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Department of Pharmacognosy, Medical University of Lublin, Poland

SYBILLA M. ZAJDEL, KAZIMIERZ GŁOWNIAK

Penstemon – a short characteristic of the genus with a special consideration of its chemical composition and a role in ethnomedicine

Penstemon – krótka charakterystyka rodzaju ze szczególnym uwzględnieniem składu chemicznego oraz roli w etnomedycynie

GENERAL CHARACTERISTIC OF THE GENUS

Penstemons are plant species belonging to the genus *Penstemon*, which constitutes the biggest, strictly endemic genus of North America`s flowering plants, including approx. 280 species. The taxonomic affinity of the genus to the *Scrophulariaceae* family has been recently re-discussed, due to latest genetic investigations, and finally *Penstemon* has been transferred to *Plantaginaceae* [2]. Penstemons vary in size and shape, as well as in habitats, occurring in tundras, deserts, mountains, meadows etc. The area of their habitat ranges from Alaska and Canada, up to Guatemala, however most of species occur in the western part of the continent, while only 21 species were found in the East, what was probably caused by an interaction between geographic and climatic conditions. Beside of the fact that the genus is widely spread throughout the continent, penstemons are not commonly seen and additionally some species are native only to a particular state, region or even only to a specific mountain slope, what forces a need to protect them as species threatened of extinction (e.g. *P. glaucinus, P. peckii*).

The most characteristic botanical feature of penstemons are their tubular flowers with five-petal lobes, two above and three below, as well as with an open throat (apart from 2 exceptions), however the most unique feature of these plants is the presence of four fertile stamens together with an one large sterile stamen (called a staminode). In most *Penstemon* species the staminode is bearded and decorative, what gives their common name – "beardtongue". Similarly, the Latin name of the genus originates from the reference to the staminode, as "pen-stemon" means "almost staminode".

Another specific botanical feature of penstemons are opposite leaves, however there are 5 exceptions with leaves situated alternately, and also a round stem, enabling to distinguish the genus *Penstemon* from similar *Scutellaria*, which has a square stem. The flower shape depends on a species of a pollinating animal; the smallest corollas occur in penstemons pollinated only by bee-flies, big corollas are designed for bumblebees, while long and thin ones are destined to be pollinated by hummingbirds. Due to the wide variety of their flower shapes and colors (from white, through pale pink, purple and yellow, up to red and blue), penstemons are popular decorative plants and about 1500 hybrids and varieties have been created so far [13, 14].

TRADITIONAL USE IN ETHNOMEDICINE

Although species from the *Penstemon* genus are increasingly popular among gardening enthusiasts, few people know about their therapeutic properties and traditional use in ethnomedicine, as well as there is only a small number of significant studies justifying this use. The most remarkable source of knowledge about the application of penstemons as folk remedies are historical mentions of Native Americans representing various tribes, such as Teva, Lakota, Navajo, Blackfoot, Apache etc. and their customs, as well. Such sources prove that particular organs of the plants or whole plants, as well as their preparations, played an important role in ethnomedicine of the North American Continent. Apart from multiple usage of penstemons as religious or magic items, there are several mentions of their curative properties. *P. acuminatus* could be enumerated as an example of a species with multiple medicinal use among the Blackfoot tribe, e.g. a decoction of the plant was taken for stomach pain, cramps and vomiting. Likewise, *P. barbatus* played an important role in ethnomedicine of Navajo – a decoction of roots was used for menstrual pain, stomach ache and cough, while cold infusions or powdered plants were applied to burns. Similarly, poultices made from roots of this plant were applied to swellings, gun and arrow wounds, internal injuries and was a "life medicine." People from this tribe also believed that honey from flowers of *P. barbatus* sucked by pregnant women could keep a baby small for an easy labor. The people used this plant also as a veterinary aid when applied to fractured legs of sheeps [17, 25].

Another example of medicinal use of *Penstemon* species may be a Costanoan drug – *P. centranthifolius*, used as a disinfectant and dermatological aid - a poultice of the plant was applied to deep, infected sores. Poultices of crashed leaves of *P. richardsonii* were applied by Paiute people to sores, while members of Okanagan-Colville took infusions of stalks with leaves and flowers for typhoid fever. Next species, *P. laevigatus*, was a gastrointestinal remedy used by Cherokee in form of infusions for cramps, while Navajo people prepared a cold infusion from *P. jamesii* and used it as a lotion for a sore throat, as well as a cold compound infusions of the plant was taken by them for headaches caused by hunting. The plant was also applied by Navajo as an emetic and a lotion purifying newborn infants before nursing. Another representative of the genus, *P. grandiflorus*, was a drug of the Pawnee tribe that prepared decoctions of leaves for chills and fever, while Kiowa people applied a decoction of plant`s roots for stomach aches and the tribe Dakota used it for chest pains. Navajo people also found that *P. linarioides ssp. coloradoensis* may be used as a gynecological aid and they prepared decoctions of the plant to facilitate a labor and delivery of a placenta, while Kawaiisu used a poultice of mashed roots of *P. rostriflorus* as a remedy for swollen limbs [17, 25].

One of better documented medicinal usage of a *Penstemon* species concerns *P. fruticosus*. Iroquois Indians took a compound decoction of the plant as an emetic and gynecological aid - as a wash for women bothered by milk flow. Okanagan-Colville Indians of British Columbia and Washington applied infusions of plant tops for headaches, internal disorders, flu and colds, as well as a dermatological remedy (also veterinarian) for sore and itchy scalp and to bathe the skin with acne and pimples. People from this tribe placed raw roots on the tooth to relieve severe toothaches. Shuswap Indians took this plant for the bladder dysfunctions, while Indians from the tribe Thompson used a whole plant to make bathing water for rheumatism and to obtain decoctions for arthritis or any

kind of aches and sores. Thompson Indian also prepared infusions of a fresh plant and decoctions of leaves to wash sore, red eyes and used decoctions of plants as a remedy for ulcers and as poultices for broken bones. Decoctions of stems, flowers and leaves were taken by this tribe for kidney trouble and a sore back [17, 25].

Among mentions of medicinal use of penstemons by Native Americans, several species are unidentified and mentioned only as penstemon sp., however it is worth to enumerate some other curative properties of plants from the genus, to widen knowledge about it pharmacological activity profile. Therefore, people belonging to the Creek and Natchez tribes used infusions of some penstemon roots for colds, coughs and whooping cough, while Navajo prepared infusions and poultices of pounded leaves from unidentified species to rattlesnake bites [17, 25].

Nowadays, some penstemons (eg. *P. campanulatus* and *P. gentianoides*) are still used in ethnomedicine, especially by indigenous people of Mexico, as anti-inflammatory, anti-rheumatic, emollient, balsamic or laxative agents [6]. Recently, it was stated that these 2 species possess anti-inflammatory and anti-oxidant activity [6]. Another research proved that some active compounds of *P. centranthifolius* inhibits formation of bacterial biofilms created by Escherichia coli UTI89 [16], moreover it was also stated that *P. deustus* contains a cytotoxic (anti-tumor) agent – liriodendrin [12], CH_2-Cl_2-MeOH (1:1) extract from *P. linarioides* possesses a PKCR-inhibitory bioactivity [5] and that *P. barbatus* and *P. digitalis* are weakly cardiotonic plants [18].

CHEMICAL COMPOSITION

Presently a number of research dedicated to chemical composition of penstemons increases, resulting in widened knowledge about biologically active compounds possibly responsible for their curative properties, however still little is known about phytochemical profiles of particular species. In accordance with knowledge about chemical content of the family *Scrophulariaceae*, where penstemons were previously classified to, or the new one – *Plantaginaceae*, it was easily predictable that species from the genus *Penstemon* contain iridoids and their glycosides, together with monoterpens and phenylpropanoid derivatives, as the most dominant compounds, which are typical of the families. In fact, several iridoids and their glycosides were stated in extracts from various *Penstemon* species. As the most common iridoid compounds present in penstemons, aucubin, catalpol and plantarenaloside were identified, what confirmed similarity of these plants to other members of *Scrophulariaceae* and *Plantaginaceae*. Aucubin was isolated from at least 10 species, among which *P. fruticosus* and *P. fruticosus spp. fruticosus*, together with *P. barretiae* [20], *P. albidus* [1], as well as *P. rydbergii var. rydbergii* and *P. rydbergii var. aggregatus* [3] may be mentioned as examples. The second popular iridoid, catalpol, was identified in approx. 13 species, e.g. in *P. albidus* and *P. cyathophorus* [1], *P. parryi*, *P. barrettiae*, *P. newberryi* and *P. glaber* [20]. Equally significant compound, plantarenaloside, was stated also in a number of *Penstemon* species exceeding 10, where such representatives as *P. parryi*, *P. barrettiae* [20], *P. serrulatus* [4], *P. crandallii* [11] and *P. rydbergii var. rydbergii* or *P. rydbergii var. aggregatus* [3] may be specified.

Another more frequently isolated (from at least 5 species) compounds are : 8-epihastatoside (e.g. *P. secundiflorus ssp. lavendulus*, *P. grandiflorus* [9]), β-dihydrohastatoside (e.g. *P. nitidus* [22],

P. secundiflorus [8]), cornin/verbenalin and hastatoside (both compounds in *P. secundiflorus ssp. lavendulus*, *P. grandiflorus* [9], *P. nitidus* [22]), musseanoside (e.g. *P. cardwellii*, *P. newberryi*, *P. fruticosus* [20]) and geniposidic acid (*P. barretiae* [20], *P. rydbergii var. rydbergii* and *P. rydbergii var. aggregatus* [3]). Some iridoid compounds were identified for the first time in *Penstemon* and their names refer to the genus, as pensteminoside found in *P. gentianoides* [7], penstebioside isolated from *P. richardsonii* [10], penstemide found more than once – for example in *P. serrulatus* [4] and *P. richardsonii* [10] and the most common among iridoids originally found in penstemons – penstemoside, isolated from at least 8 species (e.g. *P. cyathophorus* [1], *P. secundiflorus ssp. lavendulus*, *P. grandiflorus* [9]). The total number of iridoids and their glycosides found in penstemons exceeds 80.

Another group of active compounds which may constitute significant chemotaxonomic markers of the genus *Penstemon* are monoterpens (mainly of the open-chain type) and their glycosides, among which 5,8-dihydroxy-2,6-dimethyloctadienoic acid and 8-oxo-2,6-dimethyloctadienoic acid were identified in more than 1 species (*P. albidus, P. cyathophorus,* and *P. virens* [1]), while the presence of the others was stated in single penstemons, often for the first time, like digipenstroside [23] or penstriatoside [21], both isolated from *P. digitalis*.

As mentioned previously, the third important group of compounds found in *Penstemon* are phenylpropanoid glycosides, among which the most frequently identified is verbascoside/acteoside – its presence was stated in at least 15 species, for example *P. secundiflorus* and *P. nitidus* [8], *P.* albidus, *P. virens* and *P. cyathophorus* [1] or *P. rydbergii var. rydbergii* and *P. rydbergii var. aggregates* [3]. Another remarkable compound from this group is martynoside, stated in at least 4 species (e.g. *P. digitalis* [23] or *P. gentianoides* [7]), as well as echinacoside, e.g. isolated from *P. secundiflorus* and *P. nitidus* [8].

Apart from main groups of biologically active substances described above, there are some other compounds mentioned in literature, however they are still poorly studied in penstemons. There are only few reports about alkaloid occurrence in penstemons, mainly in *P. whippleanus* [15], where 4-noractinidine, boschniakine and carbomethoxypedicularine were stated, similarly ecdysteroids, such as 20-hydroxyecdysone, makisterone A and C, taxisterone and venustone found in *P. venustus* [19], as well as flavones – diosmetin and luteolin found in *P. gentianoides* [7]. Additionally, following phenolic acids were identified in *P. serrulatus*: benzoic, cinnamic, ferulic, gentisic, caffeic, *p*-hydroxybenzoic, *p*-coumaric, protocatechuic, salicylic, sinapic and vanillic [24].

Considering a wide range of colors occurring in flowers of penstemons, especially several tints of blue, it is worth to mention the presence of anthocyanins in these plants. It was stated that flowers of several *Penstemon* species contain cyanidin, delphinidin and pelargonidin glycosides [30]. Sources describing customs of Native Americans from the past clearly indicate popular use of penstemons with blue or blue-related colors as dyes for clothes or hunting items.

Despite the fact that quite considerable collection of data exists in sources describing past penstemon-related therapeutical customs of North America`s native inhabitants, far more research is needed to know and explain mechanisms and biologically active compounds responsible for this wide range of pharmacological properties of the *Penstemon* genus, which as long as remains undiscovered, hides a lot of possibly significant remedies that could enrich and support present therapeutic tools.

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SUMMARY

Plant species from the genus *Penstemon* are hardly known as herbal remedies which have been used for centuries in ethnomedicine by indigenous people of North America. Similarly, still little is known about the chemical composition of penstemons and main biologically active compounds responsible for a wide range of their curative properties. In this paper, both traditional use in ethnomedicine, as well as results of studies concerning phytochemical profile of the plants, is discussed.

Keywords: penstemon, ethnomedicine, iridoids, monoterpens, phenylpropanoid glycosides

STRESZCZENIE

Gatunki roślin z rodzaju *Penstemon* są słabo znane jako leki ziołowe, których od wieków używa w etnomedycynie rdzenna ludność Ameryki Północnej. Również wciąż niewiele wiadomo na temat składu chemicznego penstemonów oraz głównych ciał czynnych warunkujących ich szeroki zakres właściwości leczniczych. W niniejszym artykule omówiono zarówno tradycyjne zastosowanie tych roślin w etnomedycynie, jak również wyniki dotychczasowych badań poświeconych ich profilowi fitochemicznemu.

Słowa kluczowe: penstemon, etnomedycyna, irydoidy, monoterpeny, glikozydy fenylopropanoidowe