Steroidal saponins from the genus *Allium*

Danuta Sobolewska · Klaudia Michalska · Irma Podolak · Karolina Grabowska

Received: 22 July 2014 / Accepted: 25 September 2014 / Published online: 8 October 2014
© The Author(s) 2014. This article is published with open access at Springerlink.com

**Abstract**  Steroidal saponins are widely distributed among monocots, including the Amaryllidaceae family to which the *Allium* genus is currently classified. Apart from sulfur compounds, these are important biologically active molecules that are considered to be responsible for the observed activity of *Allium* species, including antifungal, cytotoxic, enzyme-inhibitory, and other. In this paper, literature data concerning chemistry and biological activity of steroidal saponins from the *Allium* genus has been reviewed.

**Keywords**  *Allium* · Steroidal saponins · Saponins activity

**Introduction**

The genus *Allium* (Amaryllidaceae) is one of the largest monocot genera comprising more than 800 species (Li et al. 2010; APG 2009). It is widely distributed in nature and has adapted to diverse habitats across the Holarctic region, with the exception of *A. dregeanum*, which is native to South Africa (Li et al. 2010). Some *Allium* species, such as garlic, onion and leek, are widely cultivated as vegetable products, spices and for medical purposes. The most characteristic constituents in *Allium* plants are sulfur compounds, which are the most important substances both in terms of chemotaxonomic value and biological activity (Rose et al. 2005). However, various researchers tend to attribute the potential pharmacological benefits of *Allium* plants to constituents other than sulfur compounds, such as steroidal saponins. Also, polyphenolic compounds, especially flavonoids, as well as fructans, N-cyannic amides, and antioxidative enzymes are considered to be equally important (Matsuura 2001; Lanzotti 2005; Štajner et al. 2006; Amagase 2006; Lanzotti 2012).

Apart from the Amaryllidaceae family, steroidal saponins are widely distributed in other monocot families: Asparagaceae (*Agave, Asparagus, Convallaria, Hosta, Nolina, Ornithogalum, Polygonatum, Sansevieria, Yucca*), Costaceae (*Costus*), Dioscoreaceae (*Dioscorea*), Liliaceae (*Lilium*), Melanthiaceae (*Paris*), Smilacaceae (*Smilax*). Interestingly, these compounds have been reported as well in some dicotyledonous angiosperms: Zygophyllaceae (*Tribulus, Zygophyllum*), Solanaceae (*Solanum, Lycopersicon, Capsicum*), Plantaginaceae (*Digitalis*) and Fabaceae (*Trigonella*).

There are numerous reports referring to pharmacological activities of steroidal saponins. Some of them
showed promising antifungal, cytotoxic, anti-inflammatory, antithrombotic, and hypocholesterolemic effects (Sparg et al. 2004; Lanzotti 2005; Guçlü-Üstündag and Mazza 2007). Most importantly, these compounds are used as substrates in the production of steroid hormones and drugs.

Steroidal sapogenins and saponins have been identified so far in over 40 different Allium species. The earliest reports on Allium saponins date back to the 1970s and dealt with identification of diosgenin in A. albidum (Kereselidze et al. 1970) and alliogenin in the bulbs of A. giganteum (Khristulas et al. 1970). Further studies performed worldwide in the following years led to the isolation of a large number of new compounds. The first chemical survey of saponins from the genus Allium was published by Kravets in 1990, and this was followed by an update by Lanzotti in 2005 (Kravets et al. 1990; Lanzotti 2005). Since then, a large number of new compounds has been discovered, and there were also some that have not been included in the previous surveys.

A recent review by Lanzotti et al. (2014) compiled data on various compounds identified in Allium species with a reported cytotoxic and antimicrobial activity.

The present review is predominantly focused on the chemistry of Allium steroidal saponins and their biological activities.

### Chemistry of Allium saponins

Steroidal saponins from the genus Allium can be divided into three groups on the basis of the sapogenin structure: spirostanols, furostanols, and open-chain saponins. The latter group is often referred to in the literature as “cholestane saponins” (Challinor and De Voss 2013). Allium saponins are mostly mono- or bidesmosides, however a tridesmodic cholestane glycoside has been reported in the bulbs of A. macleanii (Inoue et al. 1995). The sugar residue in Allium saponins consists of linear or branched chains made up most often of glucose (Glc), rhamnose (Rha), galactose (Gal), xylose (Xyl), and arabinose (Ara) units.

#### Spirostane-type saponins

A vast structural diversity of Allium spirostanols is associated with the differences in the structure of aglycones, especially their oxygenation patterns and stereochemistry (Table 1). In spirostane-type sapogenins, the steroid A/B ring junction is found mostly in a trans \(5\alpha\), or more rarely in a cis \(5\beta\) fusion (e.g. anzurogenin A \([48]\) and C \([58]\)). \(\Delta^{5(6)}\) unsaturation is considered to be a quite common feature (diosgenin \([4]\), ruscogenin \([17]\), yuccagenin \([19]\), lilagenin \([20]\), cepagenin \([44]\), karatavigenin C \([45]\)). However, a double bond located at C25(27) was reported in the aglycones of saponins present in A. macrostemon and in one of the sapogenins identified in A. ursinum bulbs (He et al. 2002; Sobolewska et al. 2006; Cheng et al. 2013). The C-25 methyl group is found with either \(S\) or \(R\) absolute configuration. In many cases the isolated sapogenins appear to be a mixture of diastereomers \(R\) and \(S\).

The most common spirostanol sapogenins identified in Allium plants are: diosgenin \([4]\), tigogenin \([1]\), gigotigenin \([9]\), agigenin \([34]\), alliogenin \([49]\), and \(\beta\)-chlorogenin \([12]\). It was claimed that \(\beta\)-chlorogenin, a genin present in common garlic A. sativum, could be considered as a chemical marker for its identification in various food products, as the characteristic garlic sulfur compounds are very unstable (Itakura et al. 2001).

Until now, over 130 spirostanol glycosides have been identified in various Allium species. It should be mentioned however that some of these compounds were obtained as a result of enzymatic hydrolysis of furostanol saponin fraction by \(\beta\)-glucosidase (Ikeda et al. 2000).

Allium spirostane-type saponins are typically monodesmodic with the sugar residue usually at C-3 position. In rare cases, the sugar moiety was reported to be linked at other positions, such as C-1 (e.g. alliospirosides A-D \([169, 170, 178, 179]\)) (Kravets et al. 1986a, b, 1987), C-2 (compounds from A. giganteum and A. albopilosum) (Sashida et al. 1991), C-24 (chinenoside VI \([116]\), karatavioside F \([181]\), and anzuroside \([190]\)), or C-27 (tuberose L \([104]\)) (Jiang et al. 1998; Vollerner et al. 1984; Vollerner et al. 1989; Sang et al. 2001a).

Table 3 of ESM summarizes chemical structures of spirostane-type saponins that were reported in Allium species.

#### Furostane-type saponins

Furostanol aglycones possess either a cis or a trans fusion between ring A and B, or a double bond between C-5 and C-6 leading to \(5\alpha, 5\beta\) or \(\Delta^{5(6)}\) series.
| No. | Common name | Structure | Species |
|-----|-------------|-----------|---------|
| 1   | Tigogenin   | (25R)-5α-spirostan-3β-ol | A. affine, A. chinense, A. fistulosum, A. macrostemon, A. rotundum, A. sativum |
| 2   | Neotigogenin| (25S)-5α-spirostan-3β-ol | A. chinense, A. tuberosum |
| 3   | Smilagenin  | (25R)-5β-spirostan-3β-ol | A. macrostemon |
| 4   | Diosgenin   | (25S)-spirost-5(6)-ene-3β-ol | A. affine, A. albidum, A. ampoloprasum, A. angulosum, A. cepa, A. cernuum, A. fistulosum, A. flavum, A. fuscoviolaceum, A. giganteum, A. gramineum, A. karataviense, A. narcissiflorum, A. nutans, A. porrum, A. rotundum, A. schoenoprasum, A. senescens, A. ursinum, A. vineale, A. waldsteinii |
| 5   | Laxogenin   | (25R)-5α-spirostan-3β-ol-6-one | A. chinense, A. schoenoprasum |
| 6   | Hecogenin   | (25R)-5α-spirostan-3β-12-one | A. albidum, A. rotundum |
| 7   | Gitogenin   | (25S)-5β-spirostan-1β,3β-diol | A. tuberosum |
| 8   | Neogitogenin| (25S)-5α-spirostan-2α,3β-diol | A. affatumense, A. chinense, A. cyrilli, A. elburzense, A. fistulosum, A. hirtifolium, A. jesdianum, A. macrostemon, A. porrum, A. rotundum, A. sativum, A. sativum L. var. Voghiera, A. victorialis var. platyphyllum |
| 9   | β-Chlorogenin| (25R)-5α-spirostan-3β,6β-diol | A. erubescens, A. giganteum, A. gramineum, A. leucanthum, A. porrum, A. rotundum, A. sativum, A. waldsteinii |
| 10  | 25-Epi-ruizgenin | (25S)-5β-spirostan-3β,6α-diol | A. tuberosum |
| 11  | Hecogenin   | (25R)-5α-spirostan-3β,11α-diol | A. schoenoprasum |
| 12  | Ruscogenin  | (25R)-5α-spirostan-3β,12β-diol | A. chinense |
| 13  | Yuccagenin  | (25R)-spirost-5(6)-ene-2α,3β-diol | A. affine, A. albidum, A. nutans |
| 14  | Lilagenin   | (25S)-spirost-5(6)-ene-2α,3β-diol | A. tuberosum |
| 15  | Neoporrigenin| (25S)-5α-spirostan-3β,6β-diol-2-one | A. ampoloprasum, A. porrum |
| 16  | Neoagigenone| (25S)-5α-spirostan-2α,3α-diol-6-one | A. macrostemon |
| 17  | Porragenin B| (25R)-5α-spirostan-2α,5α-epoxy-3β,6β-diol | A. turcomanicum |
| 18  | Porrigenin B| (25S)-5α-spirostan-2α,5α-epoxy-3β,6β-diol | A. stipitatum/A. suvorovii |
| 19  | Nualigenin  | (22S,25S)-22,25-epoxy-furost-5(6)-ene-3β,26-diol | A. vineale |
| 20  | 12-Ketoporrigenin | (25R)-5α-spirostan-3β,6β-diol-12-one | A. vineale |
| 21  | Izonutigenin | (25R)-spirost-5(6)-ene-3β,25β-diol | A. vineale |
| 22  | Izonutigenin | (25R)-spirost-5(6)-ene-3β,25β-diol | A. vineale |
| 23  | Izonutigenin | (25R)-spirost-5(6)-ene-3β,25β-diol | A. vineale |
| No. | Common name                      | Structure                                                                 | Species                                      |
|-----|----------------------------------|---------------------------------------------------------------------------|----------------------------------------------|
| 30  | Porrigenin C                     | $^{(25R)}$-5α-spirostan-3β,6β-diol-2,12-dione                            | *A. porrum*                                 |
| 31  | Agapanthagenin                   | $^{(25R)}$-5α-spirostan-2α,3β,5α-triol                                    | *A. afatumense, A. elburzense, A. hirtifolium*|
| 32  |                                 | $^{(25S)}$-5β-spirostan-2β,3β,5β-triol                                     | *A. tuberosum*                              |
| 33  | Gantogenin                       | $^{(25R)}$-5α-spirostan-2α,3β,6α-triol                                     | *A. giganteum, A. jesdianum*                |
| 34  | Agigenin                         | $^{(25R)}$-5α-spirostan-2α,3β,6β-triol                                     | *A. albopilosum, A. ameloprasum, A. atroviolescens, A. giganteum, A. gramineae, A. hirtifolium, A. leucanthum, A. macleanii, A. ostrowskianum, A. porrum, A. rotundum, A. sativum var. Voghiera, A. schuberti* |
| 35  |                                 | 2-O-[(S)-3-hydroxy-3-methylglutaryl]-agigenin                             | *A. albopilosum*                            |
| 36  | Neoagigenin                      | $^{(25S)}$-5α-spirostan-2α,3β,6β-triol                                     | *A. albopilosum, A. ameloprasum ssp. persicum, A. giganteum, A. minutilflorum, A. nigrum, A. porrum, A. schuberti, A. turcomanicum* |
| 37  |                                 | 6-O-benzoyl-(25S)-5α-spirostan-2α,3β,6β-triol                             | *A. turcomanicum*                           |
| 38  | Porrigenin A                     | $^{(25R)}$-5α-spirostan-2β,3β,6β-triol                                     | *A. porrum*                                 |
| 39  | Neoporrigenin A                  | $^{(25S)}$-5α-spirostan-2β,3β,6β-triol                                     | *A. porrum*                                 |
| 40  |                                 | $^{(25R)}$-5α-spirostan-2α,3β,27-triol                                     | *A. tuberosum*                              |
| 41  | Anzurogenin D                    | $^{(25R)}$-5α-spirostan-3β,5β,6β-triol                                     | *A. stipitatum/A. suvorovii*                |
| 42  |                                 | $^{(25S)}$-5α-spirostan-2α,3β,27-triol                                     | *A. tuberosum*                              |
| 43  |                                 | $^{(25S)}$-5β-spirostan-3β,5β,6β-triol                                     | *A. tuberosum*                              |
| 44  | Cepagenin                        | $^{(24S,25R)}$-spirost-5(6)-ene-1β,3β,24-triol                             | *A. cepa*                                   |
| 45  | Karatavigenin C                  | $^{(24S,25S)}$-spirost-5(6)-ene-2α,3β,24-triol                             | *A. karataviense*                           |
| 46  |                                 | $^{(20S,25S)}$-spirost-5(6)-ene-3β,11α,21-triol                            | *A. schoenoprasum*                          |
| 47  |                                 | $^{(20S,25S)}$-spirost-5(6)-ene-3β,12β,21-triol                            | *A. schoenoprasum*                          |
| 48  | Anzurogenin A                    | $^{(25R)}$-5β-spirostan-2α,3β,5β-triol-6-one                                | *A. stipitatum/A. suvorovii*                |
| 49  | Alliogenin                       | $^{(25R)}$-5α-spirostan-2α,3β,5α,6β-tetrol                                  | *A. afatumense, A. albopilosum, A. elburzense, A. giganteum, A. hirtifolium, A. karataviense, A. macleanii, A. minutilflorum, A. turcomanicum* |
| 50  | Neoalliogenin                    | $^{(25S)}$-5α-spirostan-2α,3β,5α,6β-tetrol                                  | *A. turcomanicum*                           |
| 51  | 3-O-acetylalliogenin             | 3-O-acetyl-(25R)-5α-spirostan-2α,3β,5α,6β-tetrol                            | *A. albopilosum, A. giganteum, A. karataviense* |
| 52  | Karatavigenin (3-O-benzoylalliogenin) | 3-O-benzoyl-(25R)-5α-spirostan-2α,3β,5α,6β-tetrol                          | *A. giganteum, A. karataviense, A. macleanii* |
| 53  | Karatavigenin B (2-O-benzoylalliogenin) | 2-O-benzoyl-(25R)-5α-spirostan-2α,3β,5α,6β-tetrol                          | *A. karataviense*                           |
| 54  | 3-O-(2-hydroxybutyryl)-alliogenin | 3-O-(2-hydroxybutyryl)-(25R)-5α-spirostan-2α,3β,5α,6β-tetrol               | *A. karataviense*                           |
| 55  |                                 | $^{(24S,25S)}$-5β-spirostan-2α,3β,5β,24-tetrol                             | *A. tuberosum*                              |
| 56  | Atroviolescensgenin              | $^{(24S,25S)}$-5β-spirostan-2α,3β,5β,24-tetrol                             | *A. tuberosum*                              |
| 57  |                                 | $^{(25R)}$-5α-spirostan-2α,3β,6β,27-tetrol                                  | *A. atroviolescens*                         |
| 58  | Anzurogenin C                    | $^{(24S,25S)}$-5β-spirostan-2α,3β,5,24-tetrol-6-one                        | *A. stipitatum/A. suvorovii*                |
In the case of furostane-type sapogenins a double bond may also be located at 20(22) (e.g. ascalonicoside B [220], ceparoside C [230], chinenoside II [234]) or 22(23) (four furostanols from A. tuberosum) (Fattorusso et al. 2002; Yuan et al. 2009; Peng et al. 1996b; Sang et al. 2001b). The 27-Me group may be in either R or S configuration. Furostane-type compounds isolated from Allium species usually possess an OH or OMe group at C-22. However, sapogenins with a C-22 methyl ether are considered to be artifacts resulting from the use of methanol in the extraction/isolation procedures.

From among 140 furostanol glycosides identified in the Allium genus, sixteen compounds were found to be such methoxy-derivatives.

Furostanol saponins in Allium plants are bidesmodic glycosides with sugar chains attached usually at C-3 and C-26 positions. A rare glycosylation at C-1 with a galactose unit was reported in ascalonicosides A1/A2 [217, 218] (Fattorusso et al. 2002). A vast majority of furostanol saponins possess an O-linked glucose residue attached at position C-26. In compounds such as ceposides, persicoside C [205, 206], ascalonicosides A1/A2 [217, 218] a disaccharide chain was reported at C-26 (Lanzotti 2012; Sadeghi et al. 2013; Fattorusso et al. 2002).

Cholestane-type (open-chain) saponins

A review of available literature data shows that as much as 18 cholestane-type compounds have been identified in ten different Allium species.

Allium open-chain aglycones possess $\Delta^{4(5)}$, and one of the glycosides found in A. albobilum with a saturated aglycone (Kawashima et al. 1991b; Mimaki et al. 1993). Glycosides based on/alliosterol—(22S)-cholest-5(6)-ene-1$\beta$-3$\beta$-16$\beta$-22-tetrol (Fig. 1 [196]), or related sapogenins showing the same oxygenation pattern at C-1, C-3, C-16 and C-22 are most common (Challinor and De Voss 2013). Sugar units are attached at one, two or, more seldom, at three separate positions (in A. macleanii) (Inoue et al. 1995). Most of these compounds are glycosylated at C-16, whereas in contrast to spirostanol and furostanol saponins, the attachment of sugar chain at position C-3 is almost unique (tuberoside U [353]) (Sang et al. 2003).

Table 2 lists steroidal saponins/sapogenins identified in Allium species. Plant names are cited exactly as they were referred to in the original report. It is almost certain that some of them are synonyms but as the authors of the present review are not specialists in plant taxonomy no amendments have been made.

**Biological and pharmacological properties of Allium saponins**

Saponins are considered responsible for numerous pharmacological properties of many plants, and they are recognized as active constituents of Allium species as well. It should be mentioned, however, that Allium plants are not rich sources of these compounds. Results from quantitative studies indicate that saponin content is usually very low, for example A. nigrum total saponin content in different parts of the plant was determined as: 19.38 mg/g dw in the roots, 15.65 mg/g dw—bulbs, and 10.48 mg/g dw—leaves (Mostafa...
et al. 2013). Quantitative densitometric determination of diosgenin—the main saponogen of A. ursinum, revealed some differences in its accumulation with respect to the vegetation period, nevertheless its highest percentage observed in the bulbs collected in March did not exceed 0.0029 % of fresh weight (Sobolewska et al. 2009). A significant exception, in terms of saponin content, is A. nutans, where the concentration of these compounds in the underground parts was established to be about 4 % of dry matter (Akhov et al. 1999).

It should be emphasized however that the results from many pharmacological in vitro and in vivo studies revealed several interesting activities of Allium saponins, for example antifungal, cytotoxic, antispasmodic, hypocholesterolemic, and other.

Cytotoxic properties

Cytotoxic activity of saponins was discussed in a number of experimental papers on Allium species. In vitro studies were performed on several human and animal cell cancer lines, including IGR-1—human melanoma cell line; HL-60—promyelotic leukemia cells; HCT-116, HT-29, and SW480—human colorectal cancer cell lines; DLD-1—human colon adenocarcinoma, HA549—lung cancer cell line, NCI-H460—human large-cell lung carcinoma, SF-268—human glioblastoma; MCF-7—human breast adenocarcinoma, HepG2—human hepatocellular liver carcinoma cell line; WEHI 164—murine fibrosarcoma cell line; J-774—murine monocyte/macrophage cell line; P-388 and L-1210—murine leukemia cell lines (Table 4 of ESM). Amongst tested spirostanol saponins dioscin [135], isolated from A. ampeloprasum, seemed to be most potent, with an IC$_{50}$ = 0.092 µg/mL against P388 cell line (Sata et al. 1998). This compound, which is widely distributed in species of the family Dioscoreaceae and Asparagaceae, revealed significant in vitro activity in tests performed on many other cancer cell lines (Podolak et al. 2010). Some authors claim that apart from the type of the cell line, the structure of the oligosaccharide chain, especially the site of interglycosidic linkages, rather than the sapogenin, are the modulating factors of cytotoxic properties (Rezgui et al. 2014). Some evidence that may substantiate such claims comes from the results obtained for a mixture of diosgenin tetrasaccharide and (25R)-spirost-5(6),25(27)-diene-3β-ol tetrasaccharide [141, 156] (A. ursinum) (Sobolewska et al. 2006). The sugar chain of these compounds differs from that of dioscin [135] (3-O-α-L-Rha-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Glc) by an additional terminal rhamnose moiety. Both exhibited 100 % effect already at the concentration of 2 µg/mL on melanoma B16 and sarcoma XC. Similarly, deltonin [134] (diosgenin 3-O-β-D-Glc-(1→4)-[α-L-Rha-(1→2)]-O-β-D-Glc) isolated from A. schoenoprasum showed significant activity against HCT 116 and HT-29 cell lines with an IC$_{50}$ = 0.40 and 0.75 µM, respectively (Timite et al. 2013). These results corroborate with those obtained by Mimaki et al. (2001), who suggested that an α-L-Rha-(1→2)-O-β-D-Glc sugar sequence attached to diosgenin is crucial for activity (Mimaki et al. 2001).

The most potent spirostanol glycosides include also eruboside B [79], leucospiroside A [97], yayoisaponin C [95] and aginoside [93] isolated from A. leucanthum, which showed in vitro cytotoxic activity, with relatively similar IC$_{50}$ values against A549 WS1, and DLD-1 cells (Mskhiladze et al. 2008b). The two latter compounds, that were isolated from A. ampeloprasum, showed in vitro cytotoxicity against P388 cells at 2.1 µg/mL (Sata et al. 1998). Tigogenin pentasaccharide [67] (A. macleanii) and diosgenin 3-O-α-L-Rha-(1→2)-[β-D-Glc-(1→3)]-O-β-D-Glc [140] (A. nescens) were cytotoxic towards HeLa cells at the concentration of 50 µg/mL, whereas already at 5 µg/mL they exhibited 64.7 and 11.5 % inhibition, respectively (Inoue et al. 1995). Several spirostanol glycosides, that were isolated from different Allium species, revealed fairly high cytotoxic activity in tests on promyelotic leukemia cells HL-60. Yuccagenin tetrasaccharide (karatavioside A [151]) from the bulbs of A. karataviense exhibited considerable cytostatic...
| Species               | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue                                                                 | References                  |
|----------------------|-----------------------------|-----------------|-------------------------------------------------------------------------------|-----------------------------|
| *A. affine* Ledeb.   | Tigogenin [1]               |                 |                                                                               | Kravets et al. (1990)       |
|                      | Diosgenin [4]               |                 |                                                                               | Kravets et al. (1990)       |
|                      | Ruscogenin [17]             |                 |                                                                               | Kravets et al. (1990)       |
| *A. aflatunense* B. Fedtsch. | [70]                         | Gitogenin [9]   | 3-O-β-Δ-Glc-(1→4)-O-β-Δ-Gal                                                  | Mimaki et al. (1999c)       |
|                      |                             |                 |                                                                               |                              |
|                      |                             | Gitogenin [9]   | 3-O-β-Δ-Glc-(1→2)β-[4-O-(S)-3-hydroxy-3-methylglutaryl-β-Δ-Xyl-(1→3)]-O-β-Δ-Glc- (1→4)-O-β-Δ-Gal | Mimaki et al. (1999c)       |
|                      |                             |                 |                                                                               |                              |
|                      |                             | Agapanthagenin [31] | 2-O-β-Δ-Glc                                                                     | Mimaki et al. (1999c)       |
| *A. albanum* Grossh  |                             |                 |                                                                               |                              |
|                      |                             | Alliogenin [49] | 2-O-β-Δ-Glc                                                                     | Kawashima et al. (1991a)    |
| *A. albiflorus*      |                             |                 |                                                                               |                              |
|                      |                             | Saponins present |                                                                               | Ismailov and Aliev (1976)  |
| *A. albopilosum* C.H. Wright |                      |                 |                                                                               |                              |
|                      | Agigenin [34]               |                 |                                                                               | Mimaki et al. (1993)        |
|                      | Neoagigenin [36]            |                 |                                                                               | Mimaki et al. (1993)        |
|                      | Alliogenin [49]             |                 |                                                                               | Mimaki et al. (1993)        |
|                      | AGINOSIDE [93]              |                 |                                                                               | Mimaki et al. (1993)        |
|                      |                             | Agigenin [34]   | 3-O-β-Δ-Glc-(1→2)β-[β-Δ-Xyl-(1→3)]-O-β-Δ-Glc-(1→4)-O-β-Δ-Gal                  | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      | [94, 123]                    | (25R,5)-5α-spirostan-2α,3β,6β-triol [34, 36] | 3-O-β-Δ-Glc-(1→2)β-[3-O-acetyl-β-Δ-Xyl-(1→3)]-O-β-Δ-Glc-(1→4)-O-β-Δ-Gal | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | 2-O-[(5S)-3-hydroxy-3-methylglutaryl]-agigenin [35] | 3-O-β-Δ-Glc-(1→2)β-[β-Δ-Xyl-(1→3)]-O-β-Δ-Glc-(1→4)-O-β-Δ-Gal | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | Alliogenin [49] | 2-O-β-Δ-Glc                                                                     | Mimaki et al. (1993)        |
|                      | [184]                       |                 |                                                                               | Mimaki et al. (1993)        |
|                      |                             | 3-O-acetyl-alliogenin [51] | 2-O-β-Δ-Glc                                                                     | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | [197, 198]      | 26-O-β-Δ-Glc-3-O-β-Δ-Glc-(1→2)β-[β-Δ-Xyl-(1→3)]-O-β-Δ-Glc-(1→4)-O-β-Δ-Gal | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | Alliosterol     | 1-O-α-L-Rha 16-O-α-L-Rha-(1→3)-O-β-Δ-Glc                                      | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | [1(22S)-cholest-5(6)-ene-1β,3β,16β,22-tetrol] [196] | 1-O-α-L-Rha 16-O-α-L-Rha-(1→3)-O-β-Δ-Glc | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | Cholest-5(6)-ene-1β,3β,16β-triol-22-one | 1-O-α-L-Rha 16-O-α-L-Rha-(1→3)-O-β-Δ-Glc | Mimaki et al. (1993)        |
|                      |                             |                 |                                                                               |                              |
|                      |                             | [5α-Cholestane-1β,3β,16β-triol-22-one] | 1-O-α-L-Rha 16-O-α-L-Rha-(1→3)-O-β-Δ-Glc | Mimaki et al. (1993)        |
| *A. ampeloprasum* L. |                             |                 |                                                                               |                              |
|                      | Agigenin [34]               |                 |                                                                               | Morita et al. (1988)        |
|                      | AMPELOSIDE Bs1 [90]         |                 |                                                                               | Morita et al. (1988)        |
| Species                  | Glycoside common name no. | Sapogenin no. | Sugar residue                                                                 | References               |
|--------------------------|---------------------------|---------------|--------------------------------------------------------------------------------|--------------------------|
| AGINOSIDE [93]           |                           | Agigenin [34] | 3-O-[β-D-Glc-(1→2)]-[β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal]             | Sata et al. (1998)       |
| YAYOISAPONIN C [95]      |                           | Agigenin [34] | 3-O-[β-D-Glc-(1→2)]-[β-D-Glc-(1→3)]-O-[β-D-Xyl-(1→2)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal] | Sata et al. (1998)       |
| YAYOISAPONIN A [96]      |                           | Agigenin [34] | 3-O-D-Glc-(1→2)-[β-D-Rha-(1→4)]-O-[β-D-Glc]                                    | Sata et al. (1998)       |
| DIOSCIN [135]            |                           | Diosgenin [4] | 3-O-[α-L-Rha-(1→2)]-[α-L-Rha-(1→4)]-O-[β-D-Glc]                                | Sata et al. (1998)       |
| KARATAVIOSIDE A [151]    |                           | Yuccagenin [19]| 3-O-[β-D-Glc-(1→2)]-[β-D-Xyl-(1→3)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal]             | Uchikida et al. (2009)   |
| YAYOISAPONIN B [174]     |                           | Porrigenin B [23]| 3-O-[β-D-Glc-(1→3)]-O-[β-D-Glc-(1→2)]-O-[β-D-Xyl-(1→3)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal] | Sata et al. (1998)       |
| AMPELOSIDE Bf1 [202]     | (25R)-5α-furostane-2α,3β,6β,22,26-pentaol |               | 26-O-[β-D-Glc]-O-[β-D-Glc](1→3)-O-[β-D-Glc](1→4)-O-[β-D-Gal]                   | Morita et al. (1988)     |
| AMPELOSIDE Bf2 [203]     | (25R)-5α-furostane-2α,3β,6β,22,26-pentaol |               | 26-O-[β-D-Glc]-O-[β-D-Glc](1→3)-O-[β-D-Glc](1→4)-O-[β-D-Gal]                   | Morita et al. (1988)     |
|                          | [204]                     |               | 26-O-[β-D-Glc]-O-[β-D-Glc](1→3)-O-[β-D-Glc](1→4)-O-[β-D-Gal]                   | Mimaki et al. (1999b)    |
| A. ampelesprasum L. ssp. persicum |                     |               |                                                                                   |                          |
| PERSICOSIDE A [120]      | Neoagigenin [36]          |               | 3-O-[β-D-Glc-(1→3)]-[β-D-Xyl-(1→2)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal]             | Sadeghi et al. (2013)    |
| PERSICOSIDE B [121]      | Neoagigenin [36]          |               | 3-O-[β-D-Xyl-(1→3)]-[α-L-Rha-(1→2)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal]             | Sadeghi et al. (2013)    |
| PERSICOSIDE C (C1,C2) [205, 206]| Furost-5(6)-ene-1α,β,3β,22,26-tetrol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)]-O-[β-D-Gal]         | Sadeghi et al. (2013)    |
| PERSICOSIDE D (D1,D2) [207, 208]| Furostane-2α,3β,22,26-tetrol |               | 26-O-[β-D-Glc]-O-[β-D-Glc](1→3)-O-[β-D-Glc](1→4)-O-[β-D-Gal]                   | Sadeghi et al. (2013)    |
| CEPOSIDES A1/A2 [209, 210]| (25R)-furost-5(6)-ene-1α,β,3β,22,26-tetrol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Gal]                                               | Sadeghi et al. (2013)    |
| CEPOSIDES C1/C2 [211, 212]| (25R)-furost-5(6)-ene-1α,β,3β,22,26-tetrol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Gal]                                               | Sadeghi et al. (2013)    |
| TROPEOSIDES A1/A2 [213, 214]| Furost-5(6)-ene-3β,22,26-diol |               | 26-O-[α-L-Rha]                                                                | Sadeghi et al. (2013)    |
| TROPEOSIDES B1/B2 [215, 216]| Furost-5(6)-ene-3β,22,26-diol |               | 26-O-[α-L-Rha]                                                                | Sadeghi et al. (2013)    |
| ASCALONICOSIDES A1/A2 [217, 218]| Furost-5(6)-ene-3β,22,26-diol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Glc]                                               | Sadeghi et al. (2013)    |
| PERSICOSIDE E [219]      | Alliosterol [196]         |               | 1-O-[α-L-Rha-16-O-[α-L-Rha-(1→2)]-O-[β-D-Gal]                                  | Sadeghi et al. (2013)    |
| A. angulosum Lour.       |                           |               |                                                                                   |                          |
| ASCALONICOSIDE A1 [217]  | Furost-5(6)-ene-3β,22,26-diol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Glc]                                               | Fattonusso et al. (2002) |
| ASCALONICOSIDE A2 [218]  | Furost-5(6)-ene-3β,22,26-diol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Glc]                                               | Fattonusso et al. (2002) |
| ASCALONICOSIDE B [220]   | Furost-5(6),20(22)-diene-3β-ol |               | 26-O-[α-L-Rha-(1→2)]-O-[β-D-Glc]                                               | Fattonusso et al. (2002) |
| Species | Glycoside common name [no.] | Sugars | Sapogenin [no.] | References |
|---------|-----------------------------|--------|----------------|------------|
| Boiss. Atroviolacegenin [57] | (25S),22,26-diol | -b,22 | 26-O-β-D-Glc-(1→2)-O-β-D-Gal Zolfaghari et al. (2006) | |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|-----------------------------|-----------------|--------------|------------|
| **A. cepa** L. var. *tropea* | | | | |
| TROPEOSIDE A1 [213] | Furost-5(6)-ene-3β,22β-[d]-diol | 26-O-α-L-Rha-(1→2)-O-β-D-Glc-(1→4)-O-β-D-Gal | Lanzotti et al. (2012b) |
| TROPEOSIDE A2 [214] | Furost-5(6)-ene-3β,22β-[d]-diol | 26-O-α-L-Rha-(1→2)-O-β-D-Glc-(1→4)-O-β-D-Gal | Lanzotti et al. (2012b) |
| TROPEOSIDE B1 [215] | Furost-5(6)-ene-3β,22β-[d]-diol | 26-O-α-L-Rha-(1→2)-O-β-D-Glc-(1→4)-O-β-D-Gal | Lanzotti et al. (2012b) |
| TROPEOSIDE B2 [216] | Furost-5(6)-ene-3β,22β-[d]-diol | 26-O-α-L-Rha-(1→2)-O-β-D-Glc-(1→4)-O-β-D-Gal | Lanzotti et al. (2012b) |
| ASCALONICOSIDES A1/A2 [217, 218] | | | | |
| A. cepa L. var. aggregatum (Aggregatum group) | | | | |
| ALLIOSPIROSIDE A [169] | | | | |
| ALLIOSPIROSIDE B [170] | | | | |
| A. *cernum* Roth. | | | | |
| Diosgenin [4] | | | | |
| Tigogenin [1] | | | | |
| Neotigogenin [2] | | | | |
| Laxogenin [6] | | | | |
| Gitogenin [9] | | | | |
| [65, 110] | (25R,S)-5α-spirostane-3β-ol [1, 2] | 3-O-β-D-Glc-(1→2)-[β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal | Matsuura et al. (1989b) |
| [66, 111] | (25R,S)-5α-spirostane-3β-ol [1, 2] | 3-O-β-D-Glc-(1→2)-[β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal | Matsuura et al. (1989b) |
| [71, 113] | (25R,S)-5α-spirostane-2α,3β-[d]-diol [9, 10] | 3-O-β-D-Glc-(1→2)-[β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal | Matsuura et al. (1989b) |
| [73, 115] | (25R,S)-5α-spirostane-2α,3β-[d]-diol [9, 10] | 3-O-β-D-Glc-(1→2)-[β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal | Matsuura et al. (1989b) |
| NEOMACROSTEMONOSIDE D [111] | Neotigogenin [2] | 3-O-β-D-Glc-(1→2)-[β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal | Matsuura et al. (1989b) |
| CHINENOSIDE VI [116] | (25S)-5α-spirostane-3β,24β-[d]-diol [16] | 3-O-α-L-Ara-(1→6)-O-β-D-Glc 24-O-β-D-Glc | Kuroda et al. (1995) |
| [157] | Laxogenin [6] | 3-O-α-L-Ara-(1→6)-O-β-D-Glc | Kuroda et al. (1995), Peng et al. (1996b), Baba et al. (2000) |
| [159] | Laxogenin [6] | 3-O-(2-O-acetyl-α-L-Ara)-(1→6)-O-β-D-Glc | Kuroda et al. (1995), Peng et al. (1996b), Baba et al. (2000) |
| Species          | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue                                                                 | References                              |
|------------------|------------------------------|-----------------|--------------------------------------------------------------------------------|-----------------------------------------|
| A. erubescens    | [12]                         | β-Chlorogenin    | 3-O-[β-β-Xyl(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                 | Cincharadze et al. (1979)               |
|                  | ERUBOSIDE B [79]             | β-Chlorogenin    | 3-O-[β-β-Glc(1→3)]-[β-β-Glc(1→2)]-O-[β-β-Glc(1→4)]-O-[β-β-Gal]                | Cincharadze et al. (1979)               |
|                  | A. erubescens C. Koh.        |                 |                                                                                 |                                         |
| A. cyrillii Ten. | F-GITONIN [72]               | Gitogenin [9]   | 3-O-[β-β-Glc(1→2)]-[β-β-Xyl(1→3)]-O-[β-β-Glc(1→4)]-O-[β-β-Gal]                | Tolkacheva et al. (2012)               |
|                  |                              |                 |                                                                                 |                                         |
|                  | CHINENOSIDE I [233]          |                 | 26-O-[β-β-Glc(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                | Baba et al. (2000)                     |
|                  | CHINENOSIDE II [234]         |                 | 26-O-[β-β-Glc(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                | Matsuura et al. (1989b)                |
|                  | CHINENOSIDE III [235]        |                 | 26-O-[β-β-Glc(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                | Peng et al. (1996b)                    |
|                  | CHINENOSIDE IV [236]         |                 | 26-O-[β-β-Glc(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                | Peng et al. (1996c)                    |
|                  | CHINENOSIDE V [237]          |                 | 26-O-[β-β-Glc(1→4)-]-α-L-Ara-(1→6)-O-[β-β-Glc](1→4)-O-[β-β-Gal]                | Peng et al. (1996c)                    |
|                  |                              |                 |                                                                                 |                                         |
|                  | A. elburzense Wendelbo       |                 |                                                                                 |                                         |
|                  | TEM. F-GITONIN [9]           |                 |                                                                                 |                                         |
|                  |                              |                 |                                                                                 |                                         |
|                  |                  |                 |                                                                                 |                                         |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|---------------------------|----------------|--------------|------------|
| A. fistulosum L. |  | Yuccagenin [19] |  | Kim et al. (1991) |
|  |  | Tigogenin [1] |  | Lai et al. (2012) |
|  |  | Gitogenin [9] |  | Lai et al. (2012) |
|  |  | (25R)-19-norspirosta-1,3,5(10)-triene-4-methyl-2-ol [246] | Sapogenins [1, 9, 246, 247, 248, 249] obtained from the acid hydrolysis product of the whole glycoside mixture of Welsh onion seeds | Lai et al. (2012) |
|  |  | (25R)-spirost-1(2),4(5)-dien-2,6-diol-3-one [247] |  | Lai et al. (2012) |
|  |  | (25R)-spirost-1(2),4(5)-dien-2-ol-3-one [248] |  | Lai et al. (2012) |
|  |  | (25R)-spirost-4(5)-ene-2-ol-3-one [249] |  | Lai et al. (2012) |
|  |  | Diosgenin [4] | 3-O-α-L-Rha-(1→4)-O-α-L-Rha-(1→4)-[α-L-Rha-(1→2)]-O-β-D-Glc | Jung et al. (1993) |
|  |  | Yuccagenin [19] | 3-O-α-L-Rha-(1→2)-O-β-D-Gal | Do et al. (1992) |
|  |  | Yuccagenin [19] | 3-O-α-L-Rha-(1→2)-[β-D-Glc-(1→3)]-O-β-D-Gal | Do et al. (1992) |
|  |  | Yuccagenin [19] | 3-O-β-D-Glc-(1→3)[β-D-Glc-(1→4)]-O-β-D-Gal | Do et al. (1992) |
|  |  | (25R)-furost-5(6),20(22)-diene-2,6-diol-2-one | 26-O-β-D-Glc 3-O-α-L-Rha-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3β,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-α-L-Rha-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3α,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-α-L-Rha-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3β,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3α,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3β,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3α,22α,26-triol-2-one | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3β,22α,26-tetrol | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | (25R)-furost-5(6)-ene-3α,22α,26-tetrol | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-[α-L-Rha-(1→4)]-O-β-D-Gal | Lai et al. (2010) |
|  |  | Diosgenin [4] | 3-O-α-L-Rha-(1→4)-[β-D-Glc-(1→2)]-O-β-D-Glc | Rezgui et al. (2014) |
|  |  | Yuccagenin [19] | 3-O-β-D-Xyl-(1→3)-[β-D-Gal-(1→2)]-O-β-D-Gal | Rezgui et al. (2014) |

A. flavum L.
| Species                  | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue                                                                 | References                        |
|-------------------------|-----------------------------|----------------|------------------------------------------------------------------------------|----------------------------------|
| **A. fuscoviolaceum L.**|                             |                |                                                                              |                                  |
|                         |                             | [154]          | Yuccagenin [19]                                                              | Rezgui et al. (2014)             |
|                         |                             |                | 3-O-β-D-Xyl-(1 → 3)-β-D-Glc-(1 → 2)-O-β-D-Gal-(1 → 4)-O-β-D-Gal               |                                  |
| **A. giganteum Regel**  |                             |                |                                                                              |                                  |
|                         |                             |                | Diosgenin [4]                                                                | Kravets et al. (1990)            |
|                         |                             |                | β-Chlorogenin [12]                                                           | Kelginbaev et al. (1974)         |
|                         |                             |                | Yuccagenin [19]                                                              | Kelginbaev et al. (1974)         |
|                         |                             |                | Gantogenin [33]                                                              | Kelginbaev et al. (1975)         |
|                         |                             |                | Agigenin [34]                                                                | Kelginbaev et al. (1974)         |
|                         |                             |                | Neoagigenin [36]                                                             | Kelginbaev et al. (1973, 1974)  |
|                         |                             |                | Alliogenin [49]                                                              | Krinstulas et al. (1970),        |
|                         |                             |                |                                                                              | Gorovits et al. (1971)           |
|                         |                             |                | Luvigenin [59]                                                               | Kravets et al. (1979)            |
|                         |                             |                |                                                                              |                                  |
|                         |                             | [98]           | Agigenin [34]                                                                | Mimaki et al. (1994)             |
|                         |                             |                | 3-O-β-D-Glc-(1 → 2)-[4-O-(S)-3-hydroxy-3-methylglutaryl-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal |                                  |
|                         |                             | [105]          | Alliogenin [49]                                                              | Sashida et al. (1991)            |
|                         |                             |                | 2-O-β-D-Glc                                                                  |                                  |
|                         |                             | [106]          | Alliogenin [49]                                                              | Gorovits et al. (1971)           |
|                         |                             |                | 3-O-β-D-Glc                                                                  |                                  |
|                         |                             | [184]          | 3-O-acetyl-alliogenin [51]                                                   | Sashida et al. (1991)            |
|                         |                             |                | 2-O-β-D-Glc                                                                  |                                  |
|                         |                             | [186]          | Karatavigenin [52]                                                           | Sashida et al. (1991)            |
|                         |                             |                | 2-O-β-D-Glc                                                                  |                                  |
|                         |                             | [191]          | (24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol [60]                          | Kawashima et al. (1991a)         |
|                         |                             |                | 24-O-β-D-Glc                                                                 |                                  |
|                         |                             | [193]          | 3-O-acetyl-(24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol [62]               | Mimaki et al. (1994)             |
|                         |                             |                | 2-O-β-D-Glc                                                                  |                                  |
|                         |                             | [258]          | (25R)-22-methoxy-5α-furostane-2α,3β,5α,6β,22α,26-pentaol [60]                | Mimaki et al. (1994)             |
|                         |                             |                | 26-O-β-D-Glc-3-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal |                                  |
|                         |                             | [259]          | (25R)-3-O-benzoyl-22-methoxy-5α-furostane-2α,3β,5α,6β,22α,26-hexol            | Mimaki et al. (1994)             |
|                         |                             |                | 26-O-β-D-Glc-2-O-β-D-Glc                                                     |                                  |
|                         |                             | [260]          | (25R)-3-O-acetyl-22-methoxy-5α-furostane-2α,3β,5α,6β,22α,26-hexol             | Mimaki et al. (1994)             |
|                         |                             |                | 26-O-β-D-Glc-2-O-β-D-Glc                                                     |                                  |
| **A. gramineum C. Koch.**|                             |                |                                                                              |                                  |
|                         |                             |                | Diosgenin [4]                                                                | Kravets et al. (1990)            |
|                         |                             |                | β-Chlorogenin [12]                                                           | Kravets et al. (1990)            |
|                         |                             |                | Agigenin [34]                                                                | Kravets et al. (1990)            |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|------------------------------|-----------------|--------------|------------|
| A. hirtifolium Boiss. | ERUBOSIDE B [79] | [69] Gitogenin [9] | 3-O-β-D-Glc-(1 → 4)-O-β-D-Glc | Kravets et al. (1990) |
| | | [85] Agapanthagenin [31] | 3-O-β-D-Glc | Barile et al. (2005) |
| | HIRTIFOLIOSIDE D [92] | [34] Agigenin | 3-O-β-D-Xyl-(1 → 3)-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Barile et al. (2005) |
| | [106] Alliogenin [49] | 3-O-β-D-Glc | Barile et al. (2005) |
| | HIRTIFOLIOSIDE A1 [261] | Furostane-2α,3β,22α-triol | 26-O-β-D-Glc 3-O-β-D-Xyl-(1 → 3)-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Barile et al. (2005) |
| | HIRTIFOLIOSIDE A2 [262] | Furostane-2α,3β,22β-triol | 26-O-β-D-Glc 3-O-β-D-Xyl-(1 → 3)-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Barile et al. (2005) |
| | HIRTIFOLIOSIDE B [263] | Furost-20(22)-ene-2α,3β-diol | 26-O-β-D-Glc 3-O-β-D-Xyl-(1 → 3)-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Barile et al. (2005) |
| | HIRTIFOLIOSIDE C1 [264] | Furostane-2α,3β,22α-triol | 26-O-β-D-Glc | Barile et al. (2005) |
| | HIRTIFOLIOSIDE C2 [265] | Furostane-2α,3β,22β-triol | 26-O-β-D-Glc | Barile et al. (2005) |
| A. jesdianum Boiss. | F-GITONIN [72] | [72] Gantogenin [33] | 3-O-β-D-Glc-(1 → 2)]β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mimaki et al. (1999c) |
| | [266] | Alliosterol [196] | 1-O-β-D-Glc 16-O-β-D-Glc | Mimaki et al. (1999c) |
| | [267] | Alliosterol [196] | 1-O-β-D-Glc 16-O-β-D-Glc | Mimaki et al. (1999c) |
| A. karataviense Regel | [268] | Alliogenin [49] | | |
| | | Karatavigenin c [45] | | Vollerner et al. (1983b) |
| | | Alliogenin [49] | | Vollerner et al. (1973), Mimaki et al. (1999c) |
| | | Karatavigenin [52] | | Vollerner et al. (1973) |
| | | Karatavigenin B [53] | | Krhurstas et al. (1974) |
| | [105] | Alliogenin [49] | 2-O-β-D-Glc | Mimaki et al. (1999c) |
| | [106] | Alliogenin [49] | 3-O-β-D-Glc | Gorovits et al. (1973) |
| | [107] | Alliogenin [49] | 3-O-β-D-Glc-(1 → 2)]β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mimaki et al. (1999c) |
| | KARATAVIOSIDE A [151] | | | Vollerner et al. (1978), Mimaki et al. (1999c) |
| | KARATAVIOSIDE B [152] | Yuccagenin [19] | 3-O-β-D-Glc-(1 → 2)]4-O-β-hydroxy-β-methylglutaryl-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Vollerner et al. (1983a) |
| | KARATAVIOSIDE E [180] | Karatavigenin C [45] | 3-O-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Vollerner et al. (1984) |
| | KARATAVIOSIDE F [181] | Karatavigenin C [45] | 3-O-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal 24-O-β-D-Glc | Vollerner et al. (1984) |
| Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|----------------------------|----------------|--------------|------------|
| [184] | 3-O-acetyl-alliogenin [51] | 2-O-β-D-Glc | Mimaki et al. (1999c) |
| [185] | 3-O-(2-hydroxybutyryl)-alliogenin [54] | 2-O-β-D-Glc | Khristulas et al. (1974) |
| [186] | Karatavigenin [52] | 2-O-β-D-Glc | Mimaki et al. (1999c) |
| [187] | Karatavigenin B [53] | 3-O-β-D-Glc | Mimaki et al. (1999c) |
| [192] | (24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol [61] | 2-O-β-D-Glc 24-O-β-D-Glc (1 → 2)-O-β-D-Glc | Mimaki et al. (1999c) |
| [194] | 3-O-benzoyl-(24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol [63] | 2-O-β-D-Glc | Mimaki et al. (1999c) |
| [195] | 3-O-benzoyl-(24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol [63] | 2-O-β-D-Glc 24-O-β-D-Glc | Mimaki et al. (1999c) |
| KARATAVIOSIDE C [268] | (25R)-furost-5(6)-ene-2α,3β,22α,26-tetrol | 26-O-β-D-Glc 3-O-β-D-Glc (1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Vollner et al. (1980) |
| [269] | (25R)-22-methoxy-5α-furostane-2α,3β,5α,6β,22α,26-tetrol | 26-O-β-D-Glc 2-O-β-D-Glc | Mimaki et al. (1999c) |
| A. leucanthum C. Koch | ERUBOSIDE B [79] | 3-O-β-D-Glc (1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| [80] | β-Chlorogenin [12] | 3-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| [81] | β-Chlorogenin [12] | 3-O-β-D-Glc-(1 → 3)-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| [91] | Agigenin [34] | 3-O-β-D-Glc-(1 → 2)-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| AGINOSIDE [93] | YAYOISAPONIN C [95] | 3-O-β-D-Glc-(1 → 3)-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| LEUCOSPIROSIDE A [97] | Agigenin [34] | 3-O-β-D-Glc-(1 → 3)-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Mskhiladze et al. (2008b) |
| A. macleanii Baker | AGINOSIDE [93] | Tigogenin [1] | Inoue et al. (1995) |
| [67] | Tigogenin [1] | 3-O-α-L-Rha-(1 → 2)-O-β-D-Glc-(1 → 2)-[β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Inoue et al. (1995) |
| [98] | Agigenin [34] | 3-O-β-D-Glc-(1 → 2)-[4-O-(S)-3-hydroxy-3-methylglutaryl]-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Inoue et al. (1995) |
| [100] | Agigenin [34] | 3-O-β-D-Glc-(1 → 2)-[4-O-benzyloxy]-β-D-Xyl-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Inoue et al. (1995) |
| [105] | Alliogenin [49] | 2-O-β-D-Glc | Inoue et al. (1995) |
| [186] | Karatavigenin [52] | 2-O-β-D-Glc | Inoue et al. (1995) |
| [270] | Alliosterol [196] | 1-O-α-L-Rha 3-O-α-L-Rha 16-O-β-D-Glc | Inoue et al. (1995) |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|----------------------------|----------------|---------------|------------|
| *A. macrostemon* Bunge (A. grayi Regel) | Tigogenin [1] | Smilagenin [3] | 3-O-[β-D-Glc-(1 → 2)-β-D-Glc-(1 → 3)]-O-β-D-Gal | Okanishi et al. (1975), He et al. (2002) |
|         | Tigogenin [1] | Gitogenin [9] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Okanishi et al. (1975) |
| MACROSTEMONOSIDE A [65] | 3-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1992) | Peng et al. (1992) |
| MACROSTEMONOSIDE D [66] | 3-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Cheng et al. (2013) | Cheng et al. (2013) |
| [129]   | (25R)-5β-spirostan-3β,12β-diol [15] | He et al. (2002), Cheng et al. (2013) | He et al. (2002), Cheng et al. (2013) |
| [172]   | 5β-Spirost-25(27)-ene-3β,12β-diol [21] | | |
| MACROSTEMONOSIDE S [173] | 3-O-β-D-Glc-(1 → 2)-O-β-D-Gal | | |
| MACROSTEMONOSIDE B [271] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (2007) | Peng et al. (2007) |
| MACROSTEMONOSIDE E [272] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1993) | Peng et al. (1993) |
| MACROSTEMONOSIDE F [273] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1993) | Peng et al. (1993) |
| MACROSTEMONOSIDE G [274] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1995) | Peng et al. (1995) |
| MACROSTEMONOSIDE H [275] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (2005) | Peng et al. (2005) |
| MACROSTEMONOSIDE I [276] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1995) | Peng et al. (1995) |
| MACROSTEMONOSIDE J [277] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1994) | Peng et al. (1994) |
| MACROSTEMONOSIDE K [278] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1994) | Peng et al. (1994) |
| MACROSTEMONOSIDE L [279] | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | Peng et al. (1994) | Peng et al. (1994) |
| [280]   | 26-O-[β-D-Glc-(1 → 2)-β-D-Gal] | He et al. (2002) | He et al. (2002) |
| MACROSTEMONOSIDE M [281] | 26-O-[β-D-Glc] | Chen et al. (2006) | Chen et al. (2006) |
| MACROSTEMONOSIDE N [282] | 26-O-[β-D-Glc] | Chen et al. (2006) | Chen et al. (2006) |
| MACROSTEMONOSIDE O [283] | 26-O-[β-D-Glc] | Chen et al. (2007) | Chen et al. (2007) |
| Species                          | Glycoside common name [no.] | Sapogenin [no.]                                                                 | Sugar residue                                                                                                                                                                                                 | References                      |
|---------------------------------|-----------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|
| MACROSTEMONOSIDE P [284]        | (25R)-5β-furostane-3β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2007)                                                                                                                                  |                                |
| MACROSTEMONOSIDE Q [285]        | (25R)-5β-furostane-1α,2β,3β,22,26-pentaol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2007)                                                                                                                                  |                                |
| MACROSTEMONOSIDE R [286]        | (25R)-furostane-3β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2006)                                                                                                                                  |                                |
| [287]                            | (25S)-furostane-3β,22,26-β-triol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2006)                                                                                                                                  |                                |
| [288]                            | (25R)-5α-furostane-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-β-β-Glc(1 → 3)-O-β-β-Glk(1 → 4)-O-β-β-Gal                  | Chen et al. (2010)                                                                                                                                  |                                |
| [289]                            | (25R)-5α-furostane-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-β-β-Glc(1 → 3)-O-β-β-Glk(1 → 4)-O-β-β-Gal                  | Chen et al. (2010)                                                                                                                                  |                                |
| [290]                            | (25R)-5α-furostane-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-β-β-Glc(1 → 3)-O-β-β-Glk(1 → 4)-O-β-β-Gal                  | Chen et al. (2010)                                                                                                                                  |                                |
| [291]                            | (25R)-5β-furostane-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2010)                                                                                                                                  |                                |
| [292]                            | 5β-Furost-25(27)-ene-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-β-β-Glc(1 → 3)-O-β-β-Glk(1 → 4)-O-β-β-Gal                  | Chen et al. (2009)                                                                                                                                  |                                |
| [293]                            | 5β-Furost-20(22),25(27)-dieno-3β,12β,22,26-tetrol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-O-β-β-Gal                                                                 | Chen et al. (2009)                                                                                                                                  |                                |
| [294]                            | 5β-Furostane-3β,12β,22,26-tetrol     | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 2)-β-β-Glc(1 → 3)-O-β-β-Glk(1 → 4)-O-β-β-Gal                  | Ou et al. (2012)                                                                                                                                    |                                |
| A. minutiflorum Regel           | Neoagigenin [36]              | Alliogenin [49]                                                                      |                                                                                                                                                    | Barile et al. (2007)                                                        |
| MINUTOSIDE B [119]              | Neoagigenin [36]              | 3-O-β-β-Xyl(1 → 3)-O-β-β-Glc(1 → 4)-O-β-β-Gal                                                                 | Barile et al. (2007)                                                                                                                                |                                |
| MINUTOSIDE A [285]              | (25R)-furostane-2α,3β,6β,22α,26-pentaol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 3)-O-β-β-Glc(1 → 4)-O-β-β-Gal                        | Barile et al. (2007)                                                                                                                                |                                |
| MINUTOSIDE C [286]              | (25R)-furostane-2α,3β,5α,6β,22α,26-hexol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 3)-O-β-β-Glc(1 → 4)-O-β-β-Gal                        | Barile et al. (2007)                                                                                                                                |                                |
| A. narcissiflorum Vill.         | Diosgenin [4]                | 3-O-β-β-Glc                                                                 | Krokhmalyuk and Kintya (1976b)                                                                                                                   |                                |
| DELTONIN [134]                  | Diosgenin [4]                | 3-O-α-α-Rha(1 → 2)-β-β-Glc(1 → 4)-O-β-β-Glc                                                                 | Mimaki et al. (1996)                                                                                                                              |                                |
| [139]                            | Diosgenin [4]                | 3-O-α-α-Rha(1 → 2)-β-β-Glc(1 → 4)-O-β-β-Glc                                                                 | Mimaki et al. (1996)                                                                                                                              |                                |
| [141]                            | Diosgenin [4]                | 3-O-α-α-Rha(1 → 4)-O-α-α-Rha(1 → 4)-[α-α-Rha(1 → 2)]-O-β-β-Glc                | Mimaki et al. (1996)                                                                                                                              |                                |
| ALLIUMOSIDE B [297]             | (25R)-furost-5α-ene-3β,22α,26-triol | 26-O-β-β-Glc 3-O-β-β-Glc(1 → 3)-O-β-β-Glc(1 → 4)-O-β-β-Glc                     | Krokhmalyuk and Kintya (1976b)                                                                                                                   |                                |
| ALLIUMOSIDE C [298]             | (25R)-furostane-3β,22α,26-triol | 26-O-β-β-Glc 3-O-α-α-Rha(1 → 4)-O-α-α-Rha(1 → 6)-O-β-β-Glc(1 → 6)-O-β-β-Glc  | Lazurevski et al. (1975)                                                                                                                          |                                |
| Species         | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue                                      | References               |
|-----------------|------------------------------|-----------------|----------------------------------------------------|--------------------------|
| **ALLIUMOSIDE D [299]** | (25S)-furost-5(6)-ene-3β,22α,26-triol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→4)-O-α-L-Rha-(1→6)-O-β-D-Glc-(1→2)-β-D-Glc-(1→3)-O-β-D-Glc | Krokhmalyuk and Kintya (1976a) |
| **ALLIUMOSIDE E [300]** | (25S)-furost-5(6)-ene-3β,22α,26-triol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→4)-O-α-L-Rha-(1→6)-O-β-D-Glc-(1→2)-β-D-Glc-(1→3)-O-β-D-Glc | Krokhmalyuk and Kintya (1976a) |
| [301]           | (25R)-22-methoxy-furost-5(6)-ene-3β,22α,26-triol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→2)-O-β-D-Glc                         | Mimaki et al. (1996)    |
| [302]           | (25R)-22-methoxy-furost-5(6)-ene-3β,22α,26-triol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→2)-O-β-D-Glc                         | Mimaki et al. (1996)    |
| **A. nigrum L.** |                              |                |                                                    |                          |
| **NIGROSIDES A1/A2 [89, 117]** | (25R,5)-α-spirostan-2α,3β,6β-triol [34, 36] | 3-O-α-L-Rha-(1→2)-O-β-D-Glc |                                                    | Jabrane et al. (2011) |
| **NIGROSIDES B1/B2 [88, 118]** | (25R,5)-α-spirostan-2α,3β,6β-triol [34, 36] | 2-O-β-D-Glc | 3-O-β-D-Glc                                        | Jabrane et al. (2011) |
| **AGINOSIDE [93]** | (25R,5)-α-spirostan-2α,3β,6β-triol [34, 36] | 3-O-β-D-Xyl-(1→3)-β-D-Glc-(1→2)-β-D-Glc-(1→4)-O-β-D-Gal |                                                    | Mostafa et al. (2013)  |
| [98, 124]       | (25R,5)-α-spirostan-2α,3β,6β-triol [34, 36] | 3-O-β-D-Glc-(1→2)-β-D-Glc-(1→3)-β-D-Glc-(1→4)-O-β-D-Gal |                                                    | Jabrane et al. (2011) |
| **NIGROSIDE C** | Alliosterol [196] | 1-O-α-L-Rha | 16-O-α-L-Rha-(1→3)-O-β-D-Gal                       | Jabrane et al. (2011)   |
| **NIGROSIDE B [303]** | Alliosterol [196] | 16-O-α-L-Rha-(1→3)-O-β-D-Gal |                                                    | Jabrane et al. (2011) |
| **A. nutans L.** |                              |                |                                                    |                          |
| [138]           | Diosgenin [4] | 3-O-α-L-Rha-(1→2)-β-D-Glc-(1→4)-O-β-D-Gal |                                                    | Akhov et al. (1999)     |
| [147]           | Russogenin [17] | 1-O-α-L-Rha | 16-O-β-D-Gal                                      | Akhov et al. (1999)     |
| **NOLINOFUROSIDE D [305]** | (25S)-furost-5(6)-ene-1β,3β,22α,26-tetrol | 26-O-β-D-Glc | 1-O-β-D-Gal                                       | Akhov et al. (1999)     |
| **DELTOSIDE [306]** | (25R)-furost-5(6)-ene-3β,22α,26-triol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→2)-β-D-Glc-(1→3)-O-β-D-Gal         | Akhov et al. (1999)     |
| **A. ostrowskianum Regel** |                              |                |                                                    |                          |
| **F-GITONIN [72]** | Agigenin [34] | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→2)-β-D-Glc-(1→3)-O-β-D-Gal         | Mimaki et al. (1993)    |
| **AGINOSIDE [93]** | (25R,5)-α-spirostan-2α,3β,6β,22,26-pentaol | 26-O-β-D-Glc | 3-O-α-L-Rha-(1→2)-β-D-Glc-(1→3)-O-β-D-Gal         | Mimaki et al. (1993)    |
| [196, 197]      | Alliosterol [196] | 16-O-β-D-Glc | (1→3)-O-β-D-Gal                                  | Mimaki et al. (1993)    |
| [307]           | Alliosterol [196] | 16-O-β-D-Glc | (1→3)-O-β-D-Gal                                  | Mimaki et al. (1993)    |
| Species          | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue                                                                 | References                      |
|------------------|------------------------------|-----------------|-------------------------------------------------------------------------------|---------------------------------|
| *A. porrum* L.   |                              | Diosgenin [4]   |                                                                               | Fattonuso et al. (1998)         |
|                  |                              | β-Chlorogenin [12] |                                                                                     | Fattonuso et al. (1998)         |
|                  |                              | Porrigenin B [23] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | Neoporrigenin B [24] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | 12-Ketoporrigenin [29] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | Porrigenin C [30] |                                                                                     | Fattonuso et al. (2000)         |
|                  |                              | Agigenin [34] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | Neoporrigenin [36] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | Porrigenin A [38] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | Neoporrigenin A [39] |                                                                                     | Carotenuto et al. (1997b)       |
|                  |                              | 2,3-Seco-porrigenin [64] |                                                                                     | Carotenuto et al. (1999)         |
|                  |                              | F-GITONIN [72] | 3-O-[β-D-Glc-(1→3)-O-[β-D-Glc-(1→2)-β-D-Xyl-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Carotenuto et al. (1999)         |
|                  | 74                           | Gitogenin [9] | 3-O-[β-D-Glc-(1→2)-β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Adão et al. (2011a)            |
|                  |                              | β-Chlorogenin [12] |                                                                                     | Carotenuto et al. (1999)         |
|                  | 78                           | β-Chlorogenin [12] | 6-O-[β-D-Glc | Adão et al. (2011a)            |
|                  | 80                           | β-Chlorogenin [12] | 3-O-[β-D-Glc-(1→2)-β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Carotenuto et al. (1999)         |
|                  | 82                           | β-Chlorogenin [12] | 3-O-[β-D-Glc-(1→3)-O-[β-D-Glc-(1→2)-β-D-Xyl-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Carotenuto et al. (1999)         |
|                  |                              | AGINOSIDE [93] |                                                                                     | Harmatha et al. (1987)          |
|                  |                              | LEUCOSPIROSIDE A [97] |                                                                                       | Adão et al. (2011b)          |
|                  | 162                          | 12-Ketoporrigenin [29] | 3-O-[β-D-Glc-(1→2)-β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Fattonuso et al. (2000)         |
|                  | 175                          | Porrigenin B [23] | 3-O-[β-D-Glc-(1→3)-O-[β-D-Glc-(1→2)-β-D-Glc-(1→4)-O-β-D-Gal | Adão et al. (2012)            |
|                  | 177                          | Porrigenin C [30] | 3-O-[β-D-Glc-(1→2)-β-D-Glc-(1→3)]-O-[β-D-Glc-(1→4)-O-β-D-Gal | Fattonuso et al. (2000)         |
|                  | 267                          | Alliosterol [196] | 1-O-[α-L-Rha 16-O-β-D-Glc | Fattonuso et al. (2000)         |
|                  | 308                          | Alliosterol [196] | 1-O-[α-L-Rha 16-O-β-D-Glc | Fattonuso et al. (2000)         |
| *A. rotundum* L. |                              | Tigogenin [1] |                                                                                     | Maisashvili et al. (2007)       |
|                  |                              | Diosgenin [4]   | Sapogenins [1, 4, 7, 9, 12, 19, 34] were isolated by hydrolyzing saponins directly in the raw material | Maisashvili et al. (2007)       |
|                  |                              | Hecogenin [7] |                                                                                     | Maisashvili et al. (2007)       |
|                  |                              | Gitogenin [9]   |                                                                                     | Maisashvili et al. (2007)       |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|----------------------------|----------------|--------------|------------|
| [74]   | [β-Chlorogenin [12] | Yuccagenin [19] | Agigenin [34] | Maisashvili et al. (2007) |
|   | Gitogenin [9] | 3-O-[β-D-Glc-(1 → 3)-O-[β-D-Glc-(1 → 2)]-β-D-Xyl-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Maisashvili et al. (2012) |
| DIDEGLUCOERUBOSIDE B [77] | β-Chlorogenin [12] | 3-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Maisashvili et al. (2008) |
| ERUBOSIDE B [79] | | | Maisashvili et al. (2008) |
| AGINOSIDE [93] | | | Maisashvili et al. (2008) |
| YAYOISAPONIN C [95] | | | Maisashvili et al. (2008) |
| TRILLIN (ALLIUMOSIDE A) [130] | [25R]-5α-furostane-2x,3β,22α,26-tetrol | 26-O-[β-D-Glc 3-O-[β-D-Glc-(1 → 2)]-β-D-Xyl-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Maisashvili et al. (2012) |
| A. sativum L. | SATIVOSIDE-R2 [68] | Tigogenin [1] | 3-O-[β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 2)]-β-D-Xyl-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Matsuura et al. (1989a) |
| F-GITONIN [72] | | | Matsuura et al. (1988) |
| [76] | [β-Chlorogenin [12] | | Matsuura et al. (1988) |
| DIDEGLUCOERUBOSIDE B [77] | β-Chlorogenin [12] | 3-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Matsuura et al. (1988) |
| ERUBOSIDE-B [79] (obtained by enzymatic hydrolysis of proto-eruboside B) | | | Matsuura et al. (1988) |
| ISO-ERUBOSIDE-B [310] | (25S)-5α-spirostan-3β,16β-diol | 3-O-[β-D-Glc-(1 → 2)]-β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Peng et al. (1996a) |
| SATIVOSIDE-B1 [311] | (25R)-5α-furostane-3β,6β,22,26-tetrol | 26-O-[β-D-Glc 3-O-[β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 2)]-β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Matsuura et al. (1989a) |
| SATIVOSIDE-R1 [312] | (25R)-5α-furostane-3β,22,26-tetrol | 26-O-[β-D-Glc 3-O-[β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 2)]-β-D-Xyl-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Matsuura et al. (1989a) |
| PROTO-ERUBOSIDE-B [313] | (25R)-5α-furostane-3β,6β,22,26-tetrol | 26-O-[β-D-Glc 3-O-[β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 2)]-β-D-Xyl-(1 → 3)]-O-[β-D-Glc-(1 → 4)]-O-[β-D-Gal | Matsuura et al. (1988) |
| PROTO-ISO-ERUBOSIDE-B [314] | (25S)-5α-furostane-3β,6β,22,26-tetrol | 26-O-[β-D-Glc 3-O-[β-D-Glc-(1 → 3)]-O-[β-D-Glc-(1 → 2)]-β-D-Gal | Matsuura et al. (1988) |
| PROTO-DESGALACTOTIGONIN [315] | | | Matsuura et al. (1989a) |
Table 2 continued

| Species                          | Glycoside common name [no.]                                      | Sapogenin [no.]                                                                 | Sugar residue                                                                 | References                      |
|----------------------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------|
| [316]                            | (25S)-22-methoxy-5α-furostane-3β,6β,26-triol                    | 26-O-α-L-Rha-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal | Ma et al. (2011)                                                             |                                 |
| [317]                            | (25R)-22-methoxy-5α-furostane-3β,6β,26-triol                    | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Ma et al. (2011)                                                             |                                 |
| [318]                            | (25R)-22-methoxy-5α,6β-furostane-3β,26-diol                     | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Ma et al. (2011)                                                             |                                 |
| [73] A. sativum L. var. Voghera   |                                                                  | 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                  | Lanzotti et al. (2012a)                                                      |                                 |
| AMPELOSIDE B3 [90]               |                                                                  |                                                                                |                                 |                                 |
| VOGHIEROSIDE A1 [319]            | Furostane-2β,3β,5α,22α,26-pentaol                               | 26-O-α-L-Rha-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE A2 [320]            | Furostane-2β,3β,5α,22α,26-pentaol                               | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE B1 [321]            | Furostane-2β,3β,5α,22α,26-pentaol                               | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE B2 [322]            | Furostane-2β,3β,5α,22α,26-pentaol                               | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE C1 [323]            | Furostane-2β,3β,6β,22α,26-pentaol                               | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE C2 [324]            | Furostane-2β,3β,6β,22α,26-pentaol                               | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal     | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE D1 [325]            | Furostane-2β,3β,22α,26-tetrool                                  | 26-O-α-L-Rha-β-D-Glc-(1 → 3)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal         | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE D2 [326]            | Furostane-2β,3β,22α,26-tetrool                                  | 26-O-α-L-Rha-β-D-Glc-(1 → 3)-β-L-Rha-(1 → 4)-O-β-D-Gal                        | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE E1 [327]            | Furostane-2β,3β,22α,26-tetrool                                  | 26-O-α-L-Rha-β-D-Glc-(1 → 3)-β-L-Rha-(1 → 4)-O-β-D-Gal                        | Lanzotti et al. (2012a)                                                      |                                 |
| VOGHIEROSIDE E2 [328]            | Furostane-2β,3β,22α,26-tetrool                                  | 26-O-α-L-Rha-β-D-Glc-(1 → 3)-β-L-Rha-(1 → 4)-O-β-D-Gal                        | Lanzotti et al. (2012a)                                                      |                                 |
| [83] A. schoenoprasum L.          |                                                                  | 3-O-β-D-Glc-(1 → 3)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                 | Timiš et al. (2013)                                                          |                                 |
| [131]                            | Diosgenin [4]                                                    | 3-O-α-L-Rha-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                 | Timiš et al. (2013)                                                          |                                 |
| DELTONIN [134]                   |                                                                  | 3-O-α-L-Rha-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                 | Timiš et al. (2013)                                                          |                                 |
| [158]                            | Lavogenin [6]                                                    | 3-O-α-L-Rha-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                 | Timiš et al. (2013)                                                          |                                 |
| [160]                            | Lavogenin [6]                                                    | 3-O-α-L-Rha-(1 → 2)-β-L-Rha-(1 → 3)-β-D-Glc-(1 → 4)-O-β-D-Gal                 | Timiš et al. (2013)                                                          |                                 |
| Species                  | Glycoside common name [no.]                                                                 | Sapogenin [no.]                                                                 | Sugar residue                                                                 | References            |
|-------------------------|---------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|-----------------------|
| **Sapogenin**            |                                                                                             |                                                                                |                                                                               |                       |
| [182]                   | (20S,25S)-spirost-5(6)-ene-3β,1α,21-triol [46]                                               | 3-O-α-L-Rha-(1→2)-O-β-D-Glc                                                   |                                                                               | Timiš et al. (2013)   |
| [183]                   | (20S,25S)-spirost-5(6)-ene-3β,12β,21-triol [47]                                              | 3-O-α-L-Rha-(1→2)-O-β-D-Glc                                                   |                                                                               | Timiš et al. (2013)   |
| **DELTOSIDE [306]**     |                                                                                             |                                                                                |                                                                               |                       |
| *A. schubertii* Zucc.    | [100, 126] (25R,S)-5α-spirostane-2α,3β,6β-triol [34, 36]                                     | 3-O-β-D-Glc-(1→2)-[4-O-benzoylβ-D-Xyl-(1→3)]-O-β-D-Glc-(1→4)-O-β-D-Gal       | Kawashima et al. (1993)                                                      |                       |
|                         | [99, 125] (25R,S)-5α-spirostane-2α,3β,6β-triol [34, 36]                                     | 3-O-β-D-Glc-(1→2)-[3-O-benzoylβ-D-Xyl-(1→3)]-O-β-D-Glc-(1→4)-O-β-D-Gal       | Kawashima et al. (1993)                                                      |                       |
|                         | [98, 124] (25R,S)-5α-spirostane-2α,3β,6β-triol [34, 36]                                     | 3-O-β-D-Glc-(1→2)-[4-O-(S)-3-hydroxy-3-methylglutaryl]-β-D-Xyl-(1→3)]-O-β-D-Glc-(1→4)-O-β-D-Gal | Kawashima et al. (1993)                                                      |                       |
|                         | [194, 195] (25R,S)-5α-furostane-2α,3β,6β,22,26-pentaol                                        | 26-O-β-D-Glc 3-O-β-D-Glc-(1→2)-β-D-Xyl-(1→3)-O-β-D-Glc-(1→4)-O-β-D-Gal       | Kawashima et al. (1993)                                                      |                       |
| **SCHUBERTOSIDE D**      | Alliosterol [196]                                                                            | 1-O-α-L-Rha 16-O-α-L-Rha-(1→3)-O-β-D-Gal                                      | Kawashima et al. (1991b)                                                     |                       |
| **(NIGROSIDE C [303])** |                                                                                             |                                                                                |                                                                               |                       |
| **SCHUBERTOSIDE A [329]** | (22S)-cholest-4(5)-ene-16β,22-diol-3-one                                                   | 16-O-α-L-Rha-(1→3)-O-β-D-Gal                                                  | Kawashima et al. (1991b)                                                     |                       |
| **SCHUBERTOSIDE B [330]** | (22S)-cholest-5(6)-ene-16β,22-diol-3-one                                                   | 16-O-α-L-Rha-(1→3)-O-β-D-Gal                                                  | Kawashima et al. (1991b)                                                     |                       |
| **SCHUBERTOSIDE C [331]** | (22S)-cholest-5(6)-ene-16β,22-diol-3-one                                                   | 3-O-β-D-Glc 16-O-α-L-Rha-(1→3)-O-β-D-Gal                                      | Kawashima et al. (1991b)                                                     |                       |
| **A. senescens L.**      |                                                                                             |                                                                                |                                                                               |                       |
| [140]                   | Diosgenin [4]                                                                               | 3-O-α-L-Rha-(1→2)-[β-D-Glc-(1→3)]-O-β-D-Glc                                  | Inoue et al. (1995)                                                          |                       |
| [141]                   | Diosgenin [4]                                                                               | 3-O-α-L-Rha-(1→4)-O-α-L-Rha-(1→4)-[α-L-Rha-(1→2)]-O-β-D-Glc                  | Inoue et al. (1995)                                                          |                       |
| **A. stipitatum Regel./A. suvorovii Regel.** |                                                                                         |                                                                                |                                                                               |                       |
|                         | Diosgenin [4]                                                                               | Sapogenins [4,19] obtained from the acid hydrolysis of the purified combined glycosides | Volmert et al. (1988a)                                                       |                       |
|                         | Yuccagenin [19]                                                                             |                                                                                |                                                                               |                       |
|                         | Anzurogenin B [26]                                                                         |                                                                                |                                                                               |                       |
|                         | Anzurogenin D [41]                                                                          |                                                                                |                                                                               |                       |
|                         | Anzurogenin A [48]                                                                          |                                                                                |                                                                               |                       |
|                         | Alliogenin [49]                                                                             |                                                                                |                                                                               |                       |
|                         | Anzurogenin C [58]                                                                          |                                                                                |                                                                               |                       |
|                         | Alliosterol [196]                                                                           |                                                                                |                                                                               |                       |
|                         | Alliogenone [359]                                                                           |                                                                                |                                                                               |                       |
|                         | [(25R)-5α-spirostane-2α,3β,5α-triol-6-one]                                                  |                                                                                |                                                                               |                       |
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|-----------------------------|-----------------|---------------|------------|
| KARATAVIOSIDE A [151] | | | | Kravets (1994) |
| KARATAVIOSIDE B [152] | | | | Kravets (1994) |
| ANZUROSIDE [190] | Anzurogenin C [58] | | 24-O-β-D-Glc | Vollerner et al. (1989) |
| ALLIOSIDE A [333] | Alliosterol [196] | | 16-O-β-D-Gal | Vollerner et al. (1991) |
| ALLIOSIDE B [334] | Alliosterol [196] | | 1-O-β-D-Glc 16-O-β-D-Gal | Vollerner et al. (1991) |
| A. triquetrum L. | ASCALONICOSIDES A1/A2 [217, 218] | | | |
| TRIQUETROSIDE A1 [335] | Furost-5(6)-ene-1β,22α-diol | | 26-O-α-L-Rha(1 → 2)-O-β-D-Glc | Corea et al. (2003) |
| TRIQUETROSIDE A2 [336] | Furost-5(6)-ene-1β,22β-diol | | 3-O-α-L-Rha(1 → 2)-O-β-D-Glc | Corea et al. (2003) |
| TRIQUETROSIDE B [337] | Furost-5(6),20(22)-diene-1β-ol | | 26-O-α-L-Rha(1 → 2)-O-β-D-Glc 3-O-α-L-Rha(1 → 2)-O-β-D-Glc | Corea et al. (2003) |
| TRIQUETROSIDE C1 [338] | Furost-5(6)-ene-1β,22α-diol | | 26-O-α-L-Rha(1 → 2)-O-β-D-Glc 3-O-β-D-Glc | Corea et al. (2003) |
| TRIQUETROSIDE C2 [339] | Furost-5(6)-ene-1β,22β-diol | | 26-O-α-L-Rha(1 → 2)-O-β-D-Glc 3-O-β-D-Glc | Corea et al. (2003) |
| A. tuberosum Rottl. ex Spreng | | | | |
| TUBEROSIDE J [102] | (25R)-5α-spirostan-2α,3β,27-triol [40] | | 3-O-α-L-Rha(1 → 2)-O-β-D-Glc | Sang et al. (2001a) |
| TUBEROSIDE K [103] | (25R)-5α-spirostan-2α,3β,27-triol [40] | | 3-O-α-L-Rha(1 → 2)-O-β-D-Glc | Sang et al. (2001a) |
| TUBEROSIDE L [104] | (25R)-5α-spirostan-2α,3β,27-triol [40] | | 27-O-β-D-Glc | Sang et al. (2001a) |
| NICOTIANOSIDE C [109] | Neotigogenin [2] | | 3-O-α-L-Rha(1 → 4)-O-β-D-Glc | Sang et al. (2000) |
| TUBEROSIDE D [112] | Neotigogenin [10] | | 3-O-α-L-Rha(1 → 4)-O-β-D-Glc | Sang et al. (1999a, b), Ikeda et al. (2000) |
| TUBEROSIDE E [114] | Neotigogenin [10] | | 3-O-β-D-Glc(1 → 2)-O-β-D-Glc | Sang et al. (1999a) |
| TUBEROSIDE [128] | (25S)-5α-spirostan-2α,3β,27-triol [42] | | 3-O-α-L-Rha(1 → 2)-O-β-D-Glc | Zou et al. (2001) |
| TUBEROSIDE M [163] | (25S)-5β-spirostan-1β,3β-diol [8] | | 3-O-α-L-Rha(1 → 4)-O-β-D-Glc | Sang et al. (2002) |
| TUBEROSIDE N [164] | (25S)-5β-spirostan-2β,3β-diol [11] | | 3-O-β-D-Glc(1 → 2)-O-β-D-Glc | Sang et al. (2003) |
| [165] | 25-Epi-ruizgenin [13] | | 3-O-α-L-Rha(1 → 4)-O-β-D-Glc | Ikeda et al. (2000) |
| TUBEROSIDE O [166] | (25S)-5β-spirostan-2β,3β,5β-triol [32] | | 3-O-β-D-Glc | Sang et al. (2003) |
Table 2 continued

| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|----------------------------|----------------|---------------|------------|
| TUBEROSIDE P [167] | (25S)-5β-spirostan-2β,3β,5β-triol [32] | 3-O-α-L-Rha-(1 → 4)-O-β-D-Glc | Sang et al. (2003) |
| [168] | (25S)-spiropent-3β,5β,6α-triol [43] | 3-O-α-L-Rha-(1 → 4)-O-β-D-Glc | Ikeda et al. (2000) |
| [171] | Lilagenin [20] | 3-O-α-L-Rha-(1 → 4)-O-β-D-Glc | Ikeda et al. (2000) |
| [188] | (24S,25S)-5β-spirostan-2β,3β,5β,24-tetrol [55] | 3-O-α-L-Rha-(1 → 2)-β-D-Glc-(1 → 4)-O-β-D-Glc | Hu et al. (2014) |
| TUBEROSIDE Q [189] | (24S,25S)-5β-spirostan-2β,3β,5β,24-tetrol [56] | 3-O-α-L-Rha-(1 → 4)-O-β-D-Glc | Sang et al. (2003) |
| [340] | (24S,25S)-5β-spirostan-2β,3β,24-triol | 3-O-α-L-Rha-(1 → 2)-β-D-Glc-(1 → 4)-O-β-D-Glc | Hu et al. (2009) |
| TUBEROSIDE A [341] | (25S)-5α-furost-20(22)-ene-2β,3β,26-triol | 26-O-β-D-Glc 26-O-β-D-Glc | Sang et al. (1999b) |
| TUBEROSIDE B [342] | (25S)-5α-furost-20(22)-ene-2β,3β,26-triol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (1999b) |
| TUBEROSIDE C [343] | (25S)-5α-furost-20(22)-ene-2β,3β,26-triol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (1999b) |
| TUBEROSIDE R [344] | (25S)-5β-furost-20(22)-ene-2β,3β,5β,26-tetrol | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-β-D-Glc | Sang et al. (2003) |
| TUBEROSIDE S [345] | (25S)-5β-furost-20(22)-ene-2β,3β,26-diol | 26-O-β-D-Glc 3-O-β-D-Glc-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2003) |
| TUBEROSIDE T [346] | (25S)-5α-furost-20(22)-ene-2β,3β,26-diol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2003) |
| [347] | (25S,20R)-5α-furost-22(23)-ene-2β,3β,20,26-tetrol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2001b) |
| [348] | (25S,20R)-20-methoxy-5α-furost-22(23)-ene-2β,3β,20,26-tetrol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2001b) |
| [349] | (25S,20S)-5α-furost-22(23)-ene-2β,3β,20,26-tetrol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2001b) |
| [350] | (25S,20S)-5α-furost-22(23)-ene-2β,3β,20,26-triol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2001b) |
| [351] | (25S)-5α-furostane-3β,22,26-triol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Ikeda et al. (2004) |
| [352] | (25S)-5β-furostane-3β,5β,6α,22,26-pentaol | 26-O-β-D-Glc 3-O-α-L-Rha-(1 → 2)-β-β-D-Glc-(1 → 4)-O-β-D-Glc | Ikeda et al. (2004) |
| [267] | Alliosteryl [196] | 1-O-α-L-Rha 16-O-β-D-Glc | Sang et al. (2000) |
| TUBEROSIDE U [353] | (22S,25S)-cholest-5(6)-ene-3β,16β,22,26-tetrol | 3-O-α-L-Rha-(1 → 2)-β-D-Glc-(1 → 4)-O-β-D-Glc | Sang et al. (2003) |

Sang et al. (2003)
| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|-----------------------------|-----------------|---------------|------------|
| *A. turcomanicum* Regel | Yuccagenin [19] | Neoagigenone [25] | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1977a) |
| | Neoagigenin [36] | 6-O-benzoyl neoagigenin [37] | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1977a) |
| | Alliogenin | Neoalliogenin [50] | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1977b) |
| TUROSIDE A [122] | Neoagigenin [36] | 26-O-β-D-Glc 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1979a) |
| TUROSIDE A 6-O-BENZOATE [127] | Neoagigenin [36] | 6-O-benzoyl neoagigenin [37] | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1979b) |
| TUROSIDE C [354] | (25S)-5α-furostane-2α,3β,6β,22,26-pentaol | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1977a) |
| *A. ursinum* L. | Diosgenin [4] | (25S)-spirost-5(6),25(27)-diene-3β-ol [5] | 3-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Pirtskhalava et al. (1977a) |
| [141] | Diosgenin | Sobolewska et al. (2006) |
| [156] | (25R)-spirost-5(6),25(27)-diene-3β-ol [5] | Sobolewska et al. (2006) |
| DICHOTOMIN [223] | Diosgenin [4] | Sobolewska (2004) |
| *A. vavilovii* M. Popov | ASCALONICOSIDES A1/A2 [217, 218] | Diosgenin | Zolfaghari et al. (2013) |
| VAVILOSIDE A1 [355] | (25R)-furost-5(6)-ene-1β,3β,22α,26-tetrol | 26-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Zolfaghari et al. (2013) |
| VAVILOSIDE A2 [356] | (25R)-furost-5(6)-ene-1β,3β,22β,26-tetrol | 26-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Zolfaghari et al. (2013) |
| VAVILOSIDE B1 [357] | (25R)-furost-5(6)-ene-1β,3β,22α,26-tetrol | 26-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Zolfaghari et al. (2013) |
| VAVILOSIDE B2 [358] | (25R)-furost-5(6)-ene-1β,3β,22β,26-tetrol | 26-O-β-D-Xyl-(1 → 3)-[β-D-Glc-(1 → 2)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal | Zolfaghari et al. (2013) |
| *A. victorialis* var. *platyphyllum* L. | F-GITONIN [72] | Diosgenin | Lee et al. (2001) |
| A. vineale L. | Diosgenin [4] | Nuatigenin [27] | Chen and Snyder (1989) |
| | Isonuatigenin [28] | | Chen and Snyder (1989) |
| [131] | Diosgenin [4] | 3-O-β-D-Xyl-(1 → 2)-O-β-D-Glc | Chen and Snyder (1989) |
| DELTONIN [134] | Diosgenin [4] | Zolfaghari et al. (2013) |
| [136] | Diosgenin [4] | 3-O-β-D-Xyl-(1 → 2)-O-β-D-Glc | Chen and Snyder (1989) |
| [142] | Diosgenin [4] | 3-O-β-D-Xyl-(1 → 2)-O-β-D-Glc | Chen and Snyder (1989) |
activity with an IC₅₀ value of 2.4 µg/mL as compared with etoposide (IC₅₀ 0.3 µg/mL) (Mimaki et al. 1999c). Tuberoside M [163] from the seeds of *A. tuberosum* inhibited the cells growth with IC₅₀ = 6.8 µg/mL, while F-gitonin [72] isolated from the fresh bulbs of *A. jesdianum*—with an IC₅₀ value of 1.5 µg/mL (Sang et al. 2002; Mimaki et al. 1999a). Other compounds isolated from this latter species were considered to be inactive. The authors concluded that the presence of an additional OH group at C-6 in gitogenin skeleton is detrimental to activity, while cholestanone glycosides showed no effect. It is probable that the presence of a carbonyl at C-6 in a laxogenin glycoside [158] isolated by Timiti et al. (2013) from the whole plant of *A. schoenoprasum* could be responsible for the loss of activity against two cancer cell lines HCT 116 and J-774, an effect similar to that seen by Mimaki et al. when an additional OH group was introduced at C-6 of gitogenin (Timiti et al. 2013; Mimaki et al. 1999c). In accordance with the studies of Mimaki et al. (1999a, b, c) were also the results obtained for cholestanone glycosides, nigrosides C [303] and D [304] isolated from the bulbs of *A. nigrum*, which showed no effect (IC₅₀ > 100 µM) on the HT-29 and HCT-116 cancer cell lines in the MTT assay (Jabrane et al. 2011). Opposite results were obtained however with two cholestanone glycosides isolated from *A. porrum*—alliosterol 1-Ọ-α-L-Rha 16-O-Ọ-β-D-Glc [267] and alliosterol 1-Ọ-β-D-Glc-Ö-α-L-Rha 16-O-Ọ-β-D-Gal [308], which exhibited in vitro cytotoxic properties (IC₅₀ 4.0–5.8 µg/mL) against two murine cell lines: WEHI 164 and J-774 (Fattorusso et al. 2000).

Results of cytotoxicity assays of several spirostanol sapogenins indicated their weak activity or lack of it. Agigenin [34], porrigenin A [38] and porrigenin B [23] identified in *A. porrum* tested in vitro for their growth-inhibitory activity on four different cell lines (IGR-1, WEHI 164, J-774, and P-388) exhibited much weaker activity when compared with 6-MP and were virtually inactive (>100 µg/mL) (Carotenuto et al. 1997a). However, some of the steroidal glycosides isolated from the same plant exhibited quite a good activity towards J-744 and WEHI-164 cells, the most active being gitogenin and porrigenin C derivatives (IC₅₀ ranging from 1.9 to 5.8 µg/mL) (Fattorusso et al. 2000). From among tested furostanoles the majority of compounds showed weak activity or lack of it, for example two glycosides isolated from *A. tuberosum*.

---

**Table 2 continued**

| Species | Glycoside common name [no.] | Sapogenin [no.] | Sugar residue | References |
|---------|-----------------------------|-----------------|--------------|------------|
| *A. waldsteinii* Don. | Diosgenin [144] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [145] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [146] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [147] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [148] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [149] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [150] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [151] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [152] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
| *A. waldsteinii* Don. | Diosgenin [153] | Diosgenin [4] | β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc-(1 → 4)-Ọ-β-D-Glc-(1 → 6)-Ọ-β-D-Glc-(1 → 2)-Ọ-β-D-Glc | Chen and Snyder (1989) |
showed no activity at concentrations below 5 μM against PC-12 and HCT-116 (Ikeda et al. 2004). Among numerous furostanol ethers obtained from A. macrostemon which were tested against NCI-H460, SF-268, MCF-7, and HepG2 cell lines, exclusively 26-O-β-D-Glc 5α-furost-25(27)-ene-3β,12β,22,26-tetrol 3-O-β-D-Glc-(1 → 2)-β-D-Glc-(1 → 3)]-O-β-D-Glc-(1 → 4)-O-β-D-Gal [292] was found cytotoxic towards SF-268 cell line, while 26-O-β-D-Glc 5β-furost-20(22),25(27)-diene-3β,12β,26-triol 3-O-β-D-Glc-(1 → 2)-O-β-D-Gal [293] showed cytotoxicity towards SF-268 and NCI-H460 cell lines (Chen et al. 2009).

The differences in activity between compounds having the same aglycone but differing in sugar chain was observed by Zolfaghari et al. (2013). The equilibrated mixture of furostanols: vavilosides A1/A2–B1/B2 [355–358] and ascalonicosides A1/A2 [217, 218] isolated from A. vavilovii were tested against cell lines: J-774 and WEHI-164. The activity of all saponins was dose-dependent and varied in the following order: vavilosides B1/B2 > ascalonicosides A1/A2 > vavilosides A1/A2 (Zolfaghari et al. 2013). The substitution of a galactose residue (vavilosides A1/B2) with a xylose unit (vavilosides B1/B2) caused an increase in cytotoxic activity.

Antifungal activity

Numerous steroidal saponins isolated from different plant sources have been reported to have antifungal/antiyeast activity, particularly against agricultural pathogens. Antifungal saponins require particular attention as there is a constant need for new agents that would be effective against opportunistic fungal infections and could provide an alternative to chemical fungicides used in the fight against plant pathogens. Unfortunately, only a few studies have been performed so far on Allium steroidal glycosides.

Antifungal activity of Allium saponins was modulated by both the sapogenin type and the number and structure of the sugar residue. Generally saponins with spirostanol skeleton exhibited higher antifungal activity than furostanols. Yu et al. (2013) observed several biochemical changes which could be involved in the possible mechanism of antimicrobial activity of saponins, such as reduced glucose utilization rate, decrease of catalase activity and protein content in microorganisms.

The results from in vitro assays against different plant and human pathogen strains are provided in Table 5 of ESM.

Studies by Barile et al. (2007), Lanzotti et al. (2012a, b), and Sadeghi et al. (2013) provide evidence for significant differences in the potency of saponins belonging to furostan or spirostan groups. Minutosides A-C [295, 119, 296] (A. minutiflorum) showed concentration-dependent antifungal activity against a number of pathogens: Alternaria alternata, A. porri, B. cinerea, Fusarium oxysporum, F. solani, Pythium ultimum, R. solani, Trichoderma harzianum P1, T. harzianum T39 (Barile et al. 2007). The most pronounced effect was seen with a spirostanol minuto-side B [119], as compared to both furostanols (minutosides A [295] and C [296]). Persicosides A [120] and B [121]—compounds isolated from A. amapeloprasum ssp. persicum, showed a statistically significant activity against P. italicum, A. niger and T. harzianum, higher than furostanol and cholestan compounds (Sadeghi et al. 2013). The antifungal activity of isolated compounds against B. cinerea was not significant. Interestingly, all saponins inhibited the growth of P. italicum. Antifungal properties of persicosides A [120] and B [121], ceposides A1/A2 [209, 210], tropeosides A1/A2 [213, 214] and B1/B2 [215, 216] were dose dependent. Ceposides A-C [209, 232, 211] (isolated from A. cepa) showed antifungal activity, dependent on their concentration and the fungal species used: soil-borne pathogens (Fusarium oxysporum sp. lycopersici, Rhizoctonia solani and Sclerotium cepivorum), air-borne pathogens (A. alternata, A. niger, B. cinerea, Mucor sp., and Phomopsis sp.), antagonistic fungi (Trichoderma atroviride and T. harzianum), and a pathogen specific to the Allium genus—S. cepivorum (Lanzotti et al. 2012b). Their activity varied in the following order: cepside B > cepside A ~ cepside C. The authors observed a significant synergism of action between those three saponins against B. cinerea and T. atroviride. Cepside B [232] showed significant activity against all fungi with the exception of F. oxysporum sp. lycopersici, S. cepivorum and R. solani. Ceposides A [209] and C [211] were active against all fungi with the exception of A. niger, S. cepivorum and F. oxysporum sp. lycopersici. Agigenin 3-O-trisaccharide [90] and gitogenin 3-O-tetrasaccharide [73], isolated from the bulbs of A. sativum var. Voghera, were more active against B. cinerea and T. harzianum than furostanol.
voghiertosides isolated from that plant (Lanzotti et al. 2012a). All the compounds were effective towards T. harzianum in a dose dependent manner, but only spirostanol saponins and voghiertoside C [323, 324]—against A. cinerea.

Mskhiladze et al. (2008a) in their studies on anti-

yeast effects of saponins from A. leucanthum observed that β-chlorogenin as aglycone and the branched oligosaccharide chain substituted by xylose rather than glucose are beneficial for the activity. Yayoisaponin C [95], eruboside B [79], aginoside [93], agigenin 3-O-β-D-Glc-(1→2)-O-β-D-Glc-(1→4)-O-β-D-Gal [91] and β-chlorogenin 3-O-β-D-Glc-

(1→2)-[β-D-Xyl-(1→3)]-O-β-D-Glc-(1→4)-O-

β-D-Gal [80] exhibited antifungal activity on several Candida strains, including C. albicans, C. tropicalis, C. parapsilosis, C. glabrata, C. kefyr, C. krusei, C. lusitaniae, and also on Cryptococcus neoformans, however β-chlorogenin glycoside was the most active compound with MFC from ≤6.25 to 25 μg/mL (as compared to amphotericin B 0.78–12.5 μg/mL). In another study the same compound isolated from A. porrum showed antifungal activity towards Fusarium culmorum (ED50 = 30 μg/mL) (Carotenuto et al. 1999). Eruboside B [79] (A. sativum), β-chlorogenin glycoside as well, inhibited in vitro the growth of C. albicans (MIC 25 μg/mL) (Matsuura et al. 1988).

Agigenin glycosides: aginoside [93] together with yayoisaponins A [96] and C [95] isolated from A. ampeoprasum showed antifungal activity against Mortierella ramanniana at 10 μg/disc (Sata et al. 1998). None of the saponins was active against Penicillium chrysogenum at concentrations up to 100 μg/disc. Ampeloside Bs1 [90], agigenin 3-O-β-

D-Glc-(1→4)-O-β-D-Gal [87], and furostane-type ampeloside Bf1 [202] isolated from the same species did not inhibit the growth of Aspergillus niger; spirostanols showed weak activity against Candida albicans (Morita et al. 1988). Aginoside [93] at 400 ppm completely inhibited the growth of C. gloeosporioides, Fusarium verticilloides, and Botrytis cinerea with partially suppressed F. oxysporum f. sp. cepae and F. oxysporum f. sp. radicis-lycopersici (Mostafa et al. 2013). The influence of the structure of the sugar chain on the observed anti-fungal activity of compounds bearing the same aglycone was revealed in studies by Teshima et al. (2013).

Alliospirosides A [169] and B [170] (both (25S)-ruscogenin glycosides), which are present mainly in the basal plates and roots of A. cepa Aggregatum group, to a different extent inhibited in vitro a wide range of plant pathogenic fungi: Alternaria spp., Botrytis spp., Colletotrichum spp., Curvularia lunata, Epicoccum nigrum, Fusarium spp., Magnaporthe oryzae, S. cepivorum, and Thanatephorus cucumeris (Teshima et al. 2013). Alliospiroside A [169] strongly inhibited (>80% growth inhib.) the growth of Colletotrichum spp. isolates. It was also more effective against M. oryzae and S. cepivorum compared to alliospiroside B [170], however, its antifungal activity against A. cinerea, F. oxysporum and F. solani was relatively low.

Enzyme inhibitory properties

Saponin fraction isolated from the methanol extract of A. chinense inhibited cAMP PDE (43.5 %) and Na+/K+-ATP-ase (59.3 %) at the concentration of 100 μg/mL (Kuroda et al. 1995). Both enzymes were also inhibited by (25R,S)-5α-spirostane-3β-ol tetrasaccharide [65, 110] (IC50 7.0 × 10−5 and 4.0 × 10−5 M respectively). Laxogenin glycosides exhibited significant activity only on cAMP phosphodiesterase, one of which, with an acetyl group in the saccharide moiety, was almost as potent as papaverine used as a positive control (IC50 3.3 × 10−5 and 3.0 × 10−5 M respectively).

Also, saponins isolated from A. giganteum bulbs inhibited cAMP phosphodiesterase (Mimaki et al. 1994) and in concordance with previously cited results, an acetyl derivative—3-O-acetyl-(24S,25S)-5α-spirostane-2α,3β,5α,6β,24-pentaol 2-O-β-D-Glc [193] exhibited inhibitory activity almost equal to that of papaverine (IC50 4.1 × 10−5 and 3.0 × 10−5 M respectively). In the same study, furostane saponins were revealed to be much more potent than the corresponding spirostanol glycosides. The results were in contrast to the previous studies of these authors which showed that furostanol glycosides were less active, exhibiting only weak inhibitory activity or none. The authors concluded that the anti-enzyme activity could be dependent on the number of hydroxyls in the A and B rings as in the present study the tested furostanol saponins contained several OH groups.

Saponins isolated from the fruits of A. karataviense and A. cepa as well as the products of chemical modifications of karatavioid A, were studied on a
highly purified porcine kidney Na⁺/K⁺-ATP-ase, in the concentration range from 1 × 10⁻⁴ to 1 × 10⁻⁷ M (Mirsalikhova et al. 1993). All the compounds affected the enzyme activity being capable of its inhibition, and/or activation. As was showed, the presence of a hydroxyl group in the F-ring at C-24 led to a decrease in the percentage inhibition of Na⁺/K⁺-ATP-ase. At the concentration of 1 × 10⁻⁴ M the inhibitory effect of karatavioside A [151] was 19.8 %, karatavioside B [152]—32.4 %, karatavioside C [268]—4.9 %, karatavioside E [180]—1.7 %, karatavioside F [181]—7.5 %, alliospiroside A [169]—99.7 %, alliospiroside B [170]—76.3 %, alliospiroside D [179]—67.1 %; while alliospiroside C [178] activated the enzyme by 13.4 %. A keto group at C-6 of sapogenin slightly increased the inhibition level of Na⁺/K⁺-ATP-ase.

Moreover, it was revealed that alliospiroside A [169] and B [170] were both uncompetitive enzyme inhibitors, while alliospiroside D [179]—competitive. Interestingly, alliospiroside C [178], although bearing the same aglycone as alliospiroside D—cepalogenin [44], did not inhibit Na⁺/K⁺-ATP-ase at all.

Drugs acting via inhibition of the activity of this transport enzyme may be of potential use in the treatment of many diseases of the cardiovascular system, the kidneys, the immune system, which are connected with disturbances in the active transport of ions.

Cardioprotective activity

Three saponins from A. chinense and their aglycones were tested for the protective effects against oxidative stress-induced cardiac damage (Ren et al. 2010). Their activities were evaluated on H₂O₂-injured cardiac H9C2 cells. The cytotoxicity was measured using MTT assay while the oxidative damage by determination of MDA and NO contents. All tested compounds protected cultured H9C2 cells from death in the concentration range of 5–20 μM. It was shown that glycosides exhibited less protective efficacy than sapogenins. Among these, laxogenin [6] and tigogenin [1] displayed stronger effects than furostane-type aglycones. The authors concluded that the presence of F ring in spirostanols may enhance their protective activity whereas oxidation in the B ring might be detrimental as laxogenin was less active than tigogenin.

Nine furostane saponins isolated by Lai et al. from A. fistulosum were tested for antihypoxic activity against hypoxia/reoxygenation (H/R)-induced human umbilical vein endothelial cell (HUVEC) injury (Lai et al. 2010). Cell viability was determined by MTT assay. It was observed that the saponin treatment significantly improved the survival of H/R-treated HUVEC (P < 0.05) in a dose-dependent manner. Fistulosaponin A [250] was the most effective compound with a cell viability of 59.5 ± 3.0, 76.3 ± 3.3, 80.1 ± 3.6, 82.7 ± 4.1, 86.3 ± 4.6, and 78.2 ± 2.8 % for the six dose groups (0.5, 1, 5, 10, 50, and 100 μM), respectively.

In animal studies, alloside B [334], isolated from fruits of A. suvorovii and A. stipitatum, exhibited a statistically reliable hypotriglyceridemic activity in experimental hyperlipidemia caused by 1-day starvation, Triton WR-1339 and vitamin D₂—cholesterol, when compared with lipanthyl (Aizikov et al. 1995).

The hypocholesterolemic activity of saponins was reported in many animal studies.

The cholesterol-lowering effect of garlic is probably partially due to the steroid saponin presence. In a rat model of experimental hyperlipidemia induced by feeding a 0.5 % cholesterol-enriched diet saponin-rich fraction from raw garlic administrated at 10 mg/kg/day led to a decrease of plasma total and LDL cholesterol concentration level without affecting HDL cholesterol levels after 16 weeks (Matsuura 2001). It was claimed that the reduction of concentration of plasma cholesterol concentration is the result of inhibition of cholesterol absorption by saponins in the intestine or a direct effect on cholesterol metabolism.

Antispasmodic effect

Furostanol saponins hirtifoliosides C1/C2 [264, 265] and a spirostanol glycoside agapanthagenin 3-O-Glc [85] isolated from A. hirtifolium, along with four saponins elburzensosides A1/A2 [238, 239] and C1/C2 [242, 243] and the sapogenin agapanthagenin [31], from A. elburzense, were subjected to biological assays on the guinea-pig isolated ileum in order to evaluate their possible antispasmodic activity (Barile et al. 2005). Apart from the agapanthagenin glycoside, all the tested compounds were able to reduce induced contractions, as measured by the reduction of histamine release, in a concentration-dependent manner.
Elburzensosides C1/C2 [242, 243] and agapanthage-nin [31] showed the highest activity with a maximum effect at $10^{-5}$M (approx. 50 % inhibition).

The authors concluded that the positive effect is associated with the presence of a hydroxyl group at position C-5 and of a glucose unit at position C-26. On the other hand, hydroxylation at C-6 and glucose attachment at C-3 seem to be structural features responsible for the loss of activity. Furostane-type saponins that were isolated from A. cepa var. tropea, namely tropeosides A1/A2 [213, 214] and B1/B2 [215, 216] were able to dose-dependently relieve acetylcholine- and histamine-induced contractions (50 % inhibition of contractions was seen at the concentration of $10^{-5}$ M) (Corea et al. 2005). Interestingly, other furostanols identified in this plant, such as asclonicosides A1/A2 [217, 218], were inactive.

Other activities

Macrostemonoside A [65] inhibited ADP-induced rabbit erythrocyte aggregation with $IC_{50} = 0.065$ mM (Peng et al. 1992). An in vitro inhibitory activity of ADP-induced platelet aggregation was also reported for macrostemonosides E [272], F [273] and G [274] ($IC_{50} = 0.417; 0.020; 0.871$ mM, respectively) (Peng et al. 1993, 1995). 26-O-β-d-Glc (25R)-5α-furostane-3β,12β,22,26-tetrol 3-O-β-d-Glc-(1 → 2)-[β-d-Glc-(1 → 3)]-O-β-d-Glc-(1 → 4)-O-β-d-Gal [289] and 26-O-β-d-Glc (25R)-5α-furostane-3β, 12α,22,26-tetrol 3-O-β-d-Glc-(1 → 2)-[β-d-Glc-(1 → 3)]-O-β-d-Glc-(1 → 4)-O-β-d-Gal [290] exhibited significant inhibitory activity on CD40L expression on the membrane of ADP stimulated platelets (Chen et al. 2010).

β-chlorogenin 3-O-β-d-Glc-(1 → 2)-[β-d-Glc-(1 → 3)]-O-β-d-Gal 6-O-β-d-Glc [78], isolated from the bulbs of A. ampeloprasum var. porrum, demonstrated in vivo antiinflammatory and gastroprotective effects in a carrageenan-induced oedema assay and by measuring acute gastric lesions induced by acidified ethanol (Adão et al. 2011a). Saponin administrated orally (100 mg/kg) inhibited oedema formation similar to dexamethasone (25 mg/kg). Cytoprotective activity of β-chlorogenin glycoside resulted in a significant reduction in gastric hyperemia and also in the severity and number of lesions.

Macrostemonoside A [65] increased the synthesis and release of visfatin in 3T3-L1 adipocytes and elevated mRNA levels in this cytokine in a dose- and time-dependent mode (Zhou et al. 2007). In a study on C57BL/6 mice fed on a high-fat diet, this saponin when administered at the dose of 4 mg/kg/day for 30 days moderately inhibited glucose level, glycogen hepatic content, total plasma cholesterol level and abdominal adipose tissue (Xie et al. 2008).

In the molluscidal bioassay with Biomphalaria pfeiferei diosgenin 3-O-β-d-Glc-(1 → 4)-[β-d-Glc-(1 → 6)]-O-β-d-Glc-(1 → 4)-O-α-L-Rha-(1 → 4)-[α-L-Rha-(1 → 2)]-O-β-d-Glc [146], isolated from A. vineae, exhibited 100 % effect at 25 ppm in <24 h (Chen and Snyder 1989). The authors observed that the molluscicidal activity of isolated compounds increased with an increasing number of monosaccharides in a sugar moiety.

Aginoside [93] was found to be toxic to leek-moth larvae Acrolepiopsis assectella (Harmatha et al. 1987). The compound caused mortality and ecdisial failures 56 ± 10 and 19 % respectively in larvae of A. assectella reared on semisynthetic diet at a concentration of 0.9 mg/g of diet.

Conclusions

In this paper steroidal saponins reported in various Allium species from early 1970 to March 2014 are reviewed, including their skeletal structures and sugar chains.

Until now, as many as 290 saponins have been identified, including a certain number of methoxyl derivatives originating from furostanol compounds, that should be considered as artifacts resulting from the use of methanol in the extraction/isolation procedures.

Allium genus is characterized by a great diversity of structures. Apart from spirostane- and furostane-type compounds, a rare group of open-chain saponins has been identified in several species. Allium genus is also a source of unique steroidal sapogenins, such as 25(5)-5β-spirostane-1β,3β-diol [8] and 2,3-seco-porrigentin [64]. Despite a relatively low content of steroidal glycosides in Allium species, they are considered to contribute, in addition to sulfur compounds, to the overall biological activity of these plants. Undoubtedly, stability of saponins is their advantage as compared to fairly unstable sulfur compounds, thus, they in fact may be predominant active constituents of Allium products. Bearing this aspect in mind it seems
highly feasible to develop antifungal Allium preparations against animal and plant pathogens. Also, reports on high in vitro cytotoxic activity of steroidal saponins from Allium species makes them potential candidates for further development as anti-cancer agents.

Open Access This article is distributed under the terms of the Creative Commons Attribution License which permits any use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

References

Ada˜o CR, Da Silva BP, Parente JP (2011a) A new steroidal saponin with antiinflammatory and antulcerogenic properties from the bulbs of Allium ampeloprasum var. porrum. Fitoterapia 82:1175–1180
Ada˜o CR, Da Silva BP, Parente JP (2011b) A new steroidal saponin from Allium ampeloprasum var. porrum with antiinflammatory and gastroprotective effects. Phytochem Lett 4(3):306–310
Ada˜o C, Da Silva B, Tinoco L et al (2012) Haemolytic activity and immunological adjuvant effect of a new steroidal saponin from Allium ampeloprasum var. porrum. Chem Biodivers 1(1):58–67
Aizikov MI, Kravets SD, Prokhorova IR et al (1995) Structure and hypolipidemic activity of alliocide B extracted from anzu onions. Pharm Chem J 29(8):547–548
Akhov LS, Musienko MM, Picante E et al (1999) Structure of steroidal saponins from underground parts of Allium nutans L. J Agric Food Chem 47:3193–3196
Amagase H (2006) Clarifying the real bioactive constituents of garlic. J Nutr 136(3):716S–725S
APG (2009) An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. Bot J Linn Soc 161:105–121
Azarkova AF, Glyzina GS, Melnikova TM et al (1974) Diosgenin from Allium angulosum. Chem Nat Comp 10(3):412
Azarkova AF, Stikhin VA, Cherkasov OA et al (1983) Diosgenin from Allium triquetrum and Allium cernuum. Chem Nat Comp 19(5):621
Baba M, Ohmura M, Kishi N et al (2000) Saponins isolated from Allium chinense G. Don and antitumor-promoting activities of isoliquiritigenin and laxogenin from the same drug. Biol Pharm Bull 23(5):660–662
Barile E, Zolfaghari B, Sajjadi SE et al (2004) Saponins of Allium elburzense. J Nat Prod 67:2037–2042
Barile E, Capasso R, Izzo AA et al (2005) Structure–activity relationships for saponins from Allium hirtifolium and Allium elburzense and their antispasmodic activity. Planta Med 71(11):1010–1018
Barile E, Bonanomi G, Antignani V et al (2007) Saponins from Allium minutiflorum with antifungal activity. Phytochemistry 68:596–603
Carotenuto A, Fattorusso E, Lanzotti V et al (1997a) Porrigenins A and B, novel cytotoxic and antiproliferative sapogenins isolated from Allium porrum. J Nat Prod 60(10):1003–1007
Carotenuto A, Fattorusso E, Lanzotti V et al (1997b) 12-keto-porrigenin and the unique 2,3-seco-porrigenin, new antiproliferative sapogenins from Allium porrum. Tetrahedron 53(9):3401–3406
Carotenuto A, Fattorusso E, Lanzotti V et al (1999) Spirostanol sapogenins of Allium porrum L. Phytochemistry 51:1077–1082
Challinor VL, De Voss JJ (2013) Open-chain steroidal glycosides, a diverse class of plant sapogenins. Nat Prod Rep 30:429–454
Chen S, Snyder JK (1989) Diosgenin-bearing, molluscicidal saponins from Allium vineale: an NMR approach for the structural assignment of oligosaccharide units. J Org Chem 54:3679–3689
Chen HF, Wang NL, Sun HL et al (2006) Novel furostanol sapogenins from the bulbs of Allium macrostemon B. and their bioactivity on [Ca2+] increase induced by KCl. J Asian Nat Prod Res 8(1–2):21–218
Chen H, Wang G, Wang N et al (2007) New furostanol sapogenins from the bulbs of Allium macrostemon Bunge and their cytotoxic activity. Pharmazie 62(7):544–548
Chen H-F, Wang G-H, Luo Q et al (2009) Two new steroidal sapogenins from Allium macrostemon Bunge and their cytotoxicity on different cancer cell lines. Molecules 14:2246–2253
Chen H, Ou W, Wang G et al (2010) New steroidal glycosides isolated as CD40L inhibitors of activated plateletes. Molecules 15:4589–4598
Cheng S-B, Wang Y, Zhang Y-F et al (2013) Steroidal sapogenins from Allii macrostemonis bulbs. Chin Tradit Herb Drugs 44(9):1078–1081
Chinchardze DG, Kelginbaev AN, Gorovits MB et al (1979) Steroidal saponins and sapogenins of Allium. XV. Eruboside B from Allium erubescens. Khim Prir Soedin 4:509–514
Corea G, Fattorusso E, Lanzotti V (2003) Saponins and flavonoids of Allium triquetrum. J Nat Prod 66(11):1405–1411
Corea G, Fattorusso E, Lanzotti V et al (2005) Antispasmodic sapogenins from bulbs of red onion, Allium cepa L. var. tropea. J Agric Food Chem 53:935–940
Do JC, Jung KY, Son KH (1992) Steroidal sapogenins from subterranean part of Allium fistulosum. J Nat Prod 55:168–172
Eristavi LI, Gorovits MB, Abubakirov NK (1973) Steroid sapogenins of Allium waldsteinii. Chem Nat Comp 9:124
Fattorusso E, Lanzotti V, Magno S et al (1998) Sapogenins of Allium porrum L. J Agric Food Chem 46:4904–4908
Fattorusso E, Lanzotti V, Tagliaferata-Scafati O et al (2000) Cytotoxic saponins from bulbs of Allium porrum L. J Agric Food Chem 48(8):3455–3462
Fattorusso E, Iorizzi M, Lanzotti V (2002) Chemical composition of shallot (Allium ascalonicum Hort.). J Agric Food Chem 50(20):5686–5690
Gorovits MB, Khristulas FS, Abubakirov NK (1971) Alliogenin and alliogenin B-D-glucopyranoside from Allium giganteum. J Nat Prod Comp 7(4):412–417
Gorovits MB, Khristulas FS, Abubakirov NK (1973) Steroid sapogenins and sapogenins of Allium IV. Karatavigenin—a new sapogenin from Allium karataviense. Chem Nat Comp 9(6):715–717
Güclü-Üstündag Ö, Mazza G (2007) Saponins: properties, applications and processing. Crit Rev Food Sci Nutr 47(3):231–258
Gugunishvili DN, Eristavi LI, Gvazava LN et al (2006) Steroidal saponins from Allium waldsteinii. Chem Nat Comp 42(4):499–500
Harmatha J, Mauchamp B, Arnault C et al (1987) Identification of a spirostane-type saponin in the flowers of leek with inhibitory effects on growth of leek-moth larvae. Biochem Syst Ecol 15(1):113–116
He X, Qiu F, Shoyama Y et al (2002) Two new steroidal saponins from “Gualou-xiebai-baiju-tang” consisting of Fructus Trichosanthis and Bulbus Allii macrostemon. Chem Pharm Bull 50(5):653–655
Huang S, Mao R, Ma Z (2009) A new steroidal saponin from the tubers of Allium tuberosum. Food Chem 125(2):447–455
He X, Qiu F, Shoyama Y et al (2002) Two new steroidal saponins from “Gualou-xiebai-baiju-tang” consisting of Fructus Trichosanthis and Bulbus Allii macrostemon. Chem Pharm Bull 50(5):653–655
Hu G, Mao R, Ma Z (2009) A new steroidal saponin from the tubers of Allium tuberosum. Food Chem 125(2):447–455
Hu G, Lu Y, Yu W et al (2014) A steroidal saponin from the seeds of Allium tuberosum. Chem Nat Comp 49(6):1082–1086
Ikedo T, Tsumagari H, Okawa M et al (2004) Pregnane- and furostan-type oligoglycosides from the seeds of Allium tuberosum. Chem Pharm Bull 52:142–145
Inoue T, Mimaki Y, Sashida Y et al (1995) Steroidal glycosides from Allium macleanii and A. senescens, and their inhibitory activity on tumor promoter-induced phospholipid metabolism of HeLa cells. Phytochemistry 40(2):521–525
Ismailov AI, Aliev AM (1976) Determination of steroid sapogenins in Allium albiflorus of Azerbaijan (Russian). Farmatsiya 25(2):17–20
Ismailov AI, Tagiev SA, Rasulov EM (1976) Steroidal saponins and sapogenins from Allium rubellum and A. albiflorum. Khim Prir Soedin 6(4):489
Itakura Y, Ichikawa M, Mori Y et al (2001) How to distinguish garlic from the other Allium vegetables. J Nutr 131(3):963S–967S
Jabrane A, Ben Jannet H, Miyamoto T et al (2011) Spirostane and cholestanol glycosides from the bulbs of Allium nigrum L. Food Chem 125(2):447–455
Jiang Y, Wang N-L, Yao X-S et al (1998) Structural elucidation of the anticoagulation and anticancerous constituents from Allium chinen se. Yao Xue Xue Bao 33(5):355–361
Jiang Y, Wang N-L, Yao X-S et al (1999) Steroidal saponins from the bulbs of Allium chinen se. Stud Plant Sci 6(C):212–219
Jung K-Y, Do J-C, Son K-H (1993) The structures of two diosgenin glycosides isolated from the subterranean parts of Allium fistulosum. J Korean Soc Food Nutr 22(3):313–316
Kang L-P, Liu Z-J, Zhang L et al (2007) New furostanol saponins from Allium ascalonicum L. Magn Reson Chem 45:725–733
Kawashima K, Mimaki Y, Sashida Y (1991a) Steroidal saponins from Allium giganteum and A. aflatunense. Phytochemistry 30(9):3063–3067
Kawashima K, Mimaki Y, Sashida Y (1991b) Schubertosides A-D, new (22S)-hydroxycholestane glycosides from Allium schubertii. Chem Pharm Bull 39:2761–2763
Kawashima K, Mimaki Y, Sashida Y (1993) Steroidal saponins from the bulbs of Allium schubertii. Phytochemistry 32(5):1267–1272
Kelginbaev AN, Gorovits MB, Khamidkhozdbaev SA et al (1973) Steroid saponins of Allium V. Neoagigenin from Allium giganteum. Chem Nat Comp 9:416
Kelginbaev AN, Gorovits MB, Abubakirov NK (1974) Steroid saponins and sapogenins of Allium VII. The structure of neoagigenin and agigenin. Chem Nat Comp 10:829–830
Kelginbaev AN, Gorovits MB, Abubakirov NK (1975) Steroid saponins and sapogenins of Allium VIII. Structure of gantogenin. Chem Nat Comp 11(4):546–547
Kelginbaev AN, Gorovits MB, Gorovits TT et al (1976) Steroidal saponins and sapogenins of Allium IX. The structure of aginoside. Chem Nat Comp 12(4):422–427
Kereselidze EV, Pkheidze TA, Kemertelidze EP (1970) Diosgenin from Allium albiflorum. Khim Prir Soedin 6(3):378
Khristulas FS, Gorovits MB, Luchanskaya VN et al (1970) A new steroidal sapogenin from Allium giganteum. Khim Prir Soedin 6(4):489
Khristulas FS, Gorovits MB, Abubakirov NK (1974) Steroid saponins and sapogenins of Allium VI. The 3-O-β-D-glucopyranoside of karatvigenin B. Chem Nat Comp 10(4):544–545
Kim CM, Son KH, Kim SH et al (1991) Steroidal sapogenin content in some domestic plants. Arch Pharm Res 14(4):305–310
Kinya PY, Degtyareva LP (1989) Steroid glycosides of garden onion seeds. Structure of ceposide D. Chem Nat Comp 25:124–125
Kravets SD, Vollerner YS, Gorovits MB et al (1986a) Steroids of the spirostan and furostan series from plants of the genus Allium. XXVI. Alliogenin, anzuzogenin D and karataviosides A and B from Allium suvorovii and A. stipitatum. Chem Nat Comp 30(3):408–409
Kravets SD, Vollerner YS, Gorovits MB et al (1986b) Steroids of the spirostan and furostan series from plants of the genus Allium. XXI. Structure of alliospioside A and alliofuroside A from Allium cepa. Chem Nat Comp 22(2):174–181
Kravets SD, Vollerner YS, Gorovits MB et al (1987) Steroids of the spirostan and furostan series from plants of the genus Allium. XXII. The structure of alliospioside B from Allium cepa. Chem Nat Comp 22(5):553–556
Kravets SD, Vollerner YS, Shashkov AS et al (1987) Steroids of the spirostan and furostan series from plants of the genus Allium. XXIII. Structure of cepagenin and of alliospiosides C and D from Allium cepa. Chem Nat Comp 23(6):700–706
Kravets SD, Vollerner YS, Gorovits MB et al (1990) Steroids of the spirostan and furostan series from plants of the genus Allium. Chem Nat Comp 26(4):359–373
Krokhmaluk VV, Kinya PY (1976a) Steroidal saponins of the spirostan and furostan series from plants of the genus Allium. The structure of alliosimoside D and E from Allium naccissiflorum. Chem Nat Comp 12(2):165–168
Krokhmaluk VV, Kinya PY (1976b) Steroid saponins X. Glycosides of Allium naccissiflorum. The structure of glycosides A and B. Chem Nat Comp 12(1):46–48
Kuroda M, Mimaki Y, Kameyama A et al (1995) Steroidal saponins from Allium chinense and their inhibitory activities on cyclic AMP phosphodiesterase and Na’K’-ATPase. Phytochemistry 40(4):1071–1076
Lai W, Wu Z, Lin H et al (2010) Anti-ischemia steroidal saponins from the seeds of *Allium fistulosum*. J Nat Prod 73:1053–1057

Lai W, Yang YB, Li X et al (2012) New steroidal sapogenins from the acid hydrolysis product of the whole glycoside mixture of Welsh onion seeds. Chin Chem Lett 23(2):193–196

Lanzotti V (2005) Bioactive saponins from *Allium* and *Aster* plants. Phytochem Rev 4:95–110

Lanzotti V (2012) Bioactive polar natural compounds from garlic and onions. Phytochem Rev 11(2–3):179–196

Lanzotti V, Barile E, Antignani V et al (2012a) Antifungal saponins from bulbs of garlic, *Allium sativum* L. var. Voghera. Phytochemistry 78:126–134

Lanzotti V, Romano A, Lanzuise S et al (2012b) Antifungal saponins from bulbs of white onion, *Allium cepa* L. Phytochemistry 74:133–139

Lanzotti V, Scala F, Bonanomi G (2014) Compounds from *Allium* species with cytotoxic and antimicrobial activity. Phytochem Rev. doi: 10.1007/s11101-014-9366-0

Lazurevski GV, Krokhmalyuk VV, Kintya PK (1975) Structure of steroidal glycosides of *Allium narcissiflorum*. Dokl Akad Nauk SSSR 221:744

Lee KT, Choi JH, Kim DH et al (2001) Constituents and the antitumor principle of *Allium victoriae* var. platyphyllum. Arch Pharm Res 24(1):44–50

Li Q-Q, Zhou S-D, He X-J et al (2010) Phylogeny and biogeography of *Allium* (Amaryllidaceae: Allieae) based on nuclear ribosomal internal transcribed spacer and chloroplast rps16 sequences, focusing on the inclusion of species endemic to China. Ann Bot 106:709–733

Ma Q, Luo J, Kong L (2011) Preparative isolation of steroidal sapogenins from garlic (*Allium sativum* L.) using high-speed counter-current chromatography coupled with evaporative light scattering detection. J Liq Chromatogr Relat Technol 34:1997–2007

Maisashvili MR, Eristavi LI, Gvazava LN et al (2007) Steroidal sapogenins from *Allium rotundum*. Chem Nat Comp 43(6):756–757

Maisashvili MR, Kuchukhidze DK, Gvazava LN et al (2008) Steroidal glycosides from *Allium rotundum*. Chem Nat Comp 44(4):545–547

Maisashvili MR, Kuchukhidze DK, Kolokadze VS et al (2012) Steroidal glycosides of gitogenin from *Allium rotundum*. Chem Nat Comp 48(1):86–90

Matsuura H (2001) Saponins in garlic as modifiers of the risk of cardiovascular disease. J Nutr 131(3):1000S–1005S

Matsuura H, Ushiroguchi T, Itakura Y et al (1988) A furostanol glycoside from garlic, *Allium sativum* L. Chem Pharm Bull 36(9):3659–3663

Matsuura H, Ushiroguchi T, Itakura Y et al (1989a) Further studies on steroidal glycosides from bulbs, roots and leaves of *Allium sativum* L. Chem Pharm Bull 37(10):2741–2743

Matsuura H, Ushiroguchi T, Itakura Y et al (1989b) A furostanol glycoside from *Allium chinense* G. Chem Pharm Bull 37(5):1390–1391

Mimaki Y, Kawashima K, Kamimoto T et al (1993) Steroidal glycosides from *Allium albopilosum* and *Allium ostrovskianum*. Phytochemistry 34(3):799–805

Mimaki Y, Nikaido T, Matsumoto K et al (1994) New steroidal saponins from the bulbs of *Allium giganteum* exhibiting potent inhibition of cAMP phosphodiesterase activity. Chem Pharm Bull 42(3):710–714

Mimaki Y, Satou T, Ohmura M et al (1996) Steroidal saponins from the bulbs of *Allium narcissiflorum*. Nat Med 50(4):308

Mimaki Y, Kuroda M, Fukasawa T et al (1999a) Steroidal glycosides from the bulbs of *Allium jesdianum*. J Nat Prod 62(1):194–197

Mimaki Y, Kuroda M, Sashida Y (1999b) Steroidal saponins from the bulbs of *Allium aflatunense*. Nat Med 53(2):88–93

Mimaki Y, Kuroda M, Fukasawa T et al (1999c) Steroidal saponins from the bulbs of *Allium karataviense*. Chem Pharm Bull 47(6):738–743

Mimaki Y, Yokosuka A, Kuroda M et al (2001) Cytotoxic activities and structure–cytotoxic relationships of steroidal saponins. Biol Pharm Bull 24(11):1286–1289

Mirsalikhova NM, Kravets SS, Sokolova SF et al (1993) Inhibition of highly purified porcine kidney Na, K-ATPase by steroidal glycosides of the spirostan and furostan series and a study of structure–activity relationships. Chem Nat Comp 29(4):490–497

Morita T, Ushiroguchi T, Hayashi N et al (1988) Steroidal saponins from elephant garlic, bulbs of *Allium ampeloprasum*. Chem Pharm Bull 36(9):3480–3486

Mostafa A, Sudisha J, El-Sayed M et al (2013) Aginoside sapogenin, a potent antifungal compound, and secondary metabolite analyses from *Allium nigrum* L. Phytochem Lett 6(2):274–280

Mskhiladze L, Kutchukhidze J, Chincharadze D et al (2008a) *In vitro* antifungal and antileishmanial activities of steroidal saponins from *Allium leucanatum* C.Koch a Caucasian endemic species. Georgian Med News 1(154):39–43

Mskhiladze L, Legalut J, Lavoie S et al (2008b) Cytotoxic Steroidal Saponins from the Flowers of *Allium leucanatum*. Molecules 13:2929–2934

Okanishi T, Akahori A, Yasuda F et al (1975) Steroidal sapogenins of sixteen *Liliaceae* plants. Chem Pharm Bull 23(3):575–579

Ou W-C, Chen H-F, Zhong Y et al (2012) Inhibition of platelet activation and aggregation by furostanol saponins isolated from the bulbs of *Allium macrostemon* Bunge. Am J Med Sci 344(4):261–267

Peng J, Wu Y, Yao XS et al (1992) Two new steroidal saponins from *Allium macrostemon*. Yao Xue Xue Bao 27(12):918–922

Peng J-P, Wang X, Yao XS (1993) Studies on two new furostanol glycosides from *Allium macrostemon* Bunge. Yao Xue Xue Bao 28(7):526–531

Peng J-P, Yao X, Okada Y et al (1994) Further studies on new furostanol saponins from the bulbs of *Allium macrostemon*. Chem Pharm Bull 42(10):2180–2182

Peng J-P, Yao X, Kobayashi H et al (1995) Novel furostanol glycosides from *Allium macrostemon*. Planta Med 61(1):58–61

Peng J-P, Chen H, Qiao Y-Q et al (1996a) Two new steroidal saponins from *Allium sativum* and their inhibitory effects on blood coagulability. Yao Xue Xue Bao 31(8):607–612
Vollerner YS, Abdullaev ND, Gorovits MB et al (1983b) Steroid saponins and sapogenins of Allium XIX The structure of karatavigenin C. Chem Nat Comp 19(6):699–703
Vollerner YS, Abdullaev ND, Gorovits MB et al (1984) Steroid saponins and sapogenins of Allium XX. Structure of kara-taviosides E and F. Chem Nat Comp 20:64–68
Vollerner YS, Kravets SD, Shaskov AS et al (1988a) Steroids of the spirostan and furostan series from plants of the genus Allium. Structure of anzurogenin A from Allium suvorovii and Allium stipitatum. Chem Nat Comp 24(1):58–62
Vollerner YS, Kravets SD, Shashkov AS et al (1988b) Steroids of the spirostan and furostan series from plants of the genus Allium XXV. Structure of anzurogenin B from Allium suvorovii and Allium stipitatum. Chem Nat Comp 24(2):183–186
Vollerner YS, Kravets SD, Shashkov AS et al (1989) Steroids of the spirostan and furostan series from plants of the genus Allium XXVI. Structure of anzurogenin and anzuroside from the collective fruits of Allium suvorovii and Allium stipitatum. Chem Nat Comp 25:431–435
Vollerner YS, Kravets SD, Shashkov AS et al (1991) Steroids of the spirostan and furostan series from plants of the genus Allium XXVII. Alliosterol and allulosides A and B from Allium suvorovii and Allium stipitatum—structural analogs of furostanols. Chem Nat Comp 27(2):198–207
Xie W, Zhang Y, Wang N et al (2008) Novel effects of macr-ostemonoside A, a compound from Allium macrostemon Bunge, on hyperglycemia, hyperlipidemia, and visceral obesity in high-fat diet-fed C57BL/6 mice. Europ J Pharmacol 599:159–165
Yu Z-H, Ding X-Z, Xia L-Q et al (2013) Antimicrobial activity and mechanism of total saponins from Allium chinense. Food Sci 34(15):75–80
Yuan L, Ji TF, Wang AG et al (2008) Two new furostanol saponins from the seeds of Allium cepa L. Chin Chem Lett 19:461–464
Yuan L, Ji TF, Li CJ et al (2009) Two new steroidal saponins from the seeds of Allium cepa L. J Asian Nat Prod Res 11(3):213–218
Zhou H, Yang X, Wang N-L et al (2007) Macrostemonoside A promotes visfatin expression in 3T3-L1 cells. Biol Pharm Bull 30(2):279–283
Zolfaghari B, Barile E, Capasso R et al (2006) The sapogenin atroviolcegenin and its diglycoside atroviolaceoside from Allium atroviolaceum. J Nat Prod 69:191–195
Zolfaghari B, Sadeghi M, Troiano R et al (2013) Vavilosides A1/A2-B1/B2, new furostan glycosides from the bulbs of Allium vavilovii with cytotoxic activity. Bioorg Med Chem 21(7):1905–1910
Zou Z-M, Yu D-Q, Yu D-Q et al (2001) A steroidal saponin from the seeds of Allium tuberosum. Phytochemistry 57:1219–1222