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# BIOLOGICAL ACTIVITY OF *S*-CONTAINING MONOTERPENOIDS

**L. E. Nikitina,[1*] N. P. Artemova,[1] V. A. Startseva,[1]**
**I. V. Fedyunina,[1] and V. V. Klochkov[2]**

S-*containing mono- and bicyclic monoterpenoids were reviewed with respect to antifungal, anti-inflammatory, anti-helicobacter, anticlotting, membrane-protective, antitumor, antimicrobial, antibacterial, antiparasitic, and antimalarial activity including establishment of structure–activity relationships.*

**Keywords:** *S*-containing monoterpenoids, biological activity.

Sulfur-containing (*S*-containing) monoterpenoids are aromatic principles of several plants and are interesting to researchers primarily for formulating fragrances for perfumes [1]. However, their contents in plant sources are miniscule and not highly varied. Menthane-type thioterpenoids, in particular, diastereomeric menthene-8-thiols and 2,8-*epi*-thio-*p*-menthanes (grapefruit, black currants) are the most well-known of them [2–6]. Convenient regio- and stereoselective synthetic methods for *S*-containing terpenoids of various structures that were developed in the last three decades have enabled broader research including studies of their biological activity and established structure–activity relationships [7, 8]. Herein, published research results on the biological activity of *S*-containing monoterpenoids are reviewed.

Comprehensive ecotoxicological studies of natural monoterpenoids, including acute toxicity tests in humans, animals, and plants, and genotoxicity tests for teratogenic toxicity and effects on reproductive functions showed that terpenes are nontoxic, do not possess mutagenic properties, and are not reproductive toxins [9, 10]. Monoterpenes of various structures and their derivatives are known to exhibit anti-inflammatory, wound-healing, and antiulcer activity [11–13] and to possess spasmolytic [14, 15] and analgesic activity [16] and antitumor and cytotoxic effects [17–23]. Several of them are characterized by antimutagenic, genotoxic [24–26], and antioxidant activity [27–29]. Antituberculosis activity is also known for monoterpenes [30]. The antimicrobial [31–34] and antifungal activity of monoterpenes and their *O*-containing derivatives [34–38] have become especially interesting in the last decades because of the increased incidence of mycotic and bacterial infections [39]. The broad spectrum of biological activity of monoterpenes was reviewed [40].

**Antifungal Activity.** As already mentioned, many monoterpenoids possess pronounced antifungal activity. However, the antifungal properties of (–)-$\beta$-pinene (**1**) and (–)-$\alpha$-pinene (**2**) are in general weak although (+)-$\alpha$-pinene (**3**) is moderately active against the fungi *Candida parapsilosis*, *Rhodotorula rubra*, *Candida krusei*, and *Penicillium chrysogenum* [34]. Pinane-type alcohols have increased antifungal activity because of their high hydrophilicity if hydroxyl-containing pinane-type compounds such as diastereomeric *cis*- and *trans*-verbenols **4**–**7** are compared with $\alpha$- and $\beta$-pinenes (**1** and **2**). Differences in the activities of *cis*- (**4** and **5**) and *trans*-verbenols (**6** and **7**) and between the corresponding enantiomers were observed. In particular, (–)-*cis*-verbenol (**4**) was highly active against *C. krusei* and *Aspergillus fumigatus*; (+)-*cis*-verbenol (**5**), moderately active against *Aspergillus niger* and *A. fumigatus*; and (+)-*trans*-verbenol (**7**), highly active against *C. albicans* and *C. parapsilosis* and moderately active against *R. rubra*, *P. chrysogenum*, *P. tardum*, and a pathogenic strain of *C. albicans*. (–)-*trans*-Verbenol (**6**) and (+)-myrtenol (**8**) possessed low antifungal activity. Thus, (+)-*trans*-verbenol (**7**) was the most active of these alcohols against both mycelial and yeast-like fungi.

1) Kazan State Medical University, 49 Butlerova St., Kazan, 420012 Russian Federation, e-mail: nikitl@mail.ru; 2) Kazan (Volga Region) Federal University, 18 Kremlevskaya St., Kazan, 420008, Russian Federation, e-mail: vladimir.klochkov@kpfu.ru. Translated from *Khimiya Prirodnykh Soedinenii*, No. 5, September–October, 2017, pp. 693–700. Original article submitted June 28, 2016.

  