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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).

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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, phytoecdysteroids, 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 Caryphyllaceae 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 ascertainment 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.

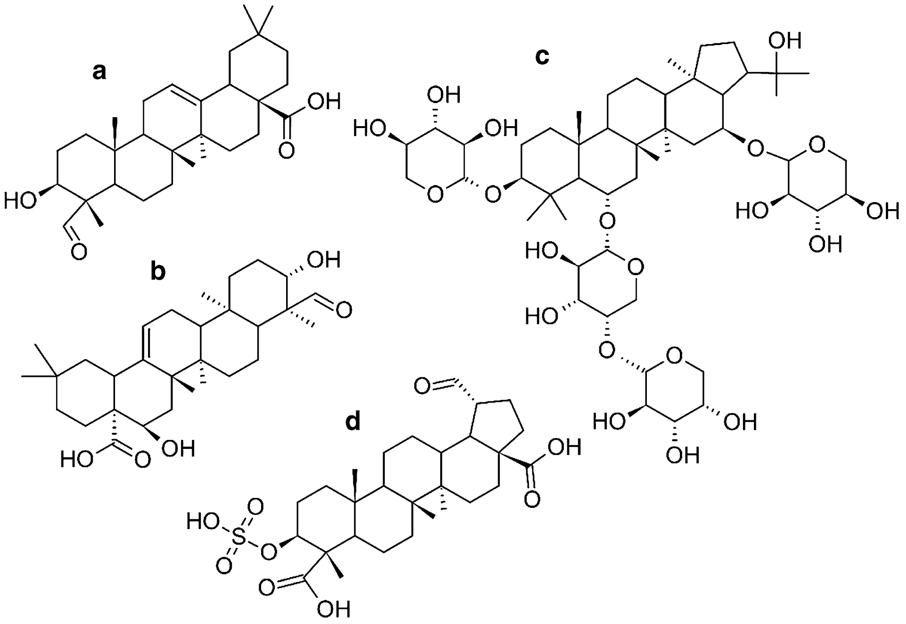


Fig. 1 The chemical structures of triterpene saponins in plants of Caryophyllaceae family. Gypsogenin (**a**), quillaic acid (**b**) succulentoside A (**c**), gypsophilin (**d**)

2018), *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 Aboutabl 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. italica*, *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-deoxyecdysterone, 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).

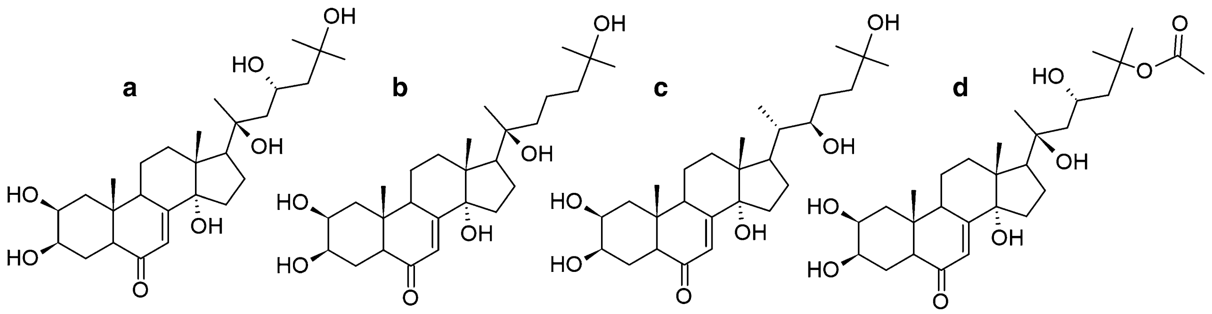


Fig. 2 The chemical structures of phytoecdysteroids in Caryophyllaceae species. 20-Hydroxyecdysone (**a**), taxisterone (**b**) α-ecdysone (**c**), viticosterone E (**d**)

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, tetracosane, phytol, 4,4-dimethyl-2-pentene, pentacosane, and hexahydrofarnesyl acetone (Yücel and Yayli 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 monoterpene 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).

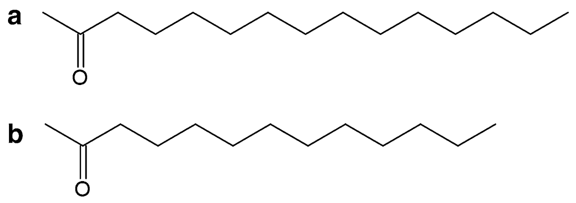


Fig. 3 The chemical structures of the main components of essential oils from Caryophyllaceae plants. 2-Pentadecanone (**a**), 2-tridecanone (**b**)

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 Δ^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 α-spinasterol 3-*O*-*β*-D-glucoside in the roots of *Psammosilene tunicoides* (Zhou et al. 2013) and the roots/rhizomes of *Silene tatarinowii* (Liang et al. 2019).

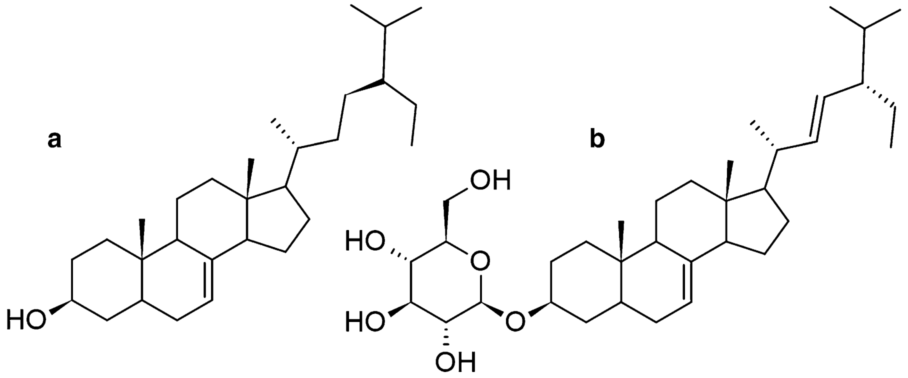


Fig. 4 The chemical structures of sterols in plant of Caryophyllaceae family. 22-Dihydrospinasterol (**a**), α-spinasterol 3-O-β-D-glucoside (**b**)

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), oldhamiaines A and B from the roots of *Gypsophila oldhamiana* (Zhang et al. 2015), and

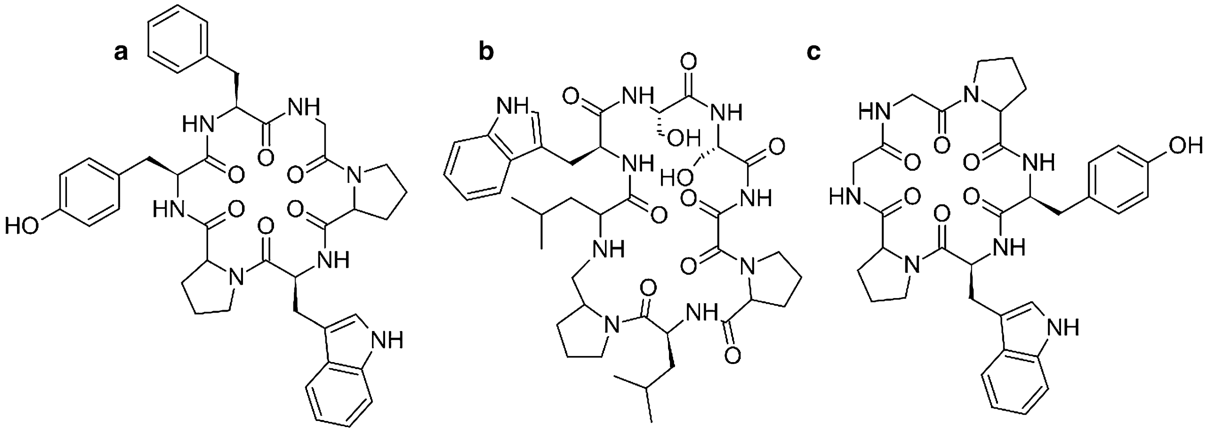


Fig. 5 The chemical structures of cyclic peptides in Caryophyllaceae species. Diandrine A (**a**), diandrine B (**b**) diandrine C (**c**)

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 *β*-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-*β*-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 (α, *β*, *γ*, *δ*) 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 *β*-carotene, a provitamin of vitamin A, was also reported (Vardavas et al. 2006; Morales et al. 2012; Mamadalieva et al. 2014). Moreover, *β*-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).

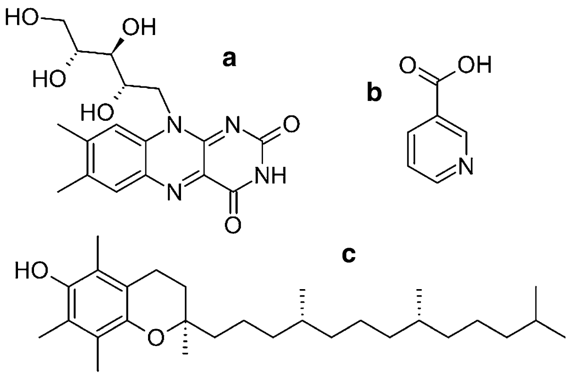


Fig. 7 The chemical structures of vitamins present in Caryophyllaceae plants. Vitamin B2 (**a**), vitamin B3 (**b**), vitamin E (**c**)

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

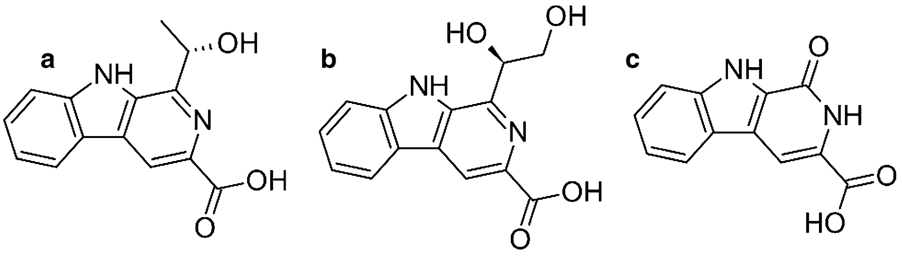


Fig. 6 The chemical structures of alkaloids in Caryophyllaceae plants. Dichotomine A (**a**), dichotomine B (**b**) dichotomine E (**c**)

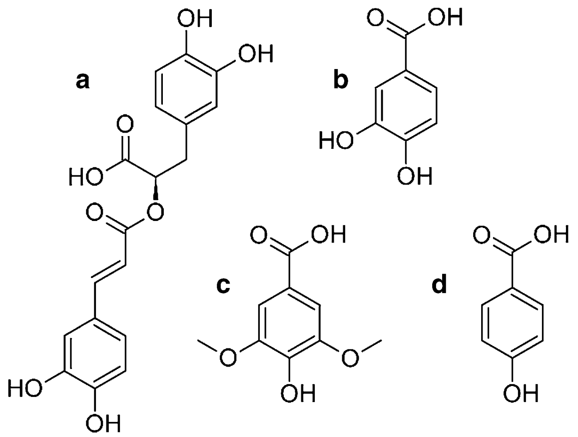


Fig. 8 The chemical structures of phenolic acids in plants of Caryophyllaceae family. Rosmarinic acid (**a**), 3,4-dihydroxybenzoic acid (**b**) syringic acid (**c**), p-hydroxybenzoic acid (**d**)

group in the pyran ring (Heim et al. 2002). Plants of the Caryophyllaceae family were also screened for flavanols, 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 epicatechin, 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 Caryophyllaceae, 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 glycoside 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. Tannins were detected in some *Minuartia* species (Zaychenko and Zernov 2017), *Stellaria laeta* (Jung et al. 1979), *Polycarpaea 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 Caryophyllaceae, 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 negatively 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

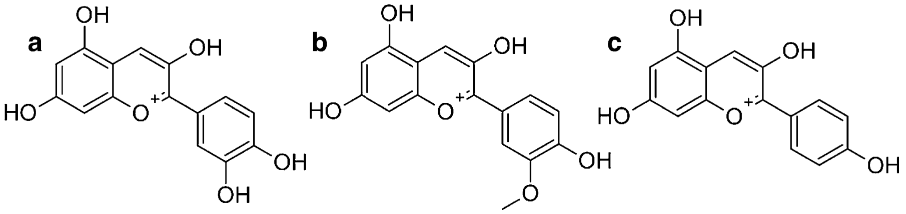


Fig. 9 The chemical structures of the anthocyanins in Caryophyllaceae. Cyanidin (**a**), peonidin (**b**) pelargonidin (**c**)

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 catabolize 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 flavonols 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 monocytic 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, antidiabetic, 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; Kozlowska 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. (Ferreres 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.

Table 1 Flavonoids compounds of the Caryophyllaceae 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)**	
	luteolin **(1)**	Liu et al. (2018), Cui et al. (2017b)
	homoeriodictyol **(217)**	
	kaempferol **(172)**	Liu et al. (2018), Tong et al. (2014)
	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 *A. serpyllifolia* *A. stenophyla* *A. juncea* *A. lychnidea*	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	Darmograi (1979)
	apigenin 8-*C*-*β*-D-glucoside (vitexin) **(49)**	
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
	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		
C. pilosum		
C. dahuricum		
C. fontanum		
C. trigynum		
Cerastium arvense	acacetin 6,8-di-*C*-β-D-galactoside **(152)**	Dubois et al. (1984)
	acacetin 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*-α-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)**	
	isomollupentin 7-*O*-glucoside-2″-*O*-xyloside **(104)**	
	isovitexin 7-*O*-glucoside-2″-*O*-arabinoside **(122)**	
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	Dubois et al. (1985)
Dianthus acieularis	apigenin 6-*C*-*anti*-α-D-glucoside (isoneoavroside) **(79)**	Boguslavskaya et al. (1983)
	apigenin 6-*C*-*syn*-α-D-glucoside (neoavroside) **(80)**	
Dianthus anatoficus	kaempferol **(172)**	Richardson (1978)
	quercetin **(189)**	
	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*-α-L-rhamnoside-6⁗-*O*-7,8-dihydroferulate **(106)**	
Dianthus hoeltzeri	apigenin 6-*C*-*anti*-α-D-glucoside (isoneoavroside) **(79)**	Boguslavskaya et al. (1983), Obmann et al. (2011a, b)
	apigenin 6-*C*-*syn*-α-D-glucoside (neoavroside) **(80)**	
	chrysoeriol 6-*C*-*syn*-α-D-glucoside **(142)**	
Dianthus dicolor		
Dianthus squarrosus	isovitexin 4′-*O*-*β*-D-glucoside (isosaponarin) **(124)**	Boguslavskaya et al. (1983)
Dianthus superbus	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	Seraya et al. (1978), Obmann et al. (2011a, b)
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	
Dianthus platycodon	kaempferol 3-*O*-(*β*-D-glucosyl-*β*-D-glucoside) **(173)**	Boguslavskaya (1976), Obmann et al. (2011a, b)
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
Dianthus ramosissimus	chrysoeriol 6-*C*-*anti*-α-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)**	
	isovitexin 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)**	

Table 1 continued

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)**	
	isoscoparin 7-*O*-galactoside **(147)**	
	isoscoparin 7-*O*-rhamnosyl-galactoside **(148)**	
	isoscoparin 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*-[α-L-rhamnosyl-(1 → 6)]-*β*-D-glucoside **(188)**	Curir et al. (2001), Obmann et al. (2011a, b)
	kaempferide 3-*O*-[2^{G}-*β*-D-glucosyl]-*β*-rutinoside **(187)**	Curir et al. (2005), Obmann et al. (2011a, b)
	quercetin 3-[6-*O*-(α-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*-[α-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*-*β*-D-glucosyl-(1^{V} → 2‴)-*O*-[α-L-rhamnosyl-(1^{IV} → 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)**	

Table 1 continued

Genus	Compounds	References
Dianthus deltoides	luteolin **(1)**	Obmann et al. (2011a, b)
	apigenin 6-*C*-*anti*-α-D-glucoside (isoneoavroside) **(79)**	
	apigenin 6-*C*-*syn*-α-D-glucoside (neoavroside) **(80)**	
	chrysoeriol 4′-*O*-*β*-D-glucoside **(150)**	
	luteolin 3′-methyl ether (chrysoeriol) **(128)**	
	luteolin 4′-*O*-*β*-D-glucoside **(40)**	
Dianthus arenarius	apigenin 4′-*O*-glucoside **(125)**	Boguslavskaya et al. (1983)
D. crinitus	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	
D. tetralepsis	apigenin 8-*C*-*β*-D-glucoside (vitexin) **(49)**	
	luteolin 4′-*O*-*β*-D-glucoside **(40)**	
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	
Dianthus grandiflora	kaempferol **(172)**	Richardson (1978)
	quercetin **(189)**	
Drymaria diandra	drymariatin A **(164)**	Ding et al. (1999), Brahmachari and Gorai (2006)
	6-trans-{2″-*O*-(rhamnosyl)}-ethenyl-5,7,4′-trihydroxyflavone **(170)**	
	drymariatin B **(165)**	Ding et al. (2005)
	drymariatin C **(166)**	
	drymariatin D **(167)**	
	5,4′-dihydroxy-7-methoxyflavone-6-*C*-(2″-*O*-α-L-rhamnosyl)-*β*-D-glucoside **(87)**	Nono et al. (2016)
	5,7,3′,4′-tetrahydroxyflavone-6-*C*-(2″-*O*-α-L-rhamnosyl)-*β*-D-glucoside **(45)**	
	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)** diandraflavone **(168)**	Hsieh et al. (2004a, b), Mandal et al. (2009)
	torosaflavone A **(169)**	
Drypis spinosa	naringenin **(220)**	Kremer et al. (2021)
	quercetin **(189)**	
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
Gymnocarpos decander	isorhamnetin 3-*O*-[(2⁗-O-acetyl − *β*-D-xylosyl-(1 → 6)-[*β*-D-apiofuranosyl-(1 → 2)]-*β*-D-glucoside **(212)**	Bechlem et al. (2017)
	isorhamnetin 3-*O*-2‴-*O*-acetyl − *β*-D-xylosyl-(1 → 6)-*β*-D-glucoside **(213)**	
	quercetin 3-*O*-(2‴-O-acetyl − *β*-D-xylosyl-(1 → 6)-*β*-D-glucoside **(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-glucoside (cynaroside) **(37)**	
	quercetin 3-*O*-*β*-D-galactoside (hyperoside) **(191)**	
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	

Table 1 continued

Genus	Compounds	References
	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)
	rivularin **(162)**	
	quercetin 3-*O*-*β*-D-glucoside (isoquercitrin) **(192)**	Zitouni (2017), Mubarek (2019)
	quercetin 3′-methyl ether (isorhamnetin) **(204)**	
Gypsophila altissima	isovitexin 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)
Gypsophila aucheri	naringenin **(220)**	Altay (2018)
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
Gypsophila repens	luteolin 7-*O*-α-L-arabinosyl-6-*C*-*β*-glucoside **(25)**	Elbandy et al. (2007)
Gypsophila elegans	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″)-*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 eriocalyx	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	Altay et al. (2019)
Gypsophila trichotoma	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)**	Zheleva-Dimitrova et al. (2018)
	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	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	Altay et al. (2018)
Gypsophila paniculata	isovitexin 7-*O*-*β*-D-glucoside (saponarin) **(105)**	Zdraveva et al. (2015)
Gypsophila perfoliata	apigenin **(48)**	Zheleva-Dimitrova et al. (2018)
	apigenin 2″-*O*-hexosyl-6-*C*-hexoside **(91)**	
	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 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
	luteolin 7-*O*-*β*-D-glucoside (cynaroside) **(37)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	

Table 1 continued

Genus	Compounds	References
Herniaria hirsuta	quercetin **(189)**	Richardson (1978)
	isorhamnetin 3-*O*-rutinoside (narcissin) **(206)**	Van Dooren et al. (2016)
	quercetin 3-*O*-(2″-*O*-α-L-rhamnosyl)-*β*-D-glucuronoside **(195)**	
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
Herniaria fontanessii	apigenin **(48)**	Tlili et al. (2019)
	kaempferol **(172)**	
	naringenin **(220)**	
	quercetin **(189)**	
	quercetin 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)**	
Herniaria 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 (narcissin) **(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)**	Kulevanova et al. (2003), El Mabruki et al. (2014)
	quercetin 3-*O*-*β*-D-glucoside (isoquercitrin) **(192)**	

Table 1 continued

Genus	Compounds	References
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	Maleš et al. (2013), Kozachok et al. (2018), El Mabruki et al. (2014)
Herniaria hemistemon	apigenin **(48)**	Elhagali et al. (2019)
	kaempferol **(172)**	
	naringenin **(220)**	
	quercetin **(189)**	
	apigenin 4′-methyl ether (acacetin) **(151)**	
	apigenin 6-*C*-α-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 (vitexin) **(49)**	
	cyanidanon 4′-methyl ether (hesperetin) **(218)**	
	hesperetin 7-*O*-α-L-rutinoside (hesperidin) **(219)**	
	kaempferol 3,7-dirhamnoside (kaempferitrin) **(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*-α-L-rhamnoside (quercetrin)	
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
	quercetin 7-methyl ether (rhamnetin) **(202)**	
Herniaria polygama	quercetin 3-*O*-α-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*-α-L-rutinoside (rutin) **(190)**	
	rhamnazin 3-*O*-glucoside **(209)**	
	rhamnazin 3-*O*-rutinoside (polygalacin) **(210)**	
	rhamnetin 3-*O*-glucoside **(193)**	

Table 1 continued

Genus	Compounds	References
Herniaria mauritanica	kaempferol 3-*O*-β-D-glucoside (astragalin) **(180)**	Cheriti and Sekkoum (1996)
	quercetin 3-*O*-β-D-glucoside (isoquercitrin) **(192)**	
Illecebrurn verticillatum	luteolin 8-*C*-β-D-glucoside (orientin) **(2)**	Richardson (1978)
	luteolin 6-*C*-β-D-glucoside (isoorientin) **(18)**	
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′-α-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)
	apigenin 8-*C*-α-D-glucoside (neovitexin) **(60)**	
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‴-acetyl)-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 (jaceoside) **(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)**	
Petrorhagia 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 (isoorientin) **(18)**	
	naringenin 8-*C*-α-L-arabinosyl-7-*O*-β-D-glucoside **(223)**	
	scoparin 2″-*O*-rhamnoside **(140)**	

Table 1 continued

Genus	Compounds	References
Petrorhagia glumacea *P. nanteuilli* *P. prolifera* *P. velutina*	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)** apigenin 8-*C*-*β*-D-glucoside (vitexin) **(49)**	Richardson (1978)
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 (vitexin) **(49)**	
Psammosilene tunicoides	tectorigenin 7-*O*-*β*-D-glucoside (tectoridin) **(228)**	Liu et al. (2007)
Pteranthus dichotomus	apigenin **(47)** apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	Allaoua et al. (2016)
	kaempferol **(172)** luteolin **(1)** kaempferol 3-*O*-rhamnoside-7-*O*-glucouronic 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)**	Atta et al. (2013)
	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)**	Yayli et al. (2001), Yayli et al. (2002)
Scleranthus annuus	kaempferol **(172)** luteolin **(1)** apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)** luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)** quercetin 3-*O*-*β*-D-glucoside (isoquercitrin) **(192)** quercetin 3-*O*-α-L-rutinoside (rutin) **(190)** vitexin 4′-*O*-α-L-rhamnoside **(61)**	Zdraveva et al. (2004)
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)** apigenin 6-*C*-*β*-D-arabinosyl-8-*C*-*β*-D-glucoside (vicenin-1) **(62)** apigenin 6-*C*-*β*-D-(*O*-rhamnosyl)-glucoside **(95)**	Zhuang (1983)
Saponaria ocymoides	quercetin **(189)**	Richardson (1978)
Saponaria vaccaria	quercetin **(189)** kaempferol **(172)**	Kumar and Khanna (1994)
	apigenin 6-*C*-[α-L-arabinosyl-(1‴ → 2″)-*β*-D-glucosyl]-7-*O*-*β*-D-glucoside (vaccarin) **(126)**	Balsevich et al. (2011)

Table 1 continued

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)**	Darmograi (1977), Mamadalieva et al. (2014)
	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 *S. chlorifolia* *S. compacta* *S. cretacea* *S. cubanensis* *S. polaris*	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)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
Silene chlorantha *S. commutate* *S. cyri* *S. foliosa* *S. graminifolia* *S. italica* *S. jenissensis* *S. macrostyla* *S. nutans* *S. wolgensis*	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-glucosyl-8-*C*-*β*-D-xyloside (vicenin-3) **(64)**	
	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	
	apigenin-8-*C*-*β*-D-glucoside (vitexin) **(49)**	
	luteolin 6-*C*-glucoside (isoorientin) **(18)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	

Table 1 continued

Genus	Compounds	References
Silene conoidea	orientin 4′-metoxy-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	apigenin **(47)**	Tomczyk (2008)
(syn. *Lychnis flos-cuculi*)	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)**	
	quercetin **(189)**	
	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	
	apigenin 6,8-di-*C*-*β*-D-glucoside (vicenin-2) **(53)**	
	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)**	
	quercetin **(189)**	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-rhamnoside	Kılınç et al. (2019)
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		

Table 1 continued

Genus	Compounds	References
Silene viscariopsis	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	Richardson (1978)
Silene vulgaris	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	Richardson (1978), Mamadalieva et al. (2014)
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
Silene repens	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 (carlinoside, lucenin-5) **(21)**	
	chrysoeriol 6-*C*-*β*-D-glucoside (isoscoparin) **(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*-D-glucoside (isoorientin) **(18)**	
	swertisin 2″-*O*-arabinoside **(96)**	
	swertisin 2″-*O*-glycoside (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)

Table 1 continued

Genus	Compounds	References
Spergularia marina	tricin **(159)**	
	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)**	

Table 1 continued

Genus	Compounds	References
	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)**	
Stellaria dichotoma	apigenin **(48)**	Mikšátková et al. (2014)
	formononetin **(224)**	
	genistein **(229)**	
	glycitein **(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)
	isoscutellarein 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)**	

Table 1 continued

Genus	Compounds	References
	apigenin 6,8-di-*C*-*β*-D-glucoside (vicenin-2) **(53)**	Sharma and Arora (2012)
	chrysoeriol 6,8-di-*C*-glucoside (stellarin-2) **(130)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	Richardson (1978), Boguslavskaya et al. (1985a, b), Ancheeva et al. (2015)
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
Stellaria media	apigenin **(48)**	Kitanov (1992), Sharma and Arora (2012), Mikšátková et al. (2014), Rogowska et al. (2017); Melnyk et al. (2018)
	luteolin **(1)**	Mikšátková et al. (2014), Melnyk et al. (2018)
	quercetin 3-*O*-α-L-rutinoside (rutin) **(190)**	
	genistein **(229)**	Kitanov (1992), Sharma and Arora (2012)
	apigenin 6,8-di-*C*-*β*-D-glucoside (vicenin-2) **(53)**	
	apigenin 6-*C*-α-L-arabinosyl-8-*C*-*β*-D-galactoside **(57)**	Dong et al. (2007)
	apigenin 6-C-*β*-D-galactosyl-8-*C*-α-L-arabinoside **(74)**	
	apigenin 6-*C*-*β*-D-galactosyl-8-*C*-*β*-L-arabinoside **(75)**	
	apigenin 6-*C*-*β*-D-glucosyl-8-*C*-*β*-D-galactoside **(50)**	
	apigenin 6,8-di-*C*-α-L-arabinoside **(73)**	
	luteolin 8-*C*-*β*-D-glucoside (orientin) **(2)**	Richardson (1978)
	luteolin 6-*C*-*β*-D-glucoside (isoorientin) **(18)**	
	quercetin 3-*O*-*β*-D-glucoside (isoquercitrin) **(192)**	Melnyk et al. (2018)
Stellaria media *S. nemorum*	formononetin **(224)**	Dong et al. (2007), Mikšátková et al. (2014)
	glycitein **(227)**	
	kaempferol **(172)**	
	naringenin **(220)**	
	quercetin **(189)**	
	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)**	

Table 1 continued

Genus	Compounds	References
Stellaria nemorum	apigenin 6-*C*-[(α-arabinosyl)-(1 → 2)-*O*-*β*-xyloside]	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*-xyloside **(55)**	
Telephium imperati	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	Richardson (1978)
	apigenin 8-*C*-*β*-D-glucoside (vitexin) **(49)**	
Vaccaria segetalis	apigenin **(48)**	Baeva et al. (1975)
	apigenin 6-*C*-*β*-D-glucoside (isovitexin) **(77)**	
	apigenin 6-*C*-arabinosyl-*O*-glucoside **(116)**	Sang et al. (2000), Qi et al. (2013), Qi et al. (2014); Zhou et al. (2016)
	apigenin 6-*C*-glucosyl-*O*-glucoside	
	apigenin 6-*C*-[α-L-arabinosyl-(1‴ → 2″)-*β*-D-glucosyl]-7-*O*-*β*-D-glucoside (vaccarin) **(126)**	Baeva et al. (1975), Sang et al. (2000), Sang et al. (2003a, b), Sang et al. (2003a), Qi et al. (2013), Qi et al. (2014), Liu et al. (2019)
	isovitexin 4′-*O*-*β*-D-glucoside (isosaponarin) **(124)**	Litvinenko et al. (1967)
	apigenin 6-*C*-[α-L-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)
	apigenin 6-*C*-[α-L-arabinosyl-(1‴ → 2″)-*β*-D-glucosyl]-7-*O*-(6⁗-*O*-dihydroferuloyl)-*β*-D-glucoside (vaccarin-E) **(118)**	Zhou et al. (2017)
	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)**	Zhang et al. (2011a, b), Zhou et al. (2016), Zhou et al. (2017)
	isovitexin 4′-*O*-*β*-D-glucoside (isosaponarin) **(124)**	Zhang et al. (2011a, b), Zhang (2012), Zhou et al. (2016)
	isovitexin-2″-*O*-α-L-arabinosyl-4′-*O*-(6⁗-*O*-dihydroferuloyl)-*β*-D-glucoside (vaccarin-H) **(127)**	
Vaccaria pyramidata	vitexin 7-*O*-*β*-D-glucoside **(117)**	Said et al. (2019)
	vitexin 2″-*O*-α-L-rhamnoside **(76)**	

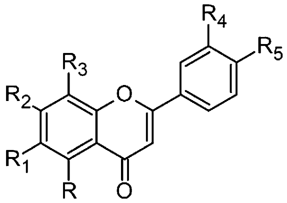
Isoflavones

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

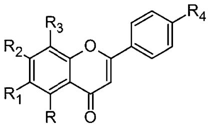


	R	R$_1$	R$_2$	R$_3$	R$_4$	R$_5$
1	OH	H	OH	H	OH	OH
2	OH	H	OH	*β*-D-*glc*	OH	OH
3	OH	*ara*	OH	*glc*	OH	OH
4	OH	H	OCH$_3$	*β*-D-*glc*	OH	OH
5	OH	*glc*	OH	*glc*	OH	OH
6	OH	*glc*-(6″-*O*-*acetyl*)	OH	*glc*	OH	OH
7	OH	*glc*-(6″-*O*-*malonyl*)	OH	*glc*	OH	OH
8	OH	*glc*-(2″-*O*-*feruloyl*)	OH	*glc*	OH	OH
9	OH	H	OH	*α*-L-*glc*-(4″-*O*-*rha*)	OH	OCH$_3$
10	OH	H	OH	*β*-D-*glc*-(2″-*O*-*xyl*)	OH	OH
11	OH	*β*-D-*glc*	OH	*β*-D-*glc* -(2″-*O*-*feruloyl*)	OH	OH
12	OH	*glc*-(2″-*O*-*malonyl, feruloyl)*	OH	*glc*-(2″-*O*-*malonyl, feruloyl)*	OH	OH
13	OH	*glc*	OH	*glc*-(4″-*O*-*malonyl*)	OH	OH
14	OH	*glc*	OH	*glc*-(2‴-*O*-*dihydroferuloyl*)	OH	OH
15	OH	*glc*	OH	*glc*-(2‴-*O*-*feruloyl*)	OH	OH
16	OH	*glc*	OH	*glc*-(2‴-*O*-*p*-*coumaroyl*)	OH	OH
17	OH	*glc*	OH	*glc*-(2‴-*O*-*sinapoyl*)	OH	OH
18	OH	*β*-D-*glc*	OH	H	OH	OH
19	OH	*β*-D-*glc* -(2”-*O*-*ara*)	OH	H	OH	OH
20	OH	*β*-D-*glc*-(2”-*O*-*rha*)	OH	H	OH	OH
21	OH	β-D-*glc*	OH	*ara*	OH	OH
22	OH	*β*-D-*glc*	*O*-*gal*	H	OH	OH
23	OH	*β*-D-*glc*	*O*-*rha*-*O*-*gal*	H	OH	OH
24	OH	*β*-D-*glc*	*O*-*rut*	H	OH	OH
25	OH	*β*-D-*glc*	*O*-*α*-L-*ara*	H	OH	OH
26	OH	*β*-D-*glc*-(2″-*O*-*xyl*)	OH	H	OH	OH
27	OH	*β*-D-*glc*	OCH$_3$	H	OCH$_3$	OH
28	OH	*glc*-(2″-*O*-*feruloyl*)	OH	H	OH	*O*-*glc*
29	OH	*hex*-(2”-*O*-*pen*)	OH	H	OH	OH
30	OH	*hex*-(2”-*O*-*pen*)	OH	H	OH/OCH$_3$	OH/OCH$_3$
31	OH	*hex*-(2”-*O*-*hex*)	OH	H	OH	OH
32	OH	*hex*	OH	*hex*	OH	OH
33	OH	*ara*-[2”-*O*-*rha*-(1‴→2″)]	OH	H	OH	OH
34	OH	*xyl*-[2”-*O*-*rha*-(1‴→2″)]	OH	H	OH	OH
35	OH	*rha*-[4″-*O*-*rha*(1‴→4″)]	OH	OH	OH	OH
36	*O*-*β*-D-*glc*	H	OH	H	OH	OH
37	OH	H	*O*-*β*-D-*glc*	H	OH	OH
38	OH	H	*glc*-*glc*	H	OH	OH
39	OH	*hex*	*O*-*hex*-*malyl*	H	OH	OH
40	OH	H	OH	H	OH	*O*-*β*-D-*glc*
41	OH	*glc*	*O*-*glc*	*glc*-(2‴-*O*-*feruloyl*)	OH	OH
42	OH	*glc*	*O*-*glc*	*glc*	OH	OH
43	OH	*glc*	*O*-*glc*	*glc*-(2‴-*O*-*sinapoyl*)	OH	OH
44	OH	*β*-D-*glc*	OH	H	O-*ara*	OH
45	OH	*β*-D-*glc* (2″-*O*-*α*-L-*rha*)	OH	H	OH	OH
46	OH	*glc*	OCH$_3$	*glc*	OH	OH
47	OH	*glc*	OCH$_3$	*ara*	OH	OH

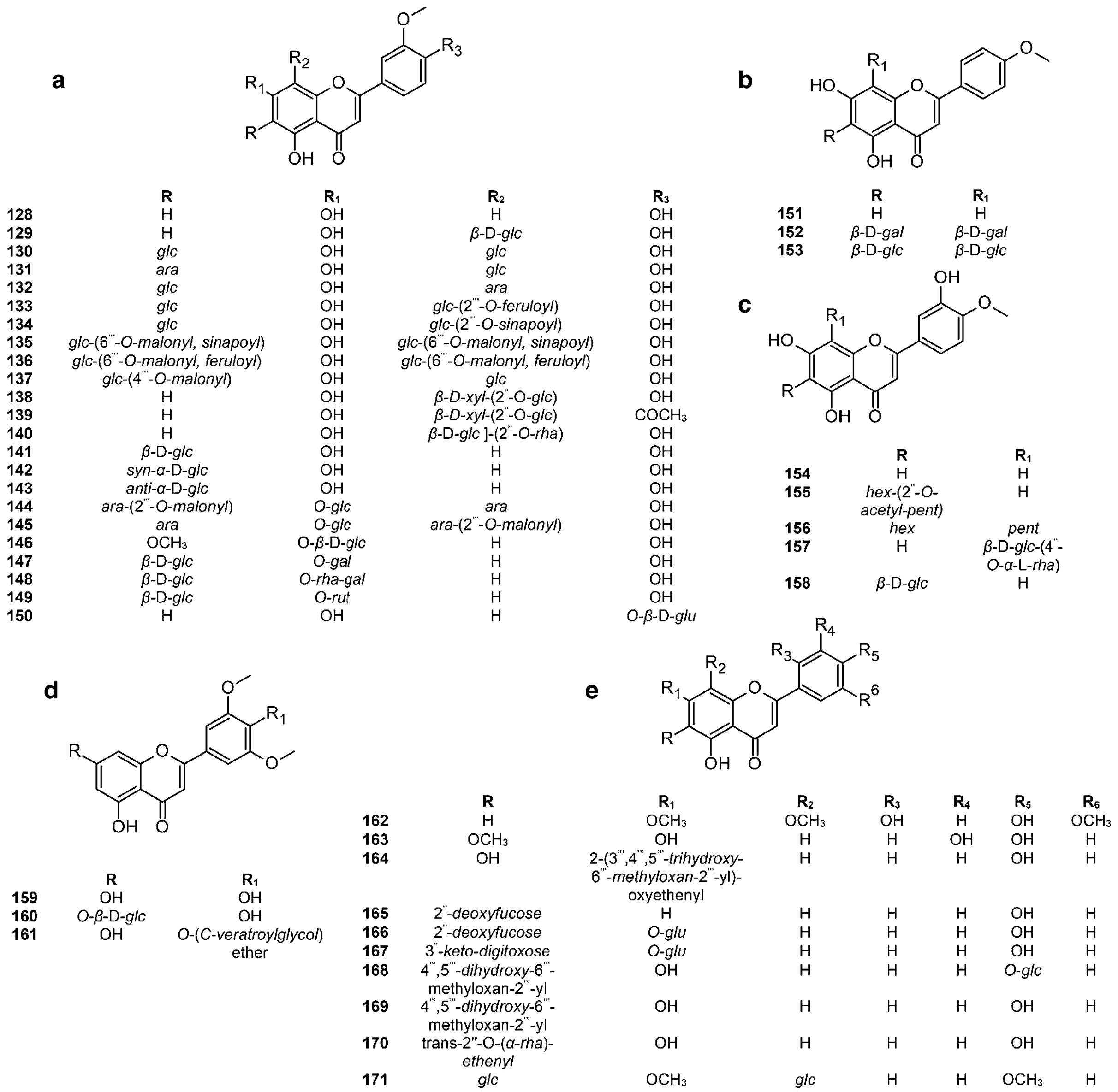
Fig. 10 The chemical structures of the luteolin and its derivatives identified in species of Caryophyllaceae family

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. 11 The chemical structures of the apigenin and its derivatives identified in species of Caryophyllaceae family



	R	R1	R2	R3	R4
48	OH	H	OH	H	OH
49	OH	H	OH	β-D-*glc*	OH
50	OH	β-D-*glc*	OH	β-D-*gal*	OH
51	OH	*xyl*	OH	*ara*	OH
52	OH	β-D-*glc*	OH	α-L-*ara*	OH
53	OH	β-D-*glc*	OH	β-D-*glc*	OH
54	OH	*gal*	OH	*ara*	OH
55	OH	β-D-*glc*	OH	β-D-*glc*	OH
56	OH	*hex*	OH	*pen*	OH
57	OH	α-L-*ara*	OH	*β-D-gal*	OH
58	OH	*glc*	OH	*rha*	OH
59	OH	*rha*	OH	*glc*	OH
60	OH	H	OH	*α-D-glc*	OH
61	OH	H	OH	*β-D-glc*	*O-α*-L-*rha*
62	OH	*β-D-ara*	OH	*β-D-glc*	OH
63	OH	H	OH	*β-D-glc* (2″-*O-glc*)	OH
64	OH	β-D-*glc*	OH	*β-D-xyl*	OH
65	OH	H	OH	*β-D-glc*-(4″-*O-rha*)	OH
66	OH	*α-ara*	OH	*β-D-glc*	OH
67	OH	*glc*	OH	*glc*-(2″-*O-feruloyl*)	OH
68	OH	*glc*-(6‴-*O-malonyl, feruloyl*)	OH	*glc*-(6‴-*O-malonyl, feruloyl*)	OH
69	OH	*glc*-(6‴-*O-malonyl, sinapoyl*)	OH	*glc*-(6‴-*O-malonyl, sinapoyl*)	OH
70	OH	*glc*-(2‴-*O-feruloyl*)	OH	*glc*	OH
71	OH	*glc*-(2‴-*O-malonyl*)	OH	*glc*	OH
72	OH	*glc*	OH	*glc*-(2″-*O-sinapoyl*)	OH
73	OH	α-L-*ara*	OH	α-L-*ara*	OH
74	OH	β-D-*gal*	OH	α-L-*ara*	OH
75	OH	β-D-*gal*	OH	β-L-*ara*	OH
76	OH	H	OH	*β-D-glc*-(2″-O-α-L-*rha*)	OH
77	OH	β-D-*glc*	OH	H	OH
78	OH	*gal*	OH	*ara*	OH
79	OH	*anti-α*-D-*glc*	OH	H	OH
80	OH	*syn-α*-D-*glc*	OH	H	OH
81	OH	*ara*	OH	H	OH
82	OH	*xyl*	OH	H	OH
83	OH	β-D-*glc-*(2″-*O-ara*)	OH	H	OH
84	OH	β-D-*glc*-(2″-*O-feruloyl*)	OH	H	OH
85	OH	β-D-*glc*-(2″-*O-glc*)	OH	H	OH
86	OH	β-D-*glc*-(2″-*O-xyl*)	OH	H	OH
87	OH	β-D-*glc*-(2″-*O-α*-L-*rha*)	OCH_3	H	OH
88	OH	*hex*-(2″-*O-acetyl-pent*)	OH	H	OH
89	OH	*hex*-(2″-*O-diacetyl-pent*)	OH	H	OH
90	OH	*hex*-(2″-*O-pent*)	OH	H	OH
91	OH	*hex*-(2″-*O-hex*)	OH	H	OH
92	$COCH_3$	β-D-*glc*-(2″-*O-rha*)	OH	H	OH
93	OH	*ara*-(*O-diglc*)	OH	H	OH
94	OH	*triglc*	OH	H	OH
95	OH	β-D-*glc*-(*O-rha*)	OH	H	OH
96	OH	*β-D-glc* (2″-*O-ara*)	OCH_3	H	OH
97	OH	*β-D-glc* -2″-*O-glc*)	OCH_3	H	OH
98	OH	*ara(*2″-*O-glc*)	OH	H	OH
99	OH	β-D-*glc*-(2″-*O-rha*)	OH	H	OH
100	OH	*ara*	OH	*xyl*	OH
101	OH	*xyl*	*O-glu*	H	OH
102	OH	*ara(*2″-*O-glc*)	*O-glu*	H	OH
103	OH	*ara(*2″-*O-ara*)	*O-glu*	H	OH
104	OH	*ara(*2″-*O-xyl*)	*O-glu*	H	OH
105	OH	β-D-*glc*	*O-β*-D-*glc*	H	OH
106	OH	β-D-*glc*-[2″-*O-rha*-(6⁗-*O*-7,8-*dihydroferulyl*)]	*O-β*-D-*glc*	H	OH
107	OH	β-D-*glc*	*O-gal*-(6″-*O-ara*)	H	OH
108	OH	β-D-*glc*	*O-gal*	H	OH
109	OH	β-D-*glc*	*O-rut*	H	OH
110	OH	*hex*	*O-hex-malyl*	H	OH
111	OH	H	*O-β*-D-*glc*	H	OH
112	OH	β-D-*glc*	O-*glc*-(6″-*O-malyl*)	H	OH
113	OH	β-D-*glc*-[*xyl*-(1‴→2′)-*O-gal*]	*O-β*-D-*glc*	H	OH
114	OH	H	*O-β*-D-*glc*-[(1‴→2′)-*O-glc*]	H	OH
115	OH	H	*β-D-O-glc*-[(1‴→2′)-*O-rha*]	H	OH
116	OH	*ara*-(*O-glc*)	*O-glc*	H	OH
117	OH	H	*β*-D-*O-glc*	β-D-*glc*	OH
118	OH	β-D-*glc*-[(1‴→2″)-*α*-L-*ara*]	*O-β*-D-*glc*-(6‴-*O*-*dihydroferuloyl*)	H	OH
119	OH	β-D-*glc*	*O-β*-D-*glc*-(6‴-*O*-*dihydroferulol*)	H	OH
120	OH	*ara*	OH	H	*O-glu*
121	OH	β-D-*glc*-(2″-*O-feruloyl*)	OH	H	*O-glu*
122	OH	β-D-*glc*-(2″-*O-ara*)	OH	H	*O-glc*
123	OH	β-D-*glc*-(2″-*O-glc*)	OH	H	*O-glc*
124	OH	β-D-*glc*	OH	H	*O-β*-D-*glu*
125	OH	H	OH	H	*O-glu*
126	OH	*β-D-glc*-[2″-*O-α*-L-*ara*-(1‴→2″)]	OH	H	*O-glu*
127	OH	β-D-*glc*-[(1‴→2″)-*α*-L-*ara*]	OH	H	*O-β*-D-*glc*-(6‴-*O*-*dihydroferuloyl*)



	R	R₁	R₂	R₃
128	H	OH	H	OH
129	H	OH	*β*-D-*glc*	OH
130	*glc*	OH	*glc*	OH
131	*ara*	OH	*glc*	OH
132	*glc*	OH	*ara*	OH
133	*glc*	OH	*glc*-(2‴-*O-feruloyl*)	OH
134	*glc*	OH	*glc*-(2‴-*O-sinapoyl*)	OH
135	*glc*-(6‴-*O-malonyl, sinapoyl*)	OH	*glc*-(6‴-*O-malonyl, sinapoyl*)	OH
136	*glc*-(6‴-*O-malonyl, feruloyl*)	OH	*glc*-(6‴-*O-malonyl, feruloyl*)	OH
137	*glc*-(4‴-*O-malonyl*)	OH	*glc*	OH
138	H	OH	*β-D-xyl*-(2″-O-*glc*)	OH
139	H	OH	*β-D-xyl*-(2″-O-*glc*)	$COCH_3$
140	H	OH	*β*-D-*glc*]-(2″-*O-rha*)	OH
141	*β*-D-*glc*	OH	H	OH
142	*syn-α*-D-*glc*	OH	H	OH
143	*anti-α*-D-*glc*	OH	H	OH
144	*ara*-(2‴-*O-malonyl*)	*O-glc*	*ara*	OH
145	*ara*	*O-glc*	*ara*-(2‴-*O-malonyl*)	OH
146	OCH_3	O-*β*-D-*glc*	H	OH
147	*β*-D-*glc*	*O-gal*	H	OH
148	*β*-D-*glc*	*O-rha-gal*	H	OH
149	*β*-D-*glc*	*O-rut*	H	OH
150	H	OH	H	*O-β*-D-*glu*

	R	R₁
151	H	H
152	*β*-D-*gal*	*β*-D-*gal*
153	*β*-D-*glc*	*β*-D-*glc*

	R	R₁
154	H	H
155	*hex*-(2″-*O-acetyl-pent)*	H
156	*hex*	*pent*
157	H	*β*-D-*glc*-(4″-*O*-*α*-L-*rha*)
158	*β*-D-*glc*	H

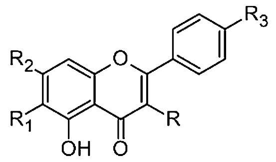
	R	R₁
159	OH	OH
160	*O-β*-D-*glc*	OH
161	OH	*O*-(*C-veratroylglycol*) ether

	R	R₁	R₂	R₃	R₄	R₅	R₆
162	H	OCH_3	OCH_3	OH	H	OH	OCH_3
163	OCH_3	OH	H	H	OH	OH	H
164	OH	2-(3‴,4‴,5‴-*trihydroxy*-6‴-*methyloxan*-2‴-yl)-oxyethenyl	H	H	H	OH	H
165	2″-*deoxyfucose*	H	H	H	H	OH	H
166	2″-*deoxyfucose*	*O-glu*	H	H	H	OH	H
167	3″-*keto-digitoxose*	*O-glu*	H	H	H	OH	H
168	4‴,5‴-*dihydroxy*-6‴-methyloxan-2‴-yl	OH	H	H	H	*O-glc*	H
169	4‴,5‴-*dihydroxy*-6‴-methyloxan-2‴-yl	OH	H	H	H	OH	H
170	trans-2''-O-(*α-rha*)-*ethenyl*	OH	H	H	H	OH	H
171	*glc*	OCH_3	*glc*	H	H	OCH_3	H

Fig. 12 The chemical structures of the chrysoeriol (**a**), acacetin (**b**), diosmetin (**c**), tricin (**d**), and their derivatives identified in species of Caryophyllaceae family

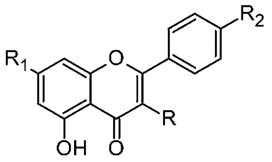
flavonoid-containing species, including those containing aglycones and their glycoside derivatives, which could be identified in 26 genera and more than 120 species within the Caryophyllaceae.

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 a



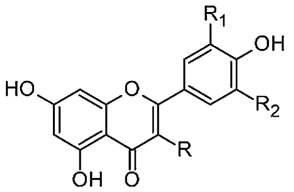
	R	R_1	R_2	R_3
172	OH	H	OH	OH
173	*O*-*β*-D-*glc*-(*O*-*β*-D-*glc*)	H	OH	OH
174	*O*-*glc*-[2‴-*O*-(6-*malyl*)-*glc*-6‴-*rha*]	H	OH	OH
175	*O*-*glc*-[2‴-*O*-*glc*-6‴-*rha*]	H	OH	OH
176	*O*-*β*-D-*rut*	H	OH	OH
177	*O*-*β*-D-*glc*-[*O*-*β*-D-*glc*(1‴→2″)-*O*-*α*-L-*rha*(1^{V}→2‴) *O*-*β*-D-*glc*-(1^{IV}→6″)]	H	OH	OH
178	*O*-*β*-D-*glc*-[*glc*(1‴→2″)-*O*-*α*-L-*rha*(1⁗→6‴)]	H	OH	OH
179	*O*-*β*-D-*glc*-(*O*-*rha*)	H	OH	OH
180	*O*-*glc*	H	OH	OH
181	*O*-*rha*	H	*O*-*rha*	OH
182	*O*-*glc*-(2″-*O*-*p*-coumaroyl)	H	OH	OH
183	OH	H	*O*-*rha*-*O*-*glc*	OH
184	*O*-*rha*	H	*O*-glucuronic acid	OH
185	*O*- *β*-*D*-*glc*-*(*1‴→2″*)*-*β*-D-*glc*	OH	OH	OH
186	OH	H	OH	OCH_3
187	*O*-[2^{G}-*β*-D-*glc*]-*β*-*rut*	H	OH	OCH_3
188	*O*-*β*-D-*glc*-[*glc*(1‴→2″)-*O*-*α*-L-*rha*(1⁗→6‴)]	H	OH	OCH_3

b



	R	R_1	R_2
189	OH	OH	OH
190	*O*-*α*-L-*rut*	OH	OH
191	*O*-*β*-D-*gal*	OH	OH
192	*O*-*β*-D-*glc*	OH	OH
193	*O*-*glc*	OCH_3	OH
194	*O*-*β*-D-*glc*-(6″-*O*-*ara*)	OH	OH
195	*O*-*β*-D-*glu*-(2″-*O*-*α*-L-*rha*)	OH	OH
196	*O*-*β*-D-*glc*-*O*-*gal*	OH	OH
197	*O*- *β*-D-*glc*-*O*- *β*-D-*glc*	OH	OH
198	*O*-*β*-D-*glc*-[(1″→6‴)-2″-*O*-*acetyl*-*O*-*β*-D-*xyl*]	OH	OH
199	*O*-*β*-D-*gal*-[(1″→6‴)-2‴-*O*-*acetyl*-*O*-*β*-D-*glc*]	OH	OH
200	*O*-*β*-D-*glc*-[(1″→2‴)-D-*apio*-*O*-*β*-D-*furanosyl*-*O*-*α*-L-*rha*(1‴→6^{IV})]	OH	OH
201	*O*-*glc*	*O*-*rha*	OH
202	OH	OCH_3	OH
203	OH	*O*-*β*-D-*glc*	OH
204	OH	OH	OCH_3
205	*O*- *β*-D-*glc*	OH	OCH_3
206	*O*-*rut*	OH	OCH_3
207	*O*-*rab*	OH	OCH_3
208	*O*-(3‴-*O*-*feruloyl*)	OH	OCH_3
209	*O*-*glc*	OCH_3	OCH_3
210	*O*-*rut*	OCH_3	OCH_3
211	*O*-*hex*-*O*-*hex*	OH	OCH_3
212	*O*-*β*-D-*glc*-[(1″→6‴)-2″-*O*-*acetyl*-*O*-*β*-D-*xyl*-(1‴→6^{IV})-*β*-D-*apiofuranozyl*]	OH	OCH_3
213	*O*-*β*-D-*glc*-[(1″→6‴)-2‴-*O*-*acetyl*-*O*-*β*-D-*xyl*]	OH	OCH_3

c

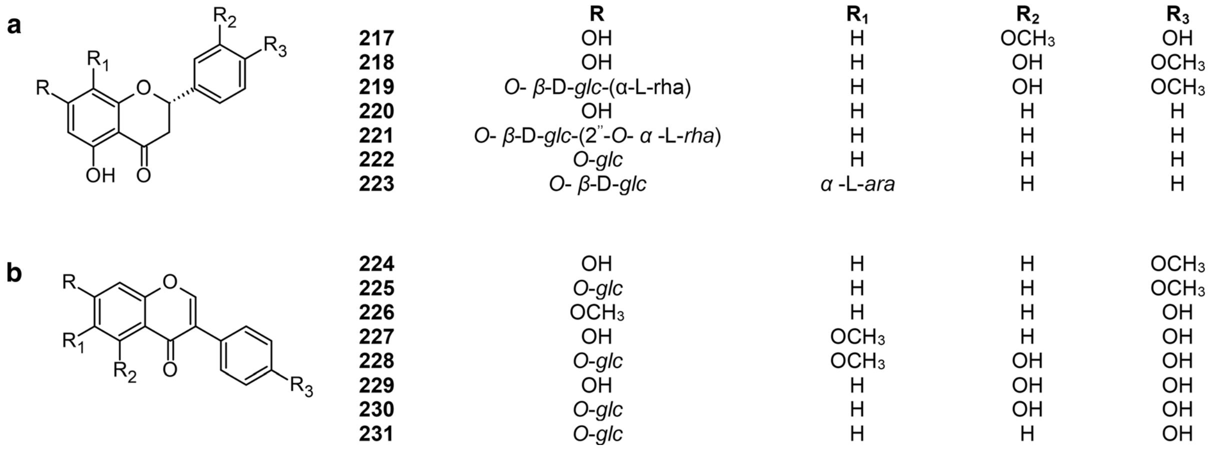


	R	R_1	R_2
214	OH	OCH_3	OH
215	*O*-*glc*	OH	OH
216	OH	OCH_3	OCH_3

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

this review, are commonly found in the Caryophyllaceae family. The genera *Silene* Mill., *Dianthus* L., *Stellaria* L., *Herniaria* L., *Spergularia* Presl., *Gypsophila* 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 pharmacological investigations.



	R	R1	R2	R3
217	OH	H	OCH_3	OH
218	OH	H	OH	OCH_3
219	*O*- *β*-D-*glc*-(α-L-rha)	H	OH	OCH_3
220	OH	H	H	H
221	*O*- *β*-D-*glc*-(2''-*O*- *α* -L-*rha*)	H	H	H
222	*O-glc*	H	H	H
223	*O*- *β*-D-*glc*	*α* -L-*ara*	H	H

	R	R1	R2	R3
224	OH	H	H	OCH_3
225	*O-glc*	H	H	OCH_3
226	OCH_3	H	H	OH
227	OH	OCH_3	H	OH
228	*O-glc*	OCH_3	OH	OH
229	OH	H	OH	OH
230	*O-glc*	H	OH	OH
231	*O-glc*	H	H	OH

Fig. 14 The chemical structures of the flavonones (**a**) and isoflavones (**b**) identified in species of Caryophyllaceae family

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Declarations

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

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