideae, according to the presence or absence of stipules as well as the type of calyx and corolla. Plants of the Caryophyllaceae family are erect, prostrate, annual or perennial herbs or shrubs with simple cross-opposite leaves and swollen nodes. Tetramerous or pentamerous flowers are frequently gathered in panicle, raceme, or capitulum inflorescences (Hegnauer 1964; Kubitzki 1993; Schweingruber 2007).
The subfamily Paronychoideae, containing the genera *Spergula* L., *Spergularia* Presl., *Polycarpon* L. *Herniaria* L., and *Paronychia* Mill., occurs mostly in warm and tropical parts of the world. The characteristic attributes of these plants are leaves with stipules and visible separation of calyx from the corolla. The lack of stipules and the unique corolla are typical for members of the subfamily Alsinoideae: The genera *Scleranthus* L., *Arenaria* L., *Sagina* L., *Cerastium* L., *Minuartia* L., *Stellaria* L., and *Colobanthus* Bartl. are widespread on all continents and are even present in Antarctica. Several species of the subfamily Caryophylloideae are field weeds that inhabit northern temperate climate regions. The specific structures of this subfamily are long calyx tubes that occur in *Agrostemma* L., *Maleandrium* Roehl., *Silene* Mill., *Gypsophila* L., and *Dianthus* L. (the largest genus). A great number of Caryophyllaceae species are grown as decorative landscape plants. Furthermore, many members of this family produce secondary metabolites with medicinal properties (Brockington et al. 2011; Volodin and Volodina 2015).

**Diversity of phytochemicals in Caryophyllaceae**

Caryophyllaceae are known to be a rich source of pharmacologically active secondary metabolites spanning several structural chemical classes. Secondary metabolites are important for plants as protective chemicals against herbivores (insects, molluscs, vertebrates) and microbial pathogens (fungi, bacteria, viruses), UV light, and other plants competing for light, water, and nutrients. In addition, many secondary metabolites serve as signalling compounds to attract pollinating and seed-dispersing animals and provide communication signals among plants and symbiotic microbes (Wink 2011).

The main secondary metabolites of Caryophyllaceae are saponins, phytocadysteroids, other sterols, flavonoids, lignans, other polyphenols, essential oils, and N-containing compounds such as vitamins, alkaloids and cyclic peptides.

**Methodology**

The search strategy helps to define appropriate search string and identify the relevant thematic databases to collect the relevant scientific literature. The search databases for this review were SCOPUS, PubMed/MEDLINE, Web of Science (SCI-EXPANDED), Wiley Online Library, Taylor & Francis Online, Google Scholar, REAXYS Database, Science Direct/ELSEVIER, and EBSCO Discovery Service (EDS). They have been searched systematically for articles published from 1950 until 2020. The following syntax was used: TITLE-ABS-KEY as additional search engine in combinations of the above keywords like “Caryophyllaceae”, OR “genus” (each genus from the Caryophyllaceae family was introduced), OR “phenolic compounds”, OR “flavonoids”, OR “flavones”, OR “flavonols”, OR “flavonones”, OR “isoflavones”, OR C-flavonoids”, OR “Caryophyllaceae”, OR “saponins”, OR “phytoecdysteroids”, OR “essential oils”, OR “volatile compounds”, OR “sterols”, OR “N-containing compounds”, OR “alkaloids”, OR “cyclic peptides”, OR “vitamins”, OR “lignans”, OR “bioavailability”, OR “metabolism”, OR “biological activity”. Search terms had run in separate or with limited combinations that considered the requirements, or limitations, of the database used. Additionally, based on USDA Plant Database and Kew Science (Royal Botanic Gardens), we have been ascertimation the genera belonging to the Caryophyllaceae family (USDA Plant Database 2020; Kew Science 2020).

**Triterpene saponins**

Triterpene saponins constitute the greatest proportion of all phytochemicals known to be present in Caryophyllaceae. The structure of Caryophyllaceae saponins may vary with respect to genera within a family, as well as to plant organs. Oleanane-type saponins, such as gypsogenin, gypsogenic acid, quillaic acid (Fig. 1), 16α-hydroxygypsogenic acid or their derivatives, constitutes the main group of saponins in these plants (Hegnauer 1989; Vincken et al. 2007; Böttger et al. 2011; Cheikh-Ali et al. 2019). For example, this class of compounds is synthesized in *Gypsophila altissima* (Chen et al. 2010a, b), *Gypsophila glomerata* (Gevrenova et al.
Gypsophila capillaris (Elgamal et al. 1995), Saponaria officinalis (Koike et al. 1999), Silene vulgaris (Kim et al. 2015), Vaccaria segetalis (Koike et al. 1998), Dianthus versicolor (Ma et al. 2009), Silene cucubalus (Larhsini et al. 2003), Paronychia chionaea (Avunduk et al. 2007) and many other species (Hegnauer 1964; Böttger and Melzig 2011). Moreover, among triterpene saponins from Caryophyllaceae, ursane-type, hopane-type, and lupane-type saponins have also been reported (Vincken et al. 2007). For instance, succulentoside A (Fig. 1) and B, which are hopane-type saponins, were isolated from Polycarpon succulentum (Meselhy and Aboutalib 1997). Gypsophilin (Fig. 1), its glucosyl ester gypsophilinoside and sulfated lupane triterpenes were detected in Gypsophila repens (Elbandy et al. 2007).

**Phytoecdysteroids**

Phytoecdysteroids, structural analogues of the insect moulting hormone ecdysone, are another group of compounds commonly found in Caryophyllaceae. Several Silene Mill. species, e.g., S. guntensis (Mamadalieva et al. 2011), S. antirrhina, S. chlorifolia, S. cretica, S. disticha, S. echinata, S. italicca, S. portensis, S. pseudotites, S. radicosa, S. regia (Meng et al. 2001), S. viridiflora, S. linicola (Mamadalieva et al. 2004), S. nutans, S. otites, and S. tatarica (Bathori et al. 1990), are rich sources of 20-hydroxyecdysone (Fig. 2). Along with 20-hydroxyecdysone, in the genus Silene Mill., a notably large number of structurally various phytoecdysteroids have been observed (Mamadalieva et al. 2014). Furthermore, plants of the genus Coronaria L. are potential producers of ecdysteroid compounds such as viticosterone E, α-ecdysone, taxisterone (Fig. 2), polypodine B, 20,26-dihydroxyecdysone, 2-deoxyecdysone, and 20-hydroxyecdysone (Mamadalieva et al. 2008). Several ecdysteroids were also established in Silene flos-cuculi (syn. Lychnis flos-cuculi) (Báthori et al. 2001; Dinan et al. 2020). Based on TLC and HPLC analyses, the biotechnological regenerated shoots and roots of L. flos-cuculi, reveals the ability to accumulate 20-hydroxyecdysone and polypodine B (Thiem et al. 2016; Maliński et al. 2019).
Essential oils and volatile compounds

Essential oils are widely distributed in the plant kingdom. This finding suggests that essential oils are also produced in flowering parts of taxa in the pink family. As essential oils are isolated by distillation, they contain a variety of volatile molecules—terpenes and terpenoids, phenol-derived aromatic components, and aliphatic constituents. Components of volatile oils isolated from *Dianthus acicularis* are chiefly 2-pentadecanone (Fig. 3) and 2-tridecanone, which are presumed to be responsible for the insect repellent activity of this plant (Kirillov et al. 2017). According to analyses of the major constituents of *Dianthus calocephalus* and *Dianthus carmelitarum* essential oils, the presence of heneicosane, docosane, tetraicosane, phytol, 4,4-dimethyl-2-pentene, pentacosane, and hexahydrofarnesyl acetone (Yu¨ celi and Yaylı 2018). Additionally, floral fragrance compounds were also established in other *Dianthus* L. species and *Saponaria officinalis* with the largest amounts of benzenoids, phenyl propanoids, and isoprenoids (Jürgens et al. 2003). Gas chromatography and gas chromatography combined with mass spectrometry (GLC-MS) examinations of aerial parts of *Silene morganae* revealed the presence of over 30 compounds with the highest content of monoterpenic hydrocarbons being of terpenoids (Azadi and Sohrabi 2014). Furthermore, benzenoids followed by FADs seems to be the dominating compound classes of aromatic compounds in night-blooming or moth-pollinated flowers of *Silene* Mill. species (Jürgens et al. 2002; Jürgens 2004). Essential oils and their volatile components were also observed in *Minuartia recurva* (Jovanović et al. 2009), *Dianthus caryophyllus* (Nerio et al. 2010), *Dianthus cruentus* (Radulović et al. 2018), some *Silene* species (Dötterl and Jürgens 2005; Mamadalieva et al. 2014; Mihaylova et al. 2018), *Gypsophila bicolor* (Shafaghat and Shafaghatlonbar 2011), and two hermaphroditic *Schiedea* species (Powers et al. 2020).

Sterols

Sterols seem to be useful chemotaxonomic markers at the species level within families of the order Caryophyllales. Atypical for higher plants but predominant in the pink family, the sterol-type class of compounds 7-sterols represented by 22-dihydrospinasterol (Fig. 4) occur in *Gypsophila perfoliata* (Schmidt et al. 1996), *Gypsophila paniculata*, *Silene cucubalus*, *Arenaria serpyllifolia*, *Cerastium vulgarum*, *Cerastium arvense*, *Myosoton aquaticum*, *Minuartia caroliniana*, *Spergula arvensis*, *Saponaria officinalis*, *Dianthus armeria*, *Lychnis alba*, *Paronychia virginica* and *Scleranthus annuus* (Salt and Adler 1986). Recent research revealed the presence of the x-spinasterol 3-O-β-D-glucoside in the roots of *Psammosielen tunicoides* (Zhou et al. 2013) and the roots/rhizomes of *Silene tatarinowii* (Liang et al. 2019).
Cyclic peptides

Cyclic peptides, consisting of a maximum of 14 amino acid residues, are typical N-containing secondary metabolites from Caryophyllaceae (Ma et al. 2006). Genera containing cyclopeptides as major phytochemicals among all plants from this family seem to be Dianthus L., Gypsophila L., Stellaria L., and Vaccaria Mill. For example, the cyclic peptides gypsophins A–F were isolated from the roots of Gypsophila oldhamiana (Wang et al. 2013); the hexapeptides dianthins E, G, and H were found in the aerial parts of Dianthus superbus (Tong et al. 2012); and diandrines A–D (Fig. 5) and drymarins A–B occur in Drymaria diandra (Hsieh et al. 2004a, b; Ding et al. 2000). According to available data, seeds of Vaccaria segetalis are a valuable source of the penta- and hexapeptides segetalin B and segetalin A, respectively (Itokawa et al. 1995; Wang et al. 2011). It is worth mentioning that this group of compounds is present in taxa of the subfamily Alsinoidae, which grow in Antarctica (Jia et al. 2004).

Alkaloids

Another group of nitrogen-containing secondary metabolites are alkaloids, which also occur in Caryophyllaceae to some degree. In particular, alkaloids belonging to the β-carboline group have been described (Dai et al. 2018). For instance, siliendines A–D were isolated from the aerial parts of Silene seoulensis (Seo et al. 2020), drymaritin from the whole plant material of Drymaria diandra (Hsieh et al. 2004a, b), oldhamianines A and B from the roots of Gypsophila oldhamiana (Zhang et al. 2015), and...
arenarines A-D from *Arenaria kansuensis* (Wu et al. 1989; Bracher and Puzik 2004). Phytochemical investigation of the roots of *Stellaria dichotoma* led to the isolation of 23 various \(\beta\)-carboline-type alkaloids, including stellarines A-B, dichotomides I-XIV, dichotomines A, B, E (Fig. 6), and K, L, glucodichotomine B and 1-acetyl-3-methoxycarbonyl-\(\beta\)-carboline (Chen et al. 2010a, b; Luo et al. 2012). *Brachystemma calycinum* also produces alkaloids: Brachystemidines A-E were isolated from the roots of this plant (Cheng et al. 2002). Superbusines A and B, which are quinolone alkaloids, were detected in *Dianthus superbus* (Sun et al. 2019).

**Vitamins**

Analysis of plant-derived vitamins showed the presence of four tocopherols (\(\alpha\), \(\beta\), \(\gamma\), \(\delta\)) with a different number of methyl substitutions in *Silene vulgaris* as well as vitamin C and phylloquinone, known as vitamin K1 (Fig. 7). Upon examination of *S. vulgaris*, the presence of the antioxidant \(\beta\)-carotene, a provitamin of vitamin A, was also reported (Vardavas et al. 2006; Morales et al. 2012; Mamadalieva et al. 2014). Moreover, \(\beta\)-carotene was reported in other Caryophyllaceae plants, e.g., in *Stellaria media* whose seeds contain vitamin B2 (riboflavin), vitamin B3 (niacin) and vitamin E (Slavokhotova et al. 2011; Taskin and Bitis 2013).

**Phenolic compounds**

Phenolic compounds constitute a large proportion of secondary metabolites in Caryophyllaceae plants. Phenolic acids are the main polyphenols produced by plants. However, only a few publications report on phenolic compound isolation and identification in Caryophyllaceae. For instance, caffeic acid was obtained from aerial parts of *Silene* (syn. *Lychnis*) *flos-cuculi* (Tomczyk 2008), \(p\)-coumaric acid, dihydroferulic acid, and syringic acid were identified in the ground roots, stems, leaves, and flowers of *Gypsophila paniculata* (Chou et al. 2008); and *Dianthus* species are a source of gentisic acid, a commonly reported aromatic acid in green plants (Griffiths 1959). Fractionation of a *Gypsophila sphaerocephala* extract resulted in the isolation of 3,4-dihydroxybenzoic acid, syringic acid, \(p\)-hydroxybenzoic acid, and rosmarinic acid (Fig. 8) from the methanol extract and rosmarinic acid and syringic acid from the water extract (Altay et al. 2018). Additionally, the *Silene* Mill. genus is also known as a source of phenolic acids (Mamadalieva et al. 2014). Derivatives of cinnamic acid or benzoic acid and aromatic amino acids (anthranilic acid), so-called anthranilamides with phytoalexin-related activity, are commonly found in parts of *Dianthus caryophyllus* infected by pathogens (Niemann 1993). Catechins (flavanol derivatives) are similar in structure to flavonols, except for the lack of a carbonyl group.

![Fig. 7 The chemical structures of vitamins present in Caryophyllaceae plants. Vitamin B2 (a), vitamin B3 (b), vitamin E (c)](fig7.jpg)

![Fig. 6 The chemical structures of alkaloids in Caryophyllaceae plants. Dichotomine A (a), dichotomine B (b), dichotomine E (c)](fig6.jpg)
group in the pyran ring (Heim et al. 2002). Plants of the 
Caryophyllaceae family were also screened for fla-
vanols, but only a few species, including 
*Herniaria fontanessii* (Mbark et al. 1999) and 
*Arenaria kansuensis* (Liu et al. 2018), contained this group of 
compounds. The major flavanols, catechin, and epi-
catechin, act as strong antioxidant agents similar to 
other polyphenols (Iacopini et al. 2008).

Lignans, insoluble elements of certain cell walls, 
are rather uncommon phytochemicals in Caryophyl-
laceae, except for *Pteranthus dichotomus*, which 
contains 8-oxo-pinoresinol (Allaoua et al. 2016).

Unlike the many taxa of the order Caryophyllales 
that produce betalains as coloured flower pigments, 
Caryophyllaceae produce anthocyanins: cyanidin gly-
coside derivatives were identified in *Silene dioica* 
(Kamsteeg et al. 1976; Kamsreeo et al. 1980) and *S. armeria* (Mamadalieva et al. 2014). Cyclic malyl 
anthocyanins were isolated from deep pink and red–
purple *Dianthus caryophyllus* flower petals 
(Nakayama et al. 2000). Moreover, the genus *Lychnis* 
is a source of the anthocyanin aglycones named 
anthocyanidins, such as cyanidin, peonidin, and 
pelargonidin (Fig. 9), as well as their glycoside 
derivatives (Kuwayama et al. 2005).

Among the many polyphenolic phytoconstituents 
 occurring in this family, tannins are also present and 
have physiological activity against herbivores. Tan-
nins were detected in some *Minuartia* species (Zay-
chenko and Zernov 2017), *Stellaria laeta* (Jung et al. 
1979), *Polycarpacea corymbosa* (Balamurugan et al. 
2013), *Drymaria cordata* (Baruah et al. 2009), *Silene vulgaris* (Kim et al. 2015), *Silene compacta* (Bakroglu 
et al. 2014), and *Spergula fallax* (Aldhebiani and 
Mufarah 2017).

However, flavonoid compounds remain one of the 
most extensive groups of polyphenols in Caryophyll-
laceae, and novel compounds are yet to be identified. 
The aglycones and their glycosides are probably 
present in almost all plants.

**Flavonoids of the Caryophyllaceae and their main 
biological activities**

Flavonoids are low-molecular-weight secondary plant 
metabolites composed of two benzene rings and one 
heterocyclic pyran ring that are chemically divided 
into groups according to their chemical substitutions. 
Flavonoid moieties can be modified by glycosylation, 
hydrogenation, hydroxylation, and methylation as 
well as malonylation and sulfatation. The chemical 
and biological activities of flavonoids and their 
derivatives are connected with their structure and the 
position of various substitutions on the molecule. The 
general activity of polyphenols concerns the reactivity 
of their phenolic OH groups. The hydroxyl groups can 
dissociate under physiological conditions to nega-
tively charged phenolate ions. Thus, polyphenols can 
interact with proteins by forming hydrogen bridges 
and, more importantly, ionic bonds with positively 
charged amino groups. As a consequence, the

![Fig. 8](image1.png) The chemical structures of phenolic acids in plants of 
The Caryophyllaceae family. Rosmarinic acid (a), 3,4-dihydroxy-
benzoic acid (b) syringic acid (c), p-hydroxybenzoic acid (d)

![Fig. 9](image2.png) The chemical structures of the anthocyanins in Caryophyllaceae. Cyanidin (a), peonidin (b) pelargonidin (c)
bioactivity of proteins can be directly changed when a polyphenol binds to a receptor side or active centre of an enzyme. Polyphenols, especially those with several phenolic OH groups (such as rosmarinic acid or tannins), can change the 3D structure of proteins and impair their bioactivity. Because of these interactions, polyphenols affect many proteins in the human body and in microbes that are medicinally relevant. This is the mechanism by which plant polyphenols are medicinally active (Wink 2015; van Wyk and Wink 2017).

The biological activities of flavonoids may be also connected with their metabolites, which are produced in vivo. The gastrointestinal tract reveals primary role in the absorption, distribution, metabolism and excretion of flavonoids, which are substrates for conjugating and hydrolyzing enzymes in the small intestine, liver, and colon to O-glucuronides, O-methyl and sulfate esters. Firstly, metabolism of flavonoids take place in the small intestine followed by the liver where they are transformed and then produced glucuronides and sulfate derivatives. Flavonoid compounds that reach the colon are catabolized to low molecular weight phenolic acids by the intestinal microflora (Thilakarathna and Rupasinghe 2013). An anaerobic bacteria found in human gastrointestinal tract (e.g. Eubacterium ramulus) splits the ring structures of several flavonoids and flavones leading to the formation of aglycones and common phenolics intermediates consisting of hydroxyphenylacetic, hydroxyphenylpropionic, acetate, and butyrate acids with varying degrees of hydroxylation (Blaut et al. 2003; Serra et al. 2012; Pei et al. 2020). The amount of urinary excretion demonstrates that the colonic catabolites are absorbed into the portal vein and this way run over the body in the circulatory system (Crozier et al. 2010). The flavonoid glucuronides and sulfate derivatives facilitate their excretion through urine and bile (Thilakarathna and Rupasinghe 2013). Urinary excretion of < 1.0% confirms that C-flavones are poorly absorbed, and 10–88% recovery from feces indicates that they may be resistant to degradation by gut bacteria in rats (Ma et al. 2010). As with flavone O-glycosides, the C-glycosides are less bioavailable in humans than in rats. Nevertheless, it is known that the absorption of dietary flavonoids may be affected by the food matrix, the metabolic processes mediated by the liver, intestine, kidneys, as well as colon microbiota (Hollman 2004; Viskupičová et al. 2008; Hostetler et al. 2017; Cosme et al. 2020; Di Lorenzo et al. 2021).

To the best of our knowledge, apigenin, found in 28 species, is the major flavone in Caryophyllaceae plants. The apigenin exhibits cancer chemopreventive activity such as antiproliferative effects on human breast cancer cells, inhibition of cell growth by apoptosis in cervical carcinoma, or selective apoptotic effects in monocytes and lymphocytic leukaemias (Shukla and Gupta 2010; Imran et al. 2020). A similar number of species contain another widely distributed aglycone—luteolin. As with many other polyphenols, luteolin is a powerful antioxidant that can prevent inflammation and allergies and suppress the expression of cancer-promoting proteins (Imran et al. 2019a, b). Other important flavones are the luteolin 8-C-glucoside and apigenin 8-C-glucoside, orientin and vitexin, respectively. Plants rich in orientin are often used in traditional medicine for the treatment of respiratory disorders, pharyngitis, skin disorders, common cold, and mild anxiety (Grundmann et al. 2008; Lam et al. 2016). In addition, luteolin 8-C-glucoside acts as an antioxidant, antiaging, anti-inflammatory, cardioprotective, radioprotective, and neuroprotective agent (Uma Devi et al. 2000; Praveena et al. 2014; Lam et al. 2016). Vitexin, successfully isolated from Caryophyllaceae, exhibits various medicinal properties, such as fat reduction, improved glucose metabolism, hepatoprotection, neuroprotection, cardioprotection, and even anticancer activity (Ganesan and Xu 2017; Peng et al. 2020).

Kaempferol exhibits multiple biological effects, such as antioxidant, anti-inflammatory, anti-diabetic, antiaging, and antimicrobial effects, and is being applied in the chemotherapy of skin, liver, and colon tumours (Zhu et al. 2018; Cho and Park 2013; Imran et al. 2019a, b). Furthermore, kaempferol can be used in the treatment of cardiovascular diseases, degenerative disorders, diabetes, and microbial contamination diseases (Imran et al. 2018, 2019a). The flavonol aglycone, quercetin can function as an antioxidant as well as a blood pressure-lowering and anticancer agent (Kukongviriyapan et al. 2012; Egert et al. 2009). Moreover, quercetin can decrease the levels of proinflammatory cytokines, e.g., interleukin 6, 8, 1β, and TNFα (Wang et al. 2016). Rutin, a 3-O-rutinoside derivative of quercetin established in 18 different species of the Caryophyllaceae, is also often used in studies due to its extensive therapeutic properties: The
health-promoting effects of rutin are linked with antioxidant, cytoprotective, neuroprotective, vasoprotective, and cardioprotective activities (Kim et al. 2009; Ganeshpurkar and Saluja 2017). The results from some studies also indicated a positive effect of rutin on Parkinson’s and Alzheimer’s diseases (Gullón et al. 2017). The main strategies for a neurodegenerative disease therapy involves the reduction of reactive oxygen species and amyloid beta-protein production, and the activation of mechanisms of neuronal death (de Andrade Teles et al. 2018).

The main biological activities of hesperidin isolated from *Herniaria hemistemon* (Elhagali et al. 2019) are chemotherapeutic, antiallergic, anti-inflammatory, endocrine, cardiovascular, and organ-protective effects (Kumar et al. 2008; Zanotti et al. 2013; Ganeshpurkar and Saluja 2019). The aglycone naringenin exhibited multiple therapeutic effects associated with its free radical-scavenging properties. Depending on the concentration and method of administration, naringenin can be useful in the treatment of viral, bacterial, and inflammatory diseases and obesity (Ke et al. 2016; Kozłowska et al. 2017; Salehi et al. 2019).

In addition, naringenin was tested for its potential anticancer activity and as a cardioprotective agent (Salehi et al. 2019). A wide range of therapeutic properties of naringin, a 7-hesperidoside derivative of naringenin, include the treatment of metabolic syndrome, oxidative stress, and conditions of the central nervous system (Sachdeva et al. 2014; Dhanya et al. 2015; Chen et al. 2016).

A medically useful group of flavonoids are isoflavones, which are also known as phytoestrogens (Heim et al. 2002). These compounds can bind to receptors of oestrogen and oestrogen hormone binding protein and inhibit an important enzyme of angiogenesis and tumour formation, tyrosinase (Wink 2015). It was concluded that plants rich in isoflavones are effective in treating cardiovascular and osteoporosis disorders as well as in reducing postmenopausal symptoms (Clarkson 2002; Atkinson et al. 2004; Vitale et al. 2013). To date, the distribution of genistein and daidzein is common in several legumes of the Fabaceae family, such as soybean (Bustamante-Rangel et al. 2018). However, there are reports of the presence of genistein in a species of the Caryophyllaceae family, e.g., *Stellaria dichotoma* or *Stellaria holostea* (Mikšátková et al. 2014).

Our approach included screening for flavonoid aglycones and their highly glycosylated derivatives within Caryophyllaceae family (Cook and Samman 1996). The flavonoid aglycone and glycoside group remains one of the most extensive groups of polyphenols in Caryophyllaceae. Most of these compounds occur in *Silene L.*, *Dianthus L.* (Obmann et al. 2011a, b; Boguslavskaya et al. 1983), *Gypsophila L.* (Zhang et al. 2011a, b; Zheleva-Dimitrova et al. 2018), *Stellaria L.* (Mikšátková et al. 2014), *Spergularia Presl.* (Ferrereres et al. 2011) and *Herniaria L.* (Elhagali et al. 2019; El Mabruki et al. 2014). Nevertheless, flavonoid compounds are probably present in almost all plants. We assembled information regarding their presence in 26 genera and over 120 species of the Caryophyllaceae family (see Table 1).

### Flavones

One of the most pharmacologically valuable flavonoid classes present is that comprising flavones, which can be synthesized by various pathways, depending on whether they contain C- or O-glycosylation, O-methylation acylation, and hydroxylated B-ring. These compounds undergo characteristic reactions ascribed to three functional structures—hydroxyl and carbonyl groups and a double bond (Singh et al. 2014; Panche et al. 2016). Their natural distribution is demonstrated for almost all plant tissues (Figs. 10, 11, 12).

### Flavonols

An additional class of flavonoids commonly found in Caryophyllaceae is that comprising flavonols, including kaempferol, quercetin and its glycoside rutin (quercetin 3-O-rutinoside). Flavonols, compared to flavones, carry an additional hydroxyl group in the pyran ring (Panche et al. 2016) (Fig. 13).

### Flavonones (dihydroflavones)

Flavonones (dihydroflavones) differ from flavones by the lack of a double bond in the pyran ring. Hesperidin, naringenin, and its glycoside naringin (naringenin 7-hesperidoside) are commonly found in citrus fruits (Panche et al. 2016), but they can also be found in certain species of the pink family.
| Genus             | Compounds                                      | References                  |
|-------------------|------------------------------------------------|-----------------------------|
| Agrostemma githago| luteolin 8-C-β-D-glucoside (orientin) (2)       | Richardson (1978)           |
|                   | luteolin 6-C-β-D-glucoside (isoorientin) (18)  |                             |
| Alsinidendron trinerve | apigenin 6-C-β-D-glucoside (isovitexin) (77)  |                             |
|                   | apigenin 8-C-β-D-glucoside (vitexin) (49)      |                             |
| Arenaria kansuensis | apigenin (48)                                 | Liu et al. (2018)           |
|                   | luteolin 3’-methyl ether (chrysoeriol) (128)    |                             |
|                   | luteolin 7-O-β-D-glucoside (cynaroside) (37)   |                             |
|                   | tricin 7-O-β-D-glucoside (160)                 |                             |
|                   | apigenin 6-C-β-D-glucoside (isovitexin) (77)   |                             |
|                   | apigenin 8-C-β-D-glucoside (vitexin) (49)      |                             |
|                   | chrysoeriol 8-C-β-D-glucoside (scoparin) (129) | Liu et al. (2018), Cui et al. (2017b) |
|                   | luteolin (1)                                   | Liu et al. (2018), Tong et al. (2014) |
|                   | homoeriodictyol (217)                          |                             |
|                   | kaempferol (172)                               |                             |
|                   | quercetin (189)                                |                             |
|                   | tricin (159)                                   | Wu et al. (1990), Liu et al. (2018), Cui et al. (2017a), Cui et al. (2017b), Cui et al. (2018) |
|                   | chrysoeriol 6-C-β-D-glucoside (isoscoparin) (141)|                             |
|                   | tricin 4’-O-(C-veratroylglycol) ether (151)     | Cui et al. (2019)           |
| Arenaria saxatilis | apigenin 6-C-β-D-glucoside (isovitexin) (77)   | Darmograi (1979)            |
| A. serpyllifolia  | apigenin 8-C-β-D-glucoside (vitexin) (49)      |                             |
| A. stenophyla     | luteolin 6-C-β-D-glucoside (isoorientin) (18)  |                             |
| A. juncea         | luteolin 8-C-β-D-glucoside (orientin) (2)      |                             |
| A. lychnidea      | luteolin 8-C-β-D-glucoside (orientin) (2)      |                             |
### Table 1 continued

| Genus               | Compounds                                      | References                  |
|---------------------|------------------------------------------------|-----------------------------|
| **Arenaria longifolia** | apigenin 6-C-β-D-glucoside (isovitexin) (77)  |                             |
|                     | apigenin 8-C-β-D-glucoside (vitexin) (49)     |                             |
|                     | chrysoeriol 6-C-β-D-glucoside (isoscoparin) (141) |                             |
|                     | luteolin 6-C-β-D-glucoside (isoorientin) (18) |                             |
|                     | luteolin 8-C-β-D-glucoside (orientin) (2)     |                             |
| **Cerastium anomalum** | apigenin (48)                                  |                             |
| C. biebersteinii     | luteolin (1)                                   |                             |
| C. falcatum          | apigenin 6-C-β-D-glucoside (isovitexin) (77)  |                             |
| C. perfoliatum       | apigenin 8-C-β-D-glucoside (vitexin) (49)     |                             |
| C. grandiflorum      | luteolin 6-C-β-D-glucoside (isoorientin) (18) |                             |
| C. cerastoides       |                                                |                             |
| C. imbricatum        | apigenin                                      |                             |
| C. pilosum           | luteolin                                      |                             |
| C. dahuricum         | apigenin                                      |                             |
| C. fontanum          | luteolin                                      |                             |
| C. trigynum          | apigenin                                      |                             |
| **Cerastium arvense** | acetin 6,8-di-C-β-D-galactoside (152)         | Dubois et al. (1984)       |
|                     | acetin 6,8-di-C-β-D-glucoside (157)           |                             |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)  |                             |
|                     | apigenin 6-C-β-D-glucosyl-8-C-β-D-galactoside (50) |                             |
|                     | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53) |                             |
|                     | apigenin 8-C-β-D-glucoside (vitexin) (49)     |                             |
|                     | apigenin 6-C-arabinoside (isomollupentin) (81) | Dubois et al. (1985)       |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)  |                             |
|                     | apigenin 6-C-xyloside (cerarvensin) (82)      |                             |
|                     | apigenin 6-C-xylosyl-8-C-arabinoside (51)     |                             |
|                     | apigenin 6-C-β-glucosyl-8-C-arabinoside (schaftoside) (52) |                 |
|                     | cerarvensin 7-O-glucoside (101)               |                             |
|                     | chrysoeriol 6-C-β-D-glucoside (isoscoparin) (141) |                             |
|                     | isomollupentin 2'-glucoside (98)             |                             |
|                     | isomollupentin 4'-glucoside (120)            |                             |
|                     | isoorientin 2''-feruloyl-4'-glucoside (28)   |                             |
|                     | isovitexin 2''-O-arabinoside (83)             |                             |
|                     | isovitexin 2''-feruloside (84)                |                             |
|                     | isovitexin 2''-feruloyl-4'-glucoside (121)   |                             |
|                     | isovitexin 2''-O-glucoside (meloside A) (85)  |                             |
|                     | isovitexin 2''-xyloside (86)                  |                             |
|                     | isovitexin 7-O-glucoside-2''-O-arabinoside (122) |                             |
|                     | isovitexin 7-glucoside-2''-O-glucoside (123)  |                             |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105) |                             |
|                     | apigenin 6-C-galactosyl-8-C-arabinoside (isocorymboside) (54) | Dubois et al. (1982), Dubois et al. (1985) |
|                     | apigenin 6-C-arabinosyl-8-C-xyloside (100)    |                             |
Table 1 continued

| Genus                     | Compounds                                                                 | References                  |
|---------------------------|---------------------------------------------------------------------------|-----------------------------|
|                           | isomollupentin 7,2”-di-O-glucoside (102)                                  | Dubois et al. (1983)        |
|                           | isomollupentin 7-O-glucoside-2”-O-arabinoside (103)                        | Dubois et al. (1985)        |
|                           | isomollupentin 7-O-glucoside-2”-O-xiloside (104)                          | Boguslavskaya et al. (1983) |
|                           | iso-vitexin 7-O-glucoside-2”-O-arabinoside (122)                           |                             |
| Dianthus acieularis       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                             |
|                           | apigenin 6-C-anti-z-D-glucoside (isoneoavroside) (79)                      | Richardson (1978)           |
|                           | apigenin 6-C-syn-z-D-glucoside (neoavroside) (80)                          |                             |
| Dianthus anatoficus       | kaempferol (172)                                                          |                             |
|                           | luteolin 6-C-β-D-glucoside (isoorientin) (18)                              |                             |
|                           | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                             |
| Dianthus japonicus        | isovitexin 7-O-β-D-glucoside (saponarin) (105)                             | Nakano et al. (2011)        |
|                           | saponarin 2”-O-z-L-rhamnose-6”-O-7,8-dihydroferrulate (106)               |                             |
| Dianthus hoeltzeri        | apigenin 6-C-anti-z-D-glucoside (isoneoavroside) (79)                      | Boguslavskaya et al. (1983), Obmann et al. (2011a, b) |
|                           | apigenin 6-C-syn-z-D-glucoside (neoavroside) (80)                          |                             |
|                           | chrysoeriol 6-C-syn-z-D-glucoside (142)                                    |                             |
| Dianthus dicolor          | isovitexin 4’-O-β-D-glucoside (isosaponarin) (124)                         | Boguslavskaya et al. (1983) |
| Dianthus squarrosus       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             | Seraya et al. (1978), Obmann et al. (2011a, b) |
| Dianthus superbus         | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                             |
|                           | kaempferol 3-O-(β-D-glucosyl-β-D-glucoside) (173)                          | Boguslavskaya (1976), Obmann et al. (2011a, b) |
| Dianthus platycodon       | quercetin 3-O-z-L-rutinoside (rutin) (190)                                 |                             |
| Dianthus ramosissimus     | chrysoeriol 6-C-anti-z-D-glucoside (143)                                   | Obmann et al. (2011a, b)    |
| Dianthus pseudosquarrosus | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                           | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                             |
|                           | iso-vitexin 4’-O-β-D-glucoside (isosaponarin) (124)                        |                             |
|                           | luteolin 5-O-glucoside (36)                                                |                             |
|                           | luteolin 7-O-diglucoside (38)                                              |                             |
|                           | luteolin 7-O-β-D-glucoside (cynaroside) (37)                               |                             |
| Genus               | Compounds                                                                 | References                                           |
|---------------------|---------------------------------------------------------------------------|------------------------------------------------------|
| **Dianthus versicolor** | apigenin (48)                                                              | Obmann et al. (2011a, b), Obmann et al. (2012)       |
|                     | apigenin 4'-methyl ether (acacetin) (151)                                  |                                                      |
|                     | luteolin (1)                                                               |                                                      |
|                     | luteolin 3'-methyl ether (chrysoeriol) (128)                                |                                                      |
|                     | luteolin 4'-methyl ether (diosmetin) (154)                                  |                                                      |
|                     | isoorientin 7-O-galactoside (22)                                            |                                                      |
|                     | isoorientin 7-O-rhamnosyl-glactoside (23)                                   |                                                      |
|                     | isoorientin 7-O-rutinoside (24)                                             |                                                      |
|                     | isoscorparin 7-O-galactoside (147)                                          |                                                      |
|                     | isoscorparin 7-O-rhamnosyl-galactoside (148)                                |                                                      |
|                     | isoscorparin 7-O-rutinoside (149)                                           |                                                      |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                              |                                                      |
|                     | isovitexin 7-O-rhamnosyl-galactoside (107)                                  |                                                      |
|                     | isovitexin 7-O-rutinoside (109)                                             |                                                      |
|                     | apigenin C-hexosyl-O-hexoside malyl ester (110)                            |                                                      |
|                     | luteolin C-hexosyl-O-hexoside malyl ester (39)                             |                                                      |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                                |                                                      |
|                     | apigenin 7-O-β-D-glucoside (cosmosiin) (111)                                |                                                      |
|                     | isovitexin 2''-O-rhamnoside (99)                                            |                                                      |
|                     | luteolin 7-O-β-D-glucoside (cynaroside) (37)                                |                                                      |
| **Dianthus caryophyllus** | kaempferide 3-O-β-D-glucosyl(1 → 2)-O-[z-L-rhamnosyl(1 → 6)]-β-D-glucoside (188) | Curir et al. (2001), Obmann et al. (2011a, b)         |
|                     | kaempferide 3-O-[2G-β-D-glucosyl]-β-rutinoside (187)                        | Curir et al. (2005), Obmann et al. (2011a, b)         |
|                     | quercetin 3-[6-O-(z-L-arabinosyl)-β-D-glucoside] (peltatoside) (194)        | Curir et al. (2003), Obmann et al. (2011a, b) Al-Snafi (2017) |
|                     | apigenin 6-C-glucosyl-7-O-(6-malyl-glucoside) (112)                        | Fukui et al. (2003), Obmann et al. (2011a, b)         |
|                     | kaempferol 3-O-[6''-rhamnosyl-2''-6-malyl-glucosyl]]-glucoside (174)        |                                                      |
|                     | kaempferol 3-O-(6''-rhamnosyl-2''-glucosyl)-glucoside (175)                 |                                                      |
|                     | kaempferol 3-O-(β-D-glucosyl-β-D-glucoside) (173)                          | Ogata et al. (2004), Obmann et al. (2011a, b), Stich et al. (1992) |
|                     | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                           | Galeotti et al. (2008a, b), Obmann et al. (2011a, b)  |
|                     | kaempferol 3-O-β-D-rutinoside (nicotiflorin) (176)                          |                                                      |
|                     | kaempferol 3-O-β-D-glucosyl-(1'' → 2'')-O-[z-L-rhamnosyl-(1'' → 6'')]-β-D-glucoside (178) | Galeotti et al. (2008a, b), Galeotti et al. (2008a), Obmann et al. (2011a, b), Iwashina et al. (2010), Al-Snafi (2017) |
|                     | kaempferol 3-O-β-D-glucosyl-(1'' → 2'')-O-[z-L-rhamnosyl-(1'' → 6'')]-β-D-glucoside (177) | Galeotti et al. (2008a), Obmann et al. (2011a, b) |
|                     | kaempferol (172)                                                           | Stich et al. (1992)                                  |
|                     | naringenin (220)                                                           |                                                      |
|                     | kaempferol 4'-methyl ether (kaempferide) (186)                              | Martineti et al. (2010)                              |
|                     | kaempferol 3-O-neohesperidoside (179)                                       | Iwashina et al. (2010)                               |
|                     | kaempferol 3-O-sophoroside (sophoraflavonoloside) (185)                    |                                                      |
| Genus            | Compounds                                                                 | References                              |
|------------------|---------------------------------------------------------------------------|-----------------------------------------|
| Dianthus deltoides | luteolin (1)                                                               | Obmann et al. (2011a, b)               |
|                  | apigenin 6-C-anti-α-D-glcoside (isoneovroside) (79)                      |                                        |
|                  | apigenin 6-C-syn-α-D-glcoside (neovroside) (80)                          |                                        |
|                  | chrysoeriol 4′-O-β-D-glcoside (150)                                      |                                        |
|                  | luteolin 3′-methyl ether (chrysoeriol) (128)                              |                                        |
|                  | luteolin 4′-O-β-D-glcoside (40)                                           |                                        |
| Dianthus arenarius | apigenin 4′-O-glcoside (125)                                              | Boguslavskaya et al. (1983)            |
| D. crinitus      | apigenin 6-C-β-D-glcoside (isovitexin) (77)                               |                                        |
| D. tetralepsis   | apigenin 8-C-β-D-glcoside (vitetin) (49)                                  |                                        |
|                  | luteolin 4′-O-β-D-glcoside (40)                                           |                                        |
|                  | luteolin 6-C-β-D-glcoside (isoorientin) (18)                              |                                        |
|                  | luteolin 8-C-β-D-glcoside (orientin) (2)                                  |                                        |
| Dianthus grandiflora | kaempferol (172)                                                          | Richardson (1978)                       |
| Drymaria diandra | drymariatin A (164)                                                       | Ding et al. (1999), Brahmchari and Gorai (2006) |
|                  | drymariatin B (165)                                                      | Ding et al. (2005)                      |
|                  | drymariatin C (166)                                                      |                                        |
|                  | drymariatin D (167)                                                      |                                        |
|                  | 6-trans-{2′-O-(rhamnosyl)}-ethenyl-5,7,4′-trihydroxyflavone (170)         |                                        |
|                  | 5,4′-dihydroxy-7-methoxyflavone-6-C-(2′-O-z-L-rhamnosyl)-β-D-glcoside (87)|                                        |
|                  | 5,7,3′,4′-tetrahydroxyflavone-6-C-(2′-O-z-L-rhamnosyl)-β-D-glcoside (45) |                                        |
| Drypis spinosa   | naringenin (220)                                                          | Kremer et al. (2021)                    |
|                  | quercetin (189)                                                          |                                        |
| Gymnocarpos decander | isorhamnetin 3-O-[2′″-O-acetyl – β-D-xylsosyl-(1 → 6)-β-D-        | Bechlem et al. (2017)                  |
|                  | apiofuransyl-(1 → 2)]-β-D-glcoside (212)                                  |                                        |
|                  | isorhamnetin 3-O-2″-O-acetyl – β-D-xylsosyl-(1 → 6)-β-D-glcoside (213)    |                                        |
|                  | quercetin 3-O-(2″-O-acetyl – β-D-xylsosyl)-(1 → 6)-β-D-glcoside (198)     |                                        |
|                  | apigenin (48)                                                            | Zitouni (2017)                         |
|                  | kaempferol (172)                                                         |                                        |
|                  | luteolin (1)                                                             |                                        |
|                  | myricetin 3′-O-methyl ether (laricitrin) (214)                             |                                        |
|                  | naringenin (220)                                                         |                                        |
|                  | kaempferol 3-O-β-D-rutinoside (nicotiflorin) (176)                        |                                        |
|                  | luteolin 7-O-β-D-glcoside (cynaroside) (37)                               |                                        |
|                  | quercetin 3-O-β-D-galactoside (hyperoside) (191)                         |                                        |
|                  | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                        |
Table 1 continued

| Genus               | Compounds                                                                 | References                                      |
|---------------------|---------------------------------------------------------------------------|------------------------------------------------|
| Gypsophila altissima| apigenin 8-C-β-D-glucoside (vitexin) (49)                                | El-Hawary et al. (2020)                        |
|                     | quercetin (189)                                                          | Zitouni (2017), Mubarek (2019), El-Hawary et al. (2020) |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                             | Mubarek (2019)                                 |
|                     | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         | Zitouni (2017), Mubarek (2019)                 |
|                     | apigenin 7-O-β-D-glucoside (saponarin) (105)                             | Zdraveva et al. (2015)                        |
|                     | Gypsophila arrosti                                                       |                                                |
|                     | quercetin 3-O-α-L-rutinoside (rutin) (190)                                | Altay et al. (2019)                            |
|                     | naringenin (220)                                                         | Altay (2018)                                   |
|                     | Gypsophila acheri                                                        |                                                |
|                     | luteolin 7-O-α-L-arabinosyl-6-C-β-glucoside (25)                          | Elbandy et al. (2007)                          |
|                     | Gypsophila repens                                                        |                                                |
|                     | isoorientin 2'-O-arabinoside (19)                                         | Zhang et al. (2011a, b), Huang et al. (2012), Lin et al. (2016) |
|                     | luteolin 6-C-β-D-glucoside (isoorientin) (18)                            | Lin et al. (2015), Tu et al. (2019)            |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                            | Zhang et al. (2011a, b), Zdraveva et al. (2015) |
|                     | apigenin 6-C-[β-D-xylosyl-(1'-2'0')-β-D-galactoside]-7-O-β-D-glucoside (113) | Zhang et al. (2011a, b)                        |
|                     | apigenin 7-O-sophoroside (114)                                            |                                                |
|                     | apigenin 8-C-β-D-glucoside (vitexin) (49)                                |                                                |
|                     | isovitexin 2'-O-glucoside (meloside A) (85)                               |                                                |
|                     | Gypsophila elegans                                                       |                                                |
|                     | quercetin 3-O-α-L-rutinoside (rutin) (190)                                | Altay et al. (2019)                            |
|                     | Gypsophila eriocalyx                                                     |                                                |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                            | Vitcheva et al. (2011), Simeonova et al. (2014), Zheleva-Dimitrova et al. (2018) |
|                     | quercetin 3-O-β-D-galactoside (hyperoside) (191)                          | Krasteva et al. (2008)                         |
|                     | apigenin 8-C-β-D-glucoside (vitexin) (49)                                | Krasteva et al. (2008), Zheleva-Dimitrova et al. (2018) |
|                     | luteolin 6-C-β-D-glucoside (isoorientin) (18)                            |                                                |
|                     | luteolin 8-C-β-D-glucoside (orientin) (2)                                 |                                                |
|                     | apigenin (48)                                                            |                                                |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                             |                                                |
|                     |isorhamnetin 3-O-β-D-glucoside (205)                                      |                                                |
|                     | luteolin 2'-O-pentosyl-6-C-hexoside (29)                                 |                                                |
|                     | luteolin 4'-methyl ether (diosmetin) (154)                               |                                                |
|                     | luteolin 7-O-β-D-glucoside (cynaroside) (37)                             |                                                |
Table 1 continued

| Genus                  | Compounds                                                                 | References                                      |
|------------------------|---------------------------------------------------------------------------|-------------------------------------------------|
| *Gypsophila glomerata* | apigenin (48)                                                             | Zheleva-Dimitrova et al. (2018)                 |
|                        | apigenin 2"-O-acetylpentosyl-6-C-hexoside (88)                            |                                                 |
|                        | apigenin 2"-O-diacetylpentosyl-6-C-hexoside (89)                           |                                                 |
|                        | apigenin 2"-O-pentosyl-6-C-hexoside (90)                                   |                                                 |
|                        | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                                                 |
|                        | apigenin 8-C-β-D-glucoside (vitexin) (49)                                 |                                                 |
|                        | diosmetin 2"-O-acetylpentosyl-6-C-hexoside (155)                          |                                                 |
|                        |isorhamnetin 3-O-β-D-glucoside (205)                                       |                                                 |
|                        | isovitexin 7-O-β-D-glucoside (saponarin) (105)                            |                                                 |
|                        | kaempferol 3-O-β-D-glucoside (astragalin) (180)                           |                                                 |
|                        | kaempferol 3-O-β-D-rutinoside (nicotiflorin) (176)                        |                                                 |
|                        | luteolin 2"-O-pentosyl-6-C-hexoside (29)                                  |                                                 |
|                        | luteolin 4'-methyl ether (diosmetin) (154)                               |                                                 |
|                        | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                                                 |
|                        | luteolin 7-O-β-D-glucoside (cynaroside) (37)                              |                                                 |
|                        | luteolin 8-C-β-D-glucoside (orientin) (2)                                 |                                                 |
|                        | luteolin methyl-2"-O-pentosyl-6-C-hexoside (30)                          |                                                 |
| *Gypsophila tuberculosa* | quercetin 3-O-α-L-rutinoside (rutin) (190)                              | Altay et al. (2019)                             |
| *Gypsophila sphaerocephala* | isovitexin 7-O-β-D-glucoside (saponarin) (105) | Altay et al. (2018)                             |
| *Gypsophila paniculata* | apigenin (48)                                                            |                                                 |
| *Gypsophila perfoliata* | apigenin 2"-O-hexosyl-6-C-hexoside (91)                                  | Zheleva-Dimitrova et al. (2018)                 |
|                        | apigenin 2"-O-pentosyl-6-C-hexoside (90)                                  |                                                 |
|                        | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                          |                                                 |
|                        | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                                                 |
|                        | apigenin 6-C-hexosyl-8-C-pentoside (56)                                   |                                                 |
|                        | apigenin 8-C-β-D-glucoside (vitexin) (49)                                 |                                                 |
|                        | diosmetin 6-C-hexosyl-8-C-pentoside (156)                                 |                                                 |
|                        | isorhamnetin 3-O-β-D-glucoside (205)                                       |                                                 |
|                        | isovitexin 4'-O-β-D-glucoside (isosaponarin) (124)                        |                                                 |
|                        | luteolin 2"-O-hexosyl-6-C-hexoside (31)                                  |                                                 |
|                        | luteolin 4'-methyl ether (diosmetin) (154)                               |                                                 |
|                        | luteolin 6-C-hexosyl-8-C-pentoside (32)                                  |                                                 |
|                        | luteolin 7-O-β-D-glucoside (saponarin) (18)                               |                                                 |
|                        | luteolin 8-C-β-D-glucoside (orientin) (2)                                 |                                                 |
| Genus          | Compounds                                                                 | References                      |
|---------------|---------------------------------------------------------------------------|---------------------------------|
| *Herniaria*   |                                                                           |                                 |
| *hirsuta*     | quercetin (189)                                                           | Richardson (1978)               |
|               |isorhamnetin 3-O-rutinoside (narcassin) (206)                              |                                 |
|               | quercetin 3-O-(2''-O-α-L-rhamnosyl)-β-D-glucuronoside (195)               |                                 |
|               | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                 |
| *Herniaria*   |                                                                           |                                 |
| *fontanessii* | apigenin (48)                                                             | Tili et al. (2019)              |
|               | kaempferol (172)                                                          |                                 |
|               | naringenin (220)                                                          |                                 |
|               | quercetin (189)                                                           |                                 |
|               |isorhamnetin 3-O-β-D-galactoside (hyperoside) (191)                        |                                 |
|               | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                 |
|               |isorhamnetin 3-O-robinobioside (207)                                       | Mbark et al. (1999)             |
|               |isorhamnetin 3''-feruloyl-3-O-robinobioside (208)                         |                                 |
| *Hernia*      |                                                                           |                                 |
| *glabra*      | apigenin (48)                                                             | El Mabruki et al. (2014)        |
|               | quercetin 3-O-β-D-galactoside (hyperoside) (191)                          |                                 |
|               | luteolin (1)                                                              | Maleš et al. (2013)             |
|               |isorhamnetin 3-O-rutinoside (narcassin) (206)                             | Kozachok et al. (2018)          |
|               |kaempferol 3-O-β-D-rutinoside (nicotiflorin) (176)                         |                                 |
|               | quercetin 3-O-[D-apio-β-D-furanosyl-(1 → 2)-O-[-α-L-rhamnosyl-(1 → 6)]- β-D-glucoside (apiorutin) (200) |                                 |
|               | quercetin (189)                                                           |                                 |
|               | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         | Kulevanova et al. (2003), El Mabruki et al. (2014) |
| Genus           | Compounds                                                                 | References                                      |
|-----------------|---------------------------------------------------------------------------|-------------------------------------------------|
| Herniaria hemistemon | quercetin 3-O-α-L-rutinoside (rutin) (190)                                | Maleš et al. (2013), Kozachok et al. (2018), El Mabruki et al. (2014) Elhagali et al. (2019) |
|                 | apigenin (48)                                                             |                                                  |
|                 | kaempferol (172)                                                          |                                                  |
|                 | naringenin (220)                                                          |                                                  |
|                 | quercetin (189)                                                           |                                                  |
|                 | apigenin 4’-methyl ether (acacetin) (151)                                  |                                                  |
|                 | apigenin 6-C-x-L-arabinosyl-8-C-β-D-galactoside (57)                       |                                                  |
|                 | apigenin 6-C-glucosyl-8-C-rhamnoside (58)                                  |                                                  |
|                 | apigenin 6-rhamnosyl-8-glucoside (59)                                     |                                                  |
|                 | apigenin 7-O-β-D-glucoside (cosmosiin) (111)                               |                                                  |
|                 | apigenin 7-O-neohesperidoside (rhoifolin) (115)                           |                                                  |
|                 | apigenin 8-C-β-D-glucoside (vexin) (49)                                   |                                                  |
|                 | cyanidanon 4’-methyl ether (hesperetin) (218)                              |                                                  |
|                 | hesperetin 7-O-α-L-rutinoside (hesperidin) (219)                           |                                                  |
|                 | kaempferol 3,7-dirhamnoside (kaempferitin) (181)                          |                                                  |
|                 | kaempferol 3-O-glucoside-2”-p-coumaroyl (182)                             |                                                  |
|                 | kaempferol 4’-methyl ether (kaempferide) (186)                            |                                                  |
|                 | kaempferol 7-O-hesperidoside (183)                                        |                                                  |
|                 | luteolin 6-C-arabinosyl-8-C-glucoside (3)                                 |                                                  |
|                 | luteolin 6-C-glucosyl-8-C-arabinoside (21)                                |                                                  |
|                 | naringenin 7-O-α-L-hesperidoside (naringin) (221)                         |                                                  |
|                 | quercetin 3-O-glucoside-7-O-rhamnoside (201)                              |                                                  |
|                 | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         |                                                  |
|                 | quercetin 3-O-z-L-hesperidoside (quercetin) (192)                         |                                                  |
|                 | quercetin 3-O-z-L-rutinoside (rutin) (190)                                |                                                  |
|                 | quercetin 7-methyl ether (rhamnetin) (202)                                |                                                  |
| Herniaria polygama | quercetin 3-O-z-L-rutinoside (rutin) (190)                                | Boguslavskaya et al. (1985a, b)                  |
| Herniaria ciliolata |isorhamnetin 3-O-rutinoside (narcissin) (206)                            |Królikowska et al. (1983)                        |
|                 | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         |                                                  |
|                 | quercetin 3-O-z-L-rutinoside (rutin) (190)                                |                                                  |
|                 | rhamnazin 3-O-glucoside (209)                                              |                                                  |
|                 | rhamnazin 3-O-rutinoside (polygalacin) (210)                              |                                                  |
|                 | rhamnetin 3-O-glucoside (193)                                             |                                                  |
| Genus                  | Compounds                                                                 | References                                |
|-----------------------|---------------------------------------------------------------------------|-------------------------------------------|
| Herniaria mauritanica | kaempferol 3-O-β-D-glucoside (astragalin) (180)                           | Cheriti and Sekkoum (1996)                |
| Illecebrum verticillatum | luteolin 8-C-β-D-glucoside (orientin) (2)                                | Richardson (1978)                        |
| Lychnis senno         | chrysoeriol 6-C-β-D-glucoside (isoscoparin) (141)                        | Shinjiro et al. (2009), Devkota et al. (2013); Maliński et al. (2014) |
|                       | isoorientin 2''-O-rhamnoside (20)                                         |                                           |
|                       | isovitexin 2''-O-rhamnoside (99)                                          |                                           |
|                       | isovitexin 5-O-acetyl-2'-x-rhamnoside (92)                                |                                           |
| Lychnis coronaria     | chrysoeriol 6-C-β-D-glucoside (isoscoparin) (141)                        | Bahar et al. (2008), Maliński et al. (2014) |
|                       | tricin 7-O-β-D-glucoside (160)                                            |                                           |
| Lychnis chalcedonica  | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                         | Smolyakova et al. (2010), Amosova et al. (2019) |
| Minuartia rossi       | apigenin 6-C-arabinosyl-diglucoside (93)                                 | Wolf et al. (1979)                       |
| M. elegans            | apigenin 6-C-glucoside (isovitexin) (77)                                  |                                           |
| M. austromontana      | apigenin 6-C-triglucoside (94)                                            |                                           |
|                       | kaempferol 3-O-β-D-sophoroside (sophoraflavonoloside) (185)              |                                           |
|                       | kaempferol 3-O-glucoside-2''-p-coumaroyl (182)                            |                                           |
|                       | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         |                                           |
|                       | quercetin 3-O-β-D-glucosyl-O-galactoside (196)                            |                                           |
|                       | quercetin 3-O-β-D-sophoroside (197)                                       |                                           |
| Paronychia argentea   | isorhamnetin 3-O-β-D-glucoside (205)                                      | Braca et al. (2008)                      |
|                       | nepetin (163)                                                            |                                           |
|                       | quercetin 3-O-[2''-acyl]-β-D-glucosyl]-(1 → 6)-β-D-galactoside (199)      | Braca et al. (2008), Sait et al. (2015)  |
|                       | quercetin 3-O-β-D-galactoside (hyperoside) (191)                          |                                           |
|                       | quercetin 3-O-β-D-glucosyl-(1 → 6)-β-D-galactoside                         |                                           |
|                       | 7-(β-D-glucosyl)-4',5-dihydroxy-3',6-dimethoxyflavone (jaccoside) (146)  |                                           |
|                       | isorhamnetin 3-O-dihexoside (211)                                         | Sait et al. (2015)                       |
|                       | quercetin 3-O-β-D-glucoside (isoquercitrin) (192)                         |                                           |
|                       | quercetin 3'-methyl ether (isorhamnetin) (204)                            | Rizk (1986), Sait et al. (2015), Adjadj et al. (2015) |
|                       | luteolin (1)                                                             |                                           |
|                       | quercetin (189)                                                          |                                           |
| Petrhoragia velutina  | isoorientin 2''-O-rhamnoside (20)                                         | Pacifico et al. (2010)                   |
|                       | luteolin 6-C-[2''-O-α-L-rhamnosyl-(1'' → 2'')]-α-L-arabinoside (33)       |                                           |
|                       | luteolin 6-C-[2''-O-α-L-rhamnosyl-(1'' → 2'')]-β-D-xyloside (34)          |                                           |
|                       | luteolin 6-C-β-D-glucoside (isorientin) (18)                              |                                           |
|                       | naringenin 8-C-α-L-arabinosyl-7-O-β-D-glucoside (223)                     |                                           |
|                       | scoparin 2''-O-rhamnoside (140)                                           |                                           |
| Genus                      | Compounds                                                                 | References                  |
|----------------------------|---------------------------------------------------------------------------|-----------------------------|
| Petrorhagia glumacea       | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              | Richardson (1978)           |
|                            | apigenin 8-C-β-D-glucoside (vitisin) (49)                                 |                             |
| P. nanteuilli               | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                             |
|                            | luteolin 8-C-β-D-glucoside (orientin) (2)                                 |                             |
| P. prolifera               | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                            | apigenin 8-C-β-D-glucoside (vitisin) (49)                                 |                             |
| P. velutina                 | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                            | apigenin 8-C-β-D-glucoside (vitisin) (49)                                 |                             |
| Petrorhagia saxifrage       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                             |
|                            | luteolin 8-C-β-D-glucoside (orientin) (2)                                 |                             |
| Polycarpon tetraphyllum    | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                            | apigenin 8-C-β-D-glucoside (vitisin) (49)                                 |                             |
| Psammosilene tunicoides    | tectorigenin 7-O-β-D-glucoside (tectoridin) (228)                         | Liu et al. (2007)           |
| Petranthus dichotomus       | apigenin (47)                                                             | Allaoua et al. (2016)       |
|                            | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                            | kaempferol (172)                                                         | Atta et al. (2013)          |
|                            | luteolin (1)                                                             |                             |
|                            | kaempferol 3-O-rhamnoside-7-O-glucuronic acid (184)                       |                             |
|                            | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                             |
|                            | luteolin 6-C-rhamnosyl-(1’’ → 4’’)-O-rhamnoside (35)                      |                             |
|                            | myricetin 3-O-glucoside (215)                                             |                             |
|                            | orientin 7-methyl ether (4)                                               |                             |
|                            | quercetin 7-O-β-D-glucoside (203)                                         |                             |
|                            | quercetin (189)                                                          |                             |
|                            |                          | Atta et al. (2013), Allaoua et al. (2016)                               |
| Scleranthus uncinatus       | 5,7,4’-trihydroxy-3’-methoxyflavone-8-C-β-D-xylosyl-2’’-O-glucoside (138) |                             |
|                            | 5,7-dihydroxy-3’-methoxy-4’-acetoxyflavone-8-C-β-D-xyloside-2’’-O-glucoside (139) |                             |
| Scleranthus annuus          | kaempferol (172)                                                         | Zdraveva et al. (2004)      |
|                            | luteolin (1)                                                             |                             |
|                            | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                             |
|                            | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                             |
|                            | quercetin 3-O-β-D-glucoside (isouercitrin) (192)                         |                             |
|                            | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                             |
|                            | vitexin 4’-O-α-L-rhamnoside (61)                                          |                             |
| Scleranthus perennis        | 5,7-dihydroxy-3’-methoxy-4’-acetoxyflavone-8-C-β-D-xylosyl-2’’-O-glucoside (139) | Jakimiuk et al. (2020)     |
| Sagina japonica            | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                         | Zhuang (1983)               |
|                            | apigenin 6-C-β-D-arabinosyl-8-C-β-D-glucoside (vicenin1) (62)             |                             |
|                            | apigenin 6-C,β-D-(O-rhamnosyl)-glucoside (95)                             |                             |
| Saponaria ocyoides          | quercetin (189)                                                          | Richardson (1978)           |
| Saponaria vaccaria          | quercetin (189)                                                          | Kumar and Khanna (1994)     |
|                            | kaempferol (172)                                                         |                             |
|                            | apigenin 6-C-[α-L-arabinosyl-(1’’ → 2’’)-β-D-glucosyl]-7-O-β-D-glucoside (126) | Balsevich et al. (2011)    |
| Genus                  | Compounds                                                                 | References                                                                 |
|-----------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| *Saponaria officinalis* | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               | Cambie (1959)                                                             |
|                       | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
| *Silene alba*         | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               | Heinsbroek et al., (1980), Mamadalieva et al. (2014)                      |
|                       | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
|                       | isovitexin 2"-O-glucoside (meloside A) (85)                                 |                                                                           |
|                       | vitexin 2"-O-glucoside (63)                                                 |                                                                           |
| *Silene brachuica*    | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               | Mamadalieva et al. (2014)                                                 |
|                       | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
| *Silene armeria*      | luteolin 8-C-β-D-glucoside (orientin) (2)                                  | Richardson (1978), Darmograi (1977), Mamadalieva et al. (2014)           |
|                       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                              |                                                                           |
|                       | luteolin 8-C-(2"-O-xylosyl)-β-D-glucoside (adonivernite) (10)              |                                                                           |
|                       | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
|                       | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
|                       | luteolin 6-C-(2"-O-xylosyl)-β-D-glucoside (homoadonivernite) (26)          |                                                                           |
|                       | isovitexin 4’-O-β-D-glucoside (isosaponarin) (124)                         |                                                                           |
| *Silene boissieri*    | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                           |                                                                           |
|                       | apigenin 6-C-β-D-arabinosyl-8-C-β-D-glucoside (vicenin-1) (62)              |                                                                           |
|                       | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
|                       | apigenin 8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
|                       | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                                                                           |
|                       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                              |                                                                           |
| *Silene bupleuroides* | luteolin 8-C-(2"-O-xylosyl)-β-D-glucoside (adonivernite) (10)              |                                                                           |
| *S. chlorifolia*      | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
| *S. compacta*         | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
| *S. cretacea*         | luteolin 6-C-(2"-O-xylosyl)-β-D-glucoside (homoadonivernite) (26)          |                                                                           |
| *S. cubanensis*       | isovitexin 4’-O-β-D-glucoside (isosaponarin) (124)                         |                                                                           |
| *S. polaris*          | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                                                                           |
|                       | luteolin 6-C-β-D-glucoside (isoorientin) (18)                              |                                                                           |
| *Silene chlorantha*   | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                           |                                                                           |
| *S. commutate*        | apigenin 6-C-β-D-arabinosyl-8-C-β-D-glucoside (vicenin-1) (62)              |                                                                           |
| *S. cyri*             | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
| *S. foliosa*          | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
| *S. graminifolia*     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                               |                                                                           |
| *S. italica*          | apigenin-8-C-β-D-glucoside (vitexin) (49)                                  |                                                                           |
| *S. jennisensis*      | luteolin 6-C-glucoside (isoorientin) (18)                                  |                                                                           |
| *S. macrostyla*       | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                                                                           |
| *S. nutans*           |                                                                          |                                                                           |
| *S. wolgensis*        |                                                                          |                                                                           |
Table 1 continued

| Genus          | Compounds                                      | References                                                                 |
|----------------|-----------------------------------------------|-----------------------------------------------------------------------------|
| *Silene conoidea* | orientin 4′-methoxy-4′-α-L-rhamnoside (9)    | Ali et al. (1999), Mamadalieva et al. (2014), Ullah et al. (2019)          |
|                | vitexin 4′-O-rhamnoside (65)                  |                                                                             |
|                | diosmetin 8-C-(4′-O-α-L-rhamnosyl)-β-D-glucoside (153) | Ahmad et al. (1998), Mamadalieva et al. (2014), Ullah et al. (2019) |
| *Silene diclinis* | kaempferol (172)                              | Richardson (1978), Mamadalieva et al. (2014)                               |
|                | apigenin 6-C-β-D-glucoside (isovitexin) (77) |                                                                             |
|                | apigenin 8-C-β-D-glucoside (vitexin) (49)    |                                                                             |
| *Silene flos-cuculi* (syn. *Lychnis flos-cuculi*) | apigenin (47)                                | Tomczyk (2008)                                                             |
|                | luteolin (1)                                  |                                                                             |
|                | apigenin 8-C-β-D-glucoside (vitexin) (49)    |                                                                             |
|                | luteolin 8-C-β-D-glucoside (orientin) (2)    |                                                                             |
| *Silene dioica* | apigenin 6-C-β-D-glucoside (isovitexin) (77) | Mamadalieva et al. (2014)                                                  |
| *Silene rubella* | apigenin (47)                                 | Hussein et al. (2019)                                                     |
|                | luteolin (1)                                  |                                                                             |
|                | luteolin 4′-methyl ether (diosmetin) (154)    |                                                                             |
|                | kaempferol (172)                              | Richardson (1978)                                                         |
|                | quercetin (189)                               | Richardson (1978), del Valle et al. (2015)                                 |
|                | apigenin 6-C-β-D-glucoside (isovitexin) (77) |                                                                             |
|                | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53) | del Valle et al. (2015)                                               |
|                | quercetin 3-O-α-L-rutinoside (rutin) (190)   |                                                                             |
|                | naringenin 7-O-α-L-hesperidoside (naringin) (221) |                                                                             |
| *Silene littorea* | kaempferol (172)                              | Richardson (1978)                                                         |
|                | luteolin 6-C-β-D-glucoside (isoorientin) (18) | Richardson (1978), del Valle et al. (2015)                                 |
| *Silene macrostyla* | apigenin (47)                               | del Valle et al. (2015)                                                  |
|                | luteolin (1)                                  |                                                                             |
|                | quercetin (189)                               |                                                                             |
|                | apigenin 6-C-β-D-glucoside (isovitexin) (77) |                                                                             |
|                | quercetin 3-O-α-L-rutinoside (rutin) (190)   |                                                                             |
| *Silene montbretiana* | kaempferol 6,8-dihydroxy-3-O-α-L-|Kılıç et al. (2019)                                                         |
|                | rhamnoside                                     |                                                                             |
| *Silene pratensis* | apigenin 6-C-β-D-glucoside (isovitexin) (77) | van Brederode et al. (1982)                                               |
|                | isovitexin 7-O-galactoside-6″-O-arabinoside (108) | Niemann (1984)                                                            |
| *Silene saxatilis* | apigenin (46)                                 | Zemtsova et al. (1976), Mamadalieva et al. (2014)                        |
|                | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53) |                                                                             |
|                | apigenin 8-C-β-D-glucoside (vitexin) (49)    |                                                                             |
|                | luteolin 6-C-β-D-glucoside (isoorientin) (18) |                                                                             |
|                | luteolin 8-C-β-D-glucoside (orientin) (2)    |                                                                             |
| *Silene schafta* | apigenin 6-C-β-D-glucosyl-8-C-α-L-arabinoside (shaftoside) | Chopin et al. (1974), Mamadalieva et al. (2014)                        |
| *Silene multifida* | apigenin 6-C-β-D-glucoside (isovitexin) (77) | Darmograi (1977), Mamadalieva et al. (2014)                               |
| *S. supina* | apigenin 8-C-β-D-glucoside (vitexin) (49)    |                                                                             |
| *S. turgida* | apigenin 6-C-β-D-glucoside (isovitexin) (77) |                                                                             |
| Genus               | Compounds                                                                 | References                                      |
|---------------------|---------------------------------------------------------------------------|------------------------------------------------|
| Silene viscariopsis | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             | Richardson (1978)                              |
|                     | luteolin 8-C-β-D-glucoside (orientin) (2)                                 | Richardson (1978), Mamadalieva et al. (2014)   |
| Silene vulgaris     | luteolin 6-C-β-D-glucoside (isoorientin) (18)                             |                                                 |
|                     | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                          | Olennikov (2020)                               |
|                     | apigenin 6-C-β-D-glucosyl-8-C-β-D-xyloside (vicenin-3) (64)               |                                                 |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                              |                                                 |
|                     | apigenin 6-C-β-glucosyl-8-C-α-arabinoside (schaftoside) (52)              |                                                 |
|                     | luteolin 6-C-β-glucosyl-8-C-arabinoside (carlinside, lucenin-5) (21)     |                                                 |
|                     | chrysoeriol 6-C-β-D-glucoside (isocarparin) (141)                         |                                                 |
|                     | genkwanin 6,8-di-C-glucoside (46)                                         |                                                 |
|                     | genkwanin 6-C-glucosyl-8-C-arabinoside (47)                               |                                                 |
|                     | isomollupentin 7-O-glucoside-2"-O-arabinoside (103)                       |                                                 |
|                     | isoorientin 2"-O-arabinoside (19)                                         |                                                 |
|                     | apigenin 6-C-α-arabinosyl-8-C-β-glucoside (isoschaftoside) (66)           |                                                 |
|                     | isovitexin 2"-O-arabinoside (83)                                          |                                                 |
|                     | isovitexin 2"-O-glucoside (meloside A) (85)                               |                                                 |
|                     | isovitexin 2"-O-xyloside (86)                                             |                                                 |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                            |                                                 |
|                     | luteolin 3'-O-arabinosyl-6-C-glucoside (lucenin-3) (44)                   |                                                 |
|                     | luteolin 6-C-β-glucoside (isoorientin) (18)                               |                                                 |
|                     | swertisin 2"-O-arabinoside (96)                                           |                                                 |
|                     | swertisin 2"-O-glucoside (spinosin) (97)                                  |                                                 |
|                     | isoorientin 7,3'-dimethyl ether (27)                                      |                                                 |
|                     | silenerepin (171)                                                        |                                                 |
| Silene schimperiana | apigenin (48)                                                             | Hussein et al. (2020)                          |
|                     | luteolin (1)                                                             |                                                 |
|                     | luteolin 4'-methyl ether (diosmetin) (154)                                |                                                 |
|                     | kaempferol (172)                                                         |                                                 |
|                     | quercetin (189)                                                          |                                                 |
|                     | cyanidanon 4'-methyl ether (hesperetin) (218)                             |                                                 |
|                     | hesperetin 7-O-α-L-rutinoside (hesperidin) (219)                          |                                                 |
|                     | kaempferol 3-O-β-D-rutinoside (nicotiflorin) (176)                        |                                                 |
|                     | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                                 |
| Spergularia diandra | tricin (159)                                                             | El-Dien et al. (2013)                          |
| Genus     | Compounds                                                                 | References                     |
|-----------|----------------------------------------------------------------------------|--------------------------------|
| *Spergularia marina* | apigenin 6-C-β-D-(2"-O-feruloyl)glucosyl-8-C-β-D-glucoside (70)  | Cho et al. (2016)               |
|           | apigenin 6-C-β-D-glucosyl-8-C-β-D-(2"-O-feruloyl)glucoside (67)          |                                |
|           | luteolin 6-C-β-D-(2"-O-feruloyl)glucosyl-8-C-β-D-glucoside (8)           |                                |
|           | luteolin 6-C-β-D-glucosyl-8-C-β-D-(2-O"-feruloyl)glucoside (11)          |                                |
| *Spergularia rubra* | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                          | Zoll et al. (1974), Bouillant et al. (1979), Ferreres et al. (2011) |
|           | apigenin 6-C-arabinoside (isomollupentin) (81)                            | Bouillant et al. (1979)         |
|           | apigenin 6-C-β-glucosyl-8-C-α-arabinoside (schaftoside) (52)             | Bouillant et al. (1979), Ferreres et al. (2011) |
|           | chrysoeriol 6,8-di-C-glucoside (stellarin-2) (130)                       | Zoll and Nouvel (1974)          |
| *Spergularia salina* | apigenin 6,8-di-C-(6"-malonyl, feruloyl)glucoside (68)                  |                                |
|           | apigenin 6,8-di-C-(6"-malonyl, sinapoyl)glucoside (69)                   |                                |
|           | apigenin 6-C-(2"-feruloyl)glucosyl-8-C-glucoside (70)                    |                                |
|           | apigenin 6-C-(4"-malonyl)glucosyl-8-C-glucoside (71)                     |                                |
|           | apigenin 6-C-glucosyl-8-C-(2"-feruloyl)glucoside (67)                    |                                |
|           | apigenin 6-C-glucosyl-8-C-(2"-sinapoyl)glucoside (72)                    |                                |
|           | chrysoeriol 6,8-di-C-(6"-malonyl, sinapoyl)glucoside (135)               |                                |
|           | chrysoeriol 6,8-di-C-(6"-malonyl, feruloyl)glucoside (136)               |                                |
|           | chrysoeriol 6,8-di-C-glucoside (stellarin-2) (130)                       |                                |
|           | chrysoeriol 6-C-(4"-malonyl)glucosyl-8-C-glucoside (137)                 |                                |
|           | chrysoeriol 6-C-arabinosyl-8-C-glucoside (131)                           |                                |
|           | chrysoeriol 6-C-glucosyl-8-C-(2"-feruloyl)glucoside (133)                |                                |
|           | chrysoeriol 6-C-glucosyl-8-C-(2"-sinapoyl)glucoside (134)                |                                |
|           | chrysoeriol 6-C-glucosyl-8-C-arabinoside (132)                           |                                |
|           | chrysoeriol 7-O-glucosyl-6-C-(2"-malonyl)-arabinosyl-8-C-arabinoside (144)|                                |
|           | chrysoeriol 7-O-glucosyl-6-C-arabinosyl-8-C-(6"-malonyl)arabinoside (145)|                                |
|           | luteolin 6,8-di-C-(2"-malonyl, feruloyl)glucoside (12)                   |                                |
|           | luteolin 6,8-di-C-glucoside (lucenin-2) (5)                              |                                |
|           | luteolin 6-C-(2"-feruloyl)glucosyl-8-C-glucoside (8)                     |                                |
|           | luteolin 6-C-(6"-acetyl)glucosyl-8-C-glucoside (6)                       |                                |
|           | luteolin 6-C-(6"-malonyl)glucosyl-8-C-glucoside (7)                      |                                |
|           | luteolin 6-C-glucosyl-8-C-(4"-malonyl)glucoside (13)                     |                                |
|           | luteolin 6-C-glucosyl-8-C-(2"-dihydroferuloyl)glucoside (14)             |                                |
|           | luteolin 6-C-glucosyl-8-C-(2"-feruloyl)glucoside (15)                    |                                |
|           | luteolin 6-C-glucosyl-8-C-(2"-p-coumaroyl)glucoside (16)                 |                                |
|           | luteolin 6-C-glucosyl-8-C-(2"-sinapoyl)glucoside (17)                    |                                |
|           | luteolin 6-C-glucosyl-8-C-arabinoside (21)                               |                                |
| Genus                | Compounds                                                                 | References                                                                 |
|---------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| **Stellaria dichotoma** | luteolin 7-O-glucosyl-6-C-glucosyl-8-C-(2"'-feruloyl)glucoside (41)       | Ferreres et al. (2011), Vinholes et al. (2011)                             |
|                     | luteolin 7-O-glucosyl-6,8-C-diglucoside (42)                               |                                                                           |
|                     | luteolin 7-O-glucosyl-6-C-glucosyl-8-C-(2"'-sinapoyl)glucoside (43)       |                                                                           |
|                     | apigenin (48)                                                             | Mikšátková et al. (2014)                                                  |
|                     | formononetin (224)                                                        |                                                                           |
|                     | genistein (229)                                                           |                                                                           |
|                     | glycine (227)                                                             |                                                                           |
|                     | isoformononetin (226)                                                     |                                                                           |
|                     | kaempferol (172)                                                          |                                                                           |
|                     | luteolin (1)                                                              |                                                                           |
|                     | naringenin (220)                                                          |                                                                           |
|                     | quercetin (189)                                                           |                                                                           |
|                     | tectorigenin 7-O-β-D-glucoside (tectoridin) (228)                         |                                                                           |
|                     | apigenin 7-O-β-D-glucoside (cosmosiin) (111)                              |                                                                           |
|                     | formononetin 7-O-β-D-glucoside (ononin) (225)                             |                                                                           |
|                     | genistein 7-O-β-D-glucoside (genistin) (230)                              |                                                                           |
|                     | luteolin 7-O-β-D-glucoside (cynaroside) (37)                              |                                                                           |
|                     | naringenin 7-O-β-D-glucoside (prunin) (222)                               |                                                                           |
|                     | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                                                           |
|                     | apigenin 6,8-di-C-β-D-glucoside (vicenin-2) (53)                          | Yasukawa et al. (1981), Sharma and Arora (2012)                           |
|                     | isoscultellarein 6-C-galactoside (78)                                     |                                                                           |
| **Stellaria graminea** | luteolin 6-C-β-D-glucoside (isoorientin) (18)                            | Richardson (1978)                                                         |
|                     | luteolin 8-C-β-D-glucoside (orientin) (2)                                  |                                                                           |
| **Stellaria holostea** | apigenin (48)                                                             | Mikšátková et al. (2014)                                                  |
|                     | genistein (229)                                                           |                                                                           |
|                     | kaempferol (172)                                                          |                                                                           |
|                     | luteolin (1)                                                              |                                                                           |
|                     | naringenin (220)                                                          |                                                                           |
|                     | quercetin (189)                                                           |                                                                           |
|                     | apigenin 7-O-β-D-glucoside (cosmosiin) (111)                              |                                                                           |
|                     | daidzein 7-O-β-D-glucoside (daidzin) (231)                                |                                                                           |
|                     | formononetin 7-O-β-D-glucoside (ononin) (225)                             |                                                                           |
|                     | genistein 7-O-β-D-glucoside (genistin) (230)                              |                                                                           |
|                     | luteolin 7-O-β-D-glucoside (cynaroside) (37)                              |                                                                           |
|                     | naringenin 7-O-β-D-glucoside (prunin) (222)                               |                                                                           |
|                     | quercetin 3-O-α-L-rutinoside (rutin) (190)                                |                                                                           |
|                     | apigenin 6-C-β-glucosyl-8-C-α-arabinoside (schaftoside) (52)              | Ancheeva et al. (2015)                                                    |
|                     | diosmetin 6-C-β-glucoside (158)                                           |                                                                           |
|                     | 3,5,7-trihydroxy-3',5'-dimethoxyflavone (216)                             |                                                                           |
| Genus     | Compounds                                                                 | References                                                                 |
|-----------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
|           | apigenin 6,8-di-C-\(\beta\)-D-glucoside (vicenin-2) (53)                 | Sharma and Arora (2012)                                                   |
|           | chrysoeriol 6,8-di-C-glucoside (stellarin-2) (130)                        |                                                                           |
|           | luteolin 8-C-\(\beta\)-D-glucoside (orientin) (2)                        | Richardson (1978), Boguslavskaya et al. (1985a, b), Ancheeva et al. (2015) |
|           | luteolin 6-C-\(\beta\)-D-glucoside (isoorientin) (18)                    |                                                                           |
| Stellaria | apigenin (48)                                                             | Kitanov (1992), Sharma and Arora (2012), Mikšíťková et al. (2014), Rogowska et al. (2017); Melnyk et al. (2018) |
| media     | luteolin (1)                                                              |                                                                           |
|           | quercetin 3-O-\(\alpha\)-L-rutinoside (rutin) (190)                       |                                                                           |
|           | genistein (229)                                                           |                                                                           |
|           | apigenin 6,8-di-C-\(\beta\)-D-glucoside (vicenin-2) (53)                 |                                                                           |
|           | apigenin 6-C-\(\alpha\)-L-arabinosyl-8-C-\(\beta\)-D-galactoside (57)    |                                                                           |
|           | apigenin 6-C-\(\beta\)-D-galactosyl-8-C-\(\alpha\)-L-arabinoside (74)    |                                                                           |
|           | apigenin 6-C-\(\beta\)-D-galactosyl-8-C-\(\beta\)-L-arabinoside (75)     |                                                                           |
|           | apigenin 6,8-di-C-\(\alpha\)-L-arabinoside (73)                          |                                                                           |
|           | luteolin 8-C-\(\beta\)-D-glucoside (orientin) (2)                        | Richardson (1978)                                                        |
|           | luteolin 6-C-\(\beta\)-D-glucoside (isoorientin) (18)                    |                                                                           |
|           | quercetin 3-O-\(\beta\)-D-glucoside (isoquercitrin) (192)                |                                                                           |
| S. nemorum| formononetin (224)                                                        | Dong et al. (2007), Mikšíťková et al. (2014)                              |
|           | glycine (227)                                                             |                                                                           |
|           | kaempferol (172)                                                          |                                                                           |
|           | naringenin (220)                                                          |                                                                           |
|           | quercetin (189)                                                           |                                                                           |
|           | apigenin 7-O-\(\beta\)-D-glucoside (cosmosin) (111)                      |                                                                           |
|           | formononetin 7-O-\(\beta\)-D-glucoside (ononin) (225)                    |                                                                           |
|           | genistein 7-O-\(\beta\)-D-glucoside (genistin) (230)                     |                                                                           |
|           | luteolin 7-O-\(\beta\)-D-glucoside (cynaroside) (37)                     |                                                                           |
|           | naringenin 7-O-\(\beta\)-D-glucoside (prunin) (222)                      |                                                                           |
Isoflavones

Phytoestrogens are non-steroidal polyphenolic compounds occurring in plants and can be chemically divided into two main groups: flavonoids (isoflavones) and non-flavonoids (lignans). The structure of isoflavone aglycone consists of a 3-phenylchroman ring that is substituted with hydroxyl groups in the positions C4 and C7 (Bustamante-Rangel et al. 2018; Krížová et al. 2019) (Fig. 14).

Because flavonoids are widely distributed in the plant kingdom and their presence in Caryophyllaceae plants has not been published until now, the authors of the article summarized the phytochemistry of 26 flavonoid-producing genera and relevant species. The flavonoid compounds occurring in Caryophyllaceae, the corresponding species and the literature references are summarized in Table 1.

### Conclusions

The Caryophyllaceae family contains a large number of genera and species that are widely distributed over different climate zones. It is evident that the plants from this family produce a wide range of

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**Table 1 continued**

| Genus               | Compounds                                                                 | References                                      |
|---------------------|----------------------------------------------------------------------------|-------------------------------------------------|
| *Stellaria nemorum* | apigenin 6-C-[α-arabinosyl](1″ → 2″)-O-β-xylloside]                         | Mikšátková et al. (2014), Ancheeva et al. (2015) |
|                     | apigenin 6-C-[α-arabinosyl](1″ → 2″)-O-β-glucoside]                         |                                                 |
|                     | apigenin 6-C-β-galactosyl-8-C-β-glucoside                                   |                                                 |
|                     | apigenin 6-C-β-glucosyl-8-C-α-arabinoside (schaftoside) (52)               |                                                 |
|                     | apigenin 6-C-β-glucosyl-8-C-β-xylloside (55)                                |                                                 |
| *Telephium imperati*| apigenin (48)                                                               | Richardson (1978)                               |
|                     | apigenin 6-C-β-D-glucoside (isovitexin) (77)                                | Baeva et al. (1975)                             |
| *Vaccaria segetalis*| apigenin 6-C-β-D-glucoside (isovitexin) (116)                              | Sang et al. (2000), Qi et al. (2013), Qi et al. (2014), Zhou et al. (2016) |
|                     | apigenin 6-C-β-glucosyl-8-C-β-glucoside                                    |                                                 |
|                     | apigenin 6-C-β-glucosyl-8-C-β-arabinoside                                  |                                                 |
|                     | isovitexin 4′-O-β-D-glucoside (isosaponarin) (124)                          | Litvinenko et al. (1967)                        |
|                     | isovitexin 6-C-[α-1-arabinopyranosyl](1″ → 2″)-β-D-glucopyranosyl]-7-O-β-D-glucoside (vaccarin) (126) | Zhang et al. (2011a, b), Zhang (2012), Zhou et al. (2016), Zhou et al. (2017) |
| *Vaccaria pyramidata*| apigenin 6-C-[α-1-arabinosyl](1″ → 2″)-β-D-glucosyl]-7-O-β-D-glucoside (vaccarin) (118) | Said et al. (2019)                              |
|                     | apigenin 6-C-β-D-glucosyl-7-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-E) (119) |                                                   |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                              |                                                 |
|                     | isovitexin 2″-O-arabinoside (83)                                            |                                                 |
|                     | isovitexin 4′-O-β-D-glucoside (isosaponarin) (124)                          | Zhang et al. (2011a, b), Zhou et al. (2016), Zhou et al. (2017) |
|                     | isovitexin 2″-O-α-1-arabinosyl-4″-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-H) (127) | Zhang et al. (2011a, b), Zhang (2012), Zhou et al. (2016) |
| *Vaccaria pyramidata*| apigenin 6-C-β-D-glucosyl-7-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-F) (119) |                                                   |
|                     | isovitexin 7-O-β-D-glucoside (saponarin) (105)                              |                                                 |
|                     | isovitexin 2″-O-arabinoside (83)                                            |                                                 |
|                     | apigenin 6-β-D-glucosyl-7-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-E) (119) |                                                   |
|                     | apigenin 6-β-D-glucosyl-7-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-F) (119) |                                                   |
|                     | apigenin 6-β-D-glucosyl-7-O-(6″-O-dihydroferuloyl)-β-D-glucoside (vaccarin-H) (127) |                                                   |
pharmaceutically promising, interesting, and valuable flavonoids and other secondary metabolites. Phytochemical data of flavonoids in plants of this family have not been published until now. Despite the dominant proportion of triterpene saponins among all phytoconstituents, polyphenols, including flavonoid compounds, remain a large group of compounds with health-related activity, such as antioxidant, anti-inflammatory, antimicrobial, organ-protective, and even anticancer effects (van Wyk and Wink 2017; Imran et al. 2019a; Ganeshpurkar and Saluja 2019). Our approach involved screening

![Fig. 10](image_url)  
Fig. 10 The chemical structures of the luteolin and its derivatives identified in species of Caryophyllaceae family
Fig. 11 The chemical structures of the apigenin and its derivatives identified in species of Caryophyllaceae family.
flavonoid-containing species, including those containing aglycones and their glycoside derivatives, which could be identified in 26 genera and more than 120 species within the Caryophyllaceae. To the best of our knowledge, apigenin is the most common aglycone in this family and can be found in 28 different species, such as *Vaccaria segetalis* (Baeva et al. 1975), *Stellaria media* (Melnyk et al. 2018), *Silene saxatilis* (Zemtsova et al. 1975), *Pteranthus dichotomus* (Allaoua et al. 2016), *Silene* (*Lychnis*) *flos-cuculi* (Tomczyk 2008), *Herniaria glabra* (El Mabruki et al. 2014) and others. Furthermore, the C-bonded apigenin glucoside isovitexin has been isolated from more than 70 plants, making it the predominant flavonoid within this family. On the basis of the data collected in Table 1, it was concluded that the highly glycosylated C- and O-flavonoids (apigenin, luteolin, chrysoeriol, kaempferol, quercetin, formononetin, genistein, myricetin, tectorigenin) with either one, two or three sugar moieties, as presented in

![Fig. 12](image-url)
this review, are commonly found in the Caryophyl-
laceae family. The genera Silene Mill., Dianthus L.,
Stellaria L., Hernia L., Spergularia Presl., Gyp-
sophila L. and Cerastium L. appear to contain high
abundances of flavonoid compounds.

In summary, the structural diversity of flavonoids
established in the Caryophyllaceae family makes them
an interesting object of phytochemical and pharma-
cological investigations.

Fig. 13 The chemical structures of the flavonols identified in Caryophyllaceae. Kaempferol and its derivatives (a), quercetin and its
derivatives (b), myricetin and its derivatives (c) identified in species of Caryophyllaceae family.
Authors’ contributions Conceptualization and Methodology, K.J., M.T.; Formal Analysis, K.J.; Investigation, K.J.; Writing – Original Draft Preparation, K.J.; Writing – Review and Editing, M.T., M.W.; Supervision, M.T.; Project Administration, M.T.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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