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Review on the Biological Activities and Phytochemistry of the Genus *Satureja*

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Abstract: The genus of *Satureja* species belongs to the Lamiaceae family and has been used as culinary spice and condiment as well as in traditional medicine for the treatment of a variety of diseases such as gastrointestinal system disorders including cramps, nausea, indigestion, and diarrhea and respiratory system disorders, skin disorders, pain and inflammation. The genus is represented by 61 taxa worldwide, and 17 taxa are distributed in Türkiye. This paper reviews biological activity and phytochemical constituents of *Satureja* species. The related scientific and books, journals, articles and Pubmed, Scopus, Science Direct and Google Scholar databases were searched using the keyword "*Satureja*" related to the studies on the phytochemistry, secondary metabolites, essential oil, volatiles, phytochemisrty and/or biological activities were evaluated and reviewed. As a result of this current review, current data on the *Satureja* genus was assessed mainly for various biological activities. Especially the anticholinergic, anti-antioxidant, cytotoxic, antimicrobial, anti-inflammatory, analgesic/antinociceptive, larvicidal, and insecticide activities of the genus are remarkable. However, only a limited number of the current literature focused on the isolated active compounds. As a result, the genus *Satureja* presents a significant potential as a natural resource for the development of agricultural products for new pharmaceuticals, cosmetics, veterinary products, and foods of different sectors. New research and in vivo bioactivity evaluations may open new avenues for the valorisation of *Satureja* preparations especially in the health and cosmetic industries.

Keywords: *Satureja*; essential oil; carvacrol; flavonoids, phenolics, biological activity

1. Introduction

The Lamiaceae family is widespread in the world, especially in the Mediterranean region. *Satureja* L., an important genus of the Lamiaceae family, which is represented by 61 taxa worldwide. Geographically Türkiye is rich in the distribution of the genus *Satureja*, where 17 taxa are in the habitat

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with 5 endemic representations [1-3]. The genus name "*Satureja*" was derived from the Latin word "satyr". In ancient times, the genus was esteemed for both its aromatic properties and its purportedly aphrodisiac effects. The genus *Satureja* was referred to as the "herb of the satyr," alluding to the fabled being that is half man and half goat, characterized by sexual desire [4]. Consequently, its cultivation was prohibited in monasteries [5]. Some species of the *Satureja* genus from the Türkiye habitat are called "Sivri Kekik (sharp pointed thyme)" and "Taş Kekiği" (rock thyme), which are widely used where it grows in Anatolian cuisine [1, 6]. *Satureja* sp. preparations are also used for various medicinal purposes since ancient times. The aerial parts or flowers of some *Satureja* species are used in folk medicine to alleviate nausea, muscle pain, indigestion and diarrhea. It is also consumed as herbal tea for decreasing the symptoms of common cold. The biological activity of *Satureja* species, including their antimicrobial, anti-inflammatory, stimulant, diuretic, and mutagenic properties were reported [6-8].

The aim of this review is to summarize the current research on chemical composition and biological/pharmacological effects of *Satureja* species.

2. Methodology

Current literature on the genus *Satureja* was acquired by searching the books, journals, articles and websites Pubmed, Scopus, Science Direct and Google Scholar without time limitation. The database searches with the keyword "*Satureja*" was delved on the phytochemistry, essential oil, phytochemical examination and/or biological activities, but not limited to. Especially, the phytochemical and biological activity studies on *Satureja* genera from the flora of Türkiye were considered.

3. Botanical Properties and Description

The genus name *Satureja* (Family: Lamiaceae, Subfamily: Nepetoideae, Tribe: Mentheae, Altoymak: Menthinae) is derived from the Latin word "saturate/saturare" to refer to the use of the plant as food [9, 10]. The species of the genus *Satureja* are perennial plants except for one species. *Satureja* sp. generally semi-shrub, their trunks are 10-100 cm tall and have a strong woody structure at the base of the trunk (Figure 1-A, B, D).

Figure 1. A) *Satureja cuneifolia*, **B**) *S. macrantha* **C**) *S. coerulea*, **D**) *S. icarica*, **E**) *S. coerulea* **F**) *S. icarica*, **G**) *S. aintabenthis* (Photo: Prof. Dr. Tuncay Dirmenci from the private archive © 2025)

Almost all *Satureja* species are fragrant due to the aromatic terpenic content of Lamiaceae type hairs (sessile-glandular hairs) that are densely present throughout the plant. The leaves of the species are narrowly linear (Figure 1-C), obverse-ovate, narrowly lanceolate, and mostly folded from the edges to the lower surface. There are 2 or more flowers in the inflorescence (Figure 1-E, F, G). Sepals are bilabiate or regular. Petals are bilabiate (Figure 1-E, F, G). Flower color can be white, lilac, pink or pale purple (Figure 1-E, F, G). The genus *Satureja* is represented by 61 taxa worldwide [2, 10-12]. Species of the genus are distributed in the northern hemisphere, the majority in the Mediterranean basin (Southern Europe, North Africa, Morocco, Spain, Italy, Greece, Türkiye), as well as in the Balkans, southern the Caucasus, Iraq and Iran (Table 1) [2, 3, 13-16]. Türkiye is the country with the highest distribution of species with 17 taxa where 5 of are endemic) [1-3]. The species of the *Satureja* genus distributed in Türkiye are as follows: *S. aintabensis* P. H. Davis (endemic), *S. amani* P. H. Davis (endemic), *S. avromanica* Maroofi, *S. boissieri* Hausskn. ex Boiss., *S. cilicica* P. H. Davis (endemic), *S. coerulea* Janka, *S. cuneifolia* Ten., *S. hortensis* L., *S. icarica* P. H. Davis, *S. macrantha* C. A. Mey., *S. parnassica* Heldr. & Sart. ex Boiss., *S. parnassica* subsp. sipylea P. H. Davis (endemic), *S. pilosa* Velen., *S. spicigera* (K. Koch) Boiss., *S. spinosa* L., *S. thymbra* L., and *S. wiedemanniana* (Avé-Lall.) Velen. (endemic) [3]. *S. hortensis* L. and *S. montana* L. are among the common best known, which are also actually the most cultivated *Satureja* species in the world. Also, among the aforementioned species, only *S. hortensis* is cultivated in Türkiye [13].

Table 1. The distribution of the genus *Satureja* in the world [2, 3, 13-16].

Number	Species	Distribution	Endemism
1	*Satureja adamovicii* Šilic	Southeastern Europe	-
2	*Satureja aintabensis* P. H. Davis	Western Asia: Türkiye	Türkiye
3	*Satureja amani* P. H. Davis	Western Asia: Türkiye	Türkiye
4	*Satureja atropatana* Bunge	Western Asia: Iran	Iran
5	*Satureja avromanica* Maroofi	Western Asia: Iran, Türkiye	-
6	*Satureja bachtiarica* Bunge	Western Asia: Iran	Iran
7	*Satureja boissieri* Hausskn. ex Boiss.	Western Asia: Iran, Türkiye	-
8	*Satureja bzybica* Woronow	Caucasus: Transcaucasus	-
9	*Satureja cilicica* P. H. Davis	Western Asia: Türkiye	Türkiye
10	*Satureja coerulea* Janka	Western Asia: Türkiye Southeastern Europe: Bulgaria, Romania, Türkiye	-
11	*Satureja cuneifolia* Ten.	Western Asia: Iraq, Türkiye Southeastern Europe: Albania, Bulgaria, Greece, Italy, Southwestern Europe: Sardegna, Spain	-
12	*Satureja edmondi* Briq.	Western Asia: Iran	Iran
13	*Satureja fukarekii* Šilic	Southeastern Europe	-
14	*Satureja hellenica* Halácsy	Southeastern Europe: Greece	Greece
15	*Satureja hortensis* L.	Caucasus: Transcaucasus, China: Xinjiang, Middle Asia: Kazakhstan, Siberia: Altay, Western Asia: Türkiye, Indian Subcontinent: West Himalaya, Eastern Europe: Krym, Southeastern Europe: Albania, Italy	-
16	*Satureja horvatii* Šilic	Southeastern Europe: Greece	-
17	*Satureja horvatii* subsp. *horvatii*	Southeastern Europe	-

18	*Satureja horvatii* subsp. *macrophylla* (Halácsy) Baden	Southeastern Europe: Greece	Greece
19	*Satureja icarica* P. H. Davis	Western Asia: East Aegean Islands. Türkiye, Greece	-
20	*Satureja innota* (Pau) Font Quer	Southwestern Europe: Spain	Spain
21	*Satureja intermedia* C. A. Mey.	Caucasus: North Caucasus, Transcaucasus, Western Asia: Iran	-
22	*Satureja intricata* Lange	Southwestern Europe: Spain	Spain
23	*Satureja intricata* subvar. *dufourii* (G. López) R. Morales, G. López & Sánchez-Gómez	Southwestern Europe: Spain	Spain
24	*Satureja intricata* var. *gracilis* (Willk.) R. Morales, G. López & Sánchez-Gómez	Southwestern Europe: Spain	Spain
25	*Satureja intricata* var. *intricata*	Southwestern Europe: Spain	Spain
26	*Satureja isophylla* Rech.f.	Western Asia: Iran	Iran
27	Satureja kermanica *Payandeh, Bordbar & Mirtadz.*	Western Asia: Iran	Iran
28	*Satureja kermanshahensis* Jamzad	Western Asia: Iran	Iran
29	*Satureja khuzistanica* Jamzad	Western Asia: Iran	Iran
30	*Satureja kitaibelii* Wierzb. ex Heuff.	Southeastern Europe: Bulgaria, Romania	-
31	*Satureja laxiflora* K. Koch	Caucasus: North Caucasus, Transcaucasus, Western Asia: Iran, Iraq	-
32	*Satureja macrantha* C. A. Mey.	Caucasus: Transcaucasus, Western Asia: Iran, Iraq, Türkiye	-
33	*Satureja metastasiantha* Rech. f.	Western Asia: Iraq	Iraq
34	*Satureja montana* L.	Western Asia: Lebanon-Syria, Middle Europe: Austria, Southeastern Europe: Albania, Greece, Italy, Southwestern Europe: France, Spain	-
35	*Satureja montana* subsp. *macedonica* (Formánek) Baden	Southeastern Europe: Greece	Greece
36	*Satureja montana* subsp. *montana*	Middle Europe: Austria, Southeastern Europe: Albania, Greece, Italy, Southwestern Europe: France, Spain	-
37	*Satureja montana* subsp. *pisidia* (Wettst.) Šilic	Western Asia: Lebanon, Syria, Southeastern Europe	-
38	*Satureja montana* subsp. *variegata* (Host) P. W. Ball	Southeastern Europe: Albania, Italy	-
39	*Satureja mutica* Fisch. & C. A. Mey.	Caucasus: Transcaucasus, Middle Asia: Turkmenistan, Western Asia: Iran	-
40	*Satureja pallsryi* J. Thiébaut	Western Asia: Lebanon, Syria	-
41	*Satureja parnassica* Heldr. & Sartori ex Boiss.	Western Asia: Türkiye, Southeastern Europe: Greece	-

42	*Satureja parnassica* subsp. *sipylea* P.H. Davis	Western Asia: Türkiye	Türkiye
43	*Satureja parnassica* subsp. *athoa* (K. Malý) Baden	Southeastern Europe: Greece	Greece
44	*Satureja parnassica* subsp. *parnassica*	Southeastern Europe: Greece	Greece
45	*Satureja pilosa* Velen.	Western Asia: Türkiye, Southeastern Europe: Bulgaria, Greece, Italy	-
46	*Satureja rumelica* Velen.	Southeastern Europe: Bulgaria	Bulgaria
47	*Satureja sahendica* Bornm.	Western Asia: Iran	Iran
48	*Satureja salzmannii* (Kuntze) P. W. Ball	Northern Africa: Morocco, Southwestern Europe: Spain	-
49	*Satureja spicigera* (K. Koch) Boiss.	Caucasus: North Caucasus, Transcaucasus, Western Asia: Iran, Türkiye	-
50	*Satureja spinosa* L.	Western Asia: East Aegean Islands, Türkiye, Southeastern Europe: Greece	-
51	*Satureja subspicata* Bartl. ex Vis.	Middle Europe: Austria, Southeastern Europe: Albania, Bulgaria, Italy	-
52	*Satureja subspicata* subsp. *liburnica* Šilic	Southeastern Europe: Italy	-
53	*Satureja subspicata* subsp. *subspicata*	Middle Europe: Austria, Southeastern Europe: Albania, Bulgaria, Italy	-
54	*Satureja taurica* Velen.	Eastern Europe: Crimea	Crimea
55	*Satureja thymbra* L.	Northern Africa: Libya, Western Asia: Cyprus, East Aegean Islands, Lebanon, Syria, Palestine, Türkiye, Southeastern Europe: Greece, Türkiye	-
56	*Satureja visianii* Šilic	Southeastern Europe	-
57	*Satureja wiedemanniana* (Avé-Lall.) Velen.	Western Asia: Türkiye	Türkiye
58	*Satureja* × *caroli-paui* G. López	Southwestern Europe: Spain	-
59	*Satureja* × delpozoi Sánchez-Gómez, J. F. Jiménez & R. Morales	Southwestern Europe: Spain	-
60	*Satureja* × *exspectata* G. López	Southwestern Europe: Spain	-
61	*Satureja* × *orjenii* Šilic	Southeastern Europe	-

4. The Applications and Economic Importance of *Satureja* species

The *Satureja* species have many health benefits and a wide range of applications in herbal medicine as well as in culinary food. They generally used as flavoring agents in spicy sauces, sausages, soups, beverages and canned meats. In Mediterranean cuisine, it is often used as a spice for meats and fish. Additionally, the species' essential oils were utilized in the cosmetics and fragrance industries [5, 17]. The genus of *Satureja* species are used extensively in traditional medicine as a tonic, carminative, and muscle pain reliever to treat gastrointestinal system disorders including cramps, nausea, indigestion, and diarrhea. They also used to alleviate the symptoms of respiratory diseases such as asthma and coughs among other application and uses [5, 8, 18].

The total amount of commercial *Satureja* species harvested from Anatolia is estimated approximately 700-800 tons. The Mediterranean and Aegean regions are the major source locations of *Satureja* collection in Türkiye. *S. cuneifolia*, *S. thymbra*, *S. hortensis* and *S. spicigera* are collected for trade. Additionally, *S. wiedemanniana*, *S. icarica*, *S. coerulea*, *S. cilicica*, *S. boissieri*, and *S. pilosa* are collected and used as spices and herbal tea beverages from the locals of the region [13].

5. The Biological Activities of *Satureja* Genus

The biological activity studies on the genus *Satureja* were summarized the Table 2. According to the literature survey, the two most remarkable taxa in terms of number and diversity of biological activities are *S. montana* L. and *S. hortensis* L. The 22 taxon without any biological activities etc. are listed as *S. adamovicii* Šilic, *S. amani* P. H. Davis, *S. bzybica* Woronow, *S. fukarekii* Šilic, *S. hellenica* Halácsy, *S. horvatii* subsp. *horvatii, S. horvatii* subsp. *macrophylla* (Halácsy) Baden, *S. innota* (Pau) Font Quer*, S. intricata* subvar. *dufourii* (G. López) R. Morales, G. López & Sánchez-Gómez, *S. intricata* var. *gracilis* (Willk.) R. Morales, G. López & Sánchez-Gómez, *S. intricata* var. *intricata, S. pallsryi* J. Thiébaut, *S. parnassica* subsp. *sipylea* P.H. Davis, *S. parnassica* subsp. *athoa* (K. Malý) Baden, *S. rumelica* Velen., *S. salzmannii* (Kuntze) P. W. Ball, *S. subspicata* subsp. *liburnica* Šilic, *S. subspicata* subsp. *subspicata*, *S. taurica* Velen., *S.* × *caroli-paui* G. López, *S.* × *exspectata* G. López and *S.* × *orje.nii* Šilic., respectively

Table 2. The biological activities of the *Satureja* genus

Activity	Taxon	Reference
Antibacterial activity	*Satureja aintabensis* P. H. Davis	[19, 20]
	Satureja bachtiarica Bunge	[23, 24, 28, 32, 100, 133]
	Satureja boissieri Hausskn. ex Boiss.	[35, 36]
	Satureja cilicica P. H. Davis	[38]
	Satureja coerulea Janka	[35, 38]
	Satureja cuneifolia Ten.	[19, 43, 44, 162]
	Satureja edmondi Briq.	[48]
	Satureja hortensis L.	[19, 58]
	Satureja horvatii Šilic	[64]
	Satureja icarica P. H. Davis	[35]
	Satureja intermedia C. A. Mey.	[67, 100]
	Satureja isophylla Rech.f.	[70]
	Satureja kermanshahensis Jamzad	[74]
	Satureja khuzistanica Jamzad	[75, 80, 86, 133]
	Satureja kitaibelii Wierzb. ex Heuff.	[92, 93, 94, 95]
	Satureja laxiflora K. Koch	[99, 100]
	Satureja macrantha C. A. Mey.	[19, 101, 102, 103]
	Satureja metastasiantha Rech. f.	[104]
	Satureja montana L.	[43, 93, 108, 116, 128, 129, 131, 157, 162]
	Satureja montana subsp. *montana*	[109, 120]
	Satureja montana subsp. *pisidia* (Wettst.) Šilic	[114]
	Satureja montana subsp. *variegata* (Host) P. W. Ball	[120]
	Satureja mutica Fisch. & C. A. Mey.	[131, 132, 135]

Biological utliziation of the genus *Satureja*

	Satureja parnassica Heldr. & Sartori ex Boiss.	[137]
	Satureja parnassica subsp. *parnassica*	[135, 136, 137]
	Satureja pilosa Velen.	[35, 140]
	Satureja sahendica Bornm.	[141, 142, 143, 145]
	Satureja spicigera (K. Koch) Boiss.	[145, 148, 149]
	Satureja spinosa L.	[137, 156]
	Satureja subspicata Bartl. ex Vis.	[140, 158]
	Satureja thymbra L.	[19, 135, 137, 161, 164, 168]
	Satureja wiedemanniana (Avé-Lall.) Velen.	[173, 174, 175]
Antifungal activity	*Satureja aintabensis* P. H. Davis	[19]
	Satureja bachtiarica Bunge	[32, 100]
	Satureja boissieri Hausskn. ex Boiss.	[35, 36]
	Satureja cilicica P. H. Davis	[38]
	Satureja coerulea Janka	[35, 38]
	Satureja cuneifolia Ten.	[19, 43, 44, 162]
.	*Satureja hortensis* L.	[19, 85, 138]
	Satureja horvatii Šilic	[64]
	Satureja icarica P. H. Davis	[35]
	Satureja intermedia C. A. Mey.	[67, 100]
	Satureja kermanica *Payandeh, Bordbar & Mirtadz.*	[73]
	Satureja khuzistanica Jamzad	[85, 86, 89, 138]
	Satureja kitaibelii Wierzb. ex Heuff.	[94, 95]
	Satureja laxiflora K. Koch	[99, 100]
	Satureja macrantha C. A. Mey.	[19, 101, 102]
	Satureja metastasiantha Rech. f.	[100]
	Satureja montana L.	[43, 108, 116, 128, 129, 157, 162]
	Satureja montana subsp. *montana*	[109, 120]
	Satureja montana subsp. *pisidia* (Wettst.) Šilic	[114]
	Satureja montana subsp. *variegata* (Host) P. W. Ball	[120]
	Satureja mutica Fisch. & C. A. Mey.	[130]
	Satureja pilosa Velen.	[35]
	Satureja sahendica Bornm.	[143, 145]
	Satureja spicigera (K. Koch) Boiss.	[85, 138, 145, 148]
	Satureja subspicata Bartl. ex Vis.	[157, 158]
	Satureja thymbra L.	[19, 164, 167,168]
	Satureja wiedemanniana (Avé-Lall.) Velen.	[174]
Cytotoxic activity	*Satureja atropatana* Bunge	[21]
	Satureja avromanica Maroofi	[22]
	Satureja bachtiarica Bunge	[26, 27]
	Satureja boissieri Hausskn. ex Boiss.	[37]
	Satureja cilicica P. H. Davis	[40, 41]
	Satureja hortensis L.	[52, 58, 61]

	Satureja intermedia C. A. Mey.	[67]
	Satureja isophylla Rech.f.	[70]
	Satureja kermanica *Payandeh, Bordbar & Mirtadz.*	[72]
	Satureja khuzistanica Jamzad	[78, 80, 81, 86]
	Satureja kitaibelii Wierzb. ex Heuff.	[98]
	Satureja macrantha C. A. Mey.	[101]
	Satureja montana L.	[112, 123-124, 128-129]
	Satureja montana subsp. *pisidia* (Wettst.) Šilic	[114]
	Satureja parnassica Heldr. & Sartori ex Boiss.	[134]
	Satureja sahendica Bornm.	[143]
	Satureja spicigera (K. Koch) Boiss.	[153]
	Satureja thymbra L.	[134, 165, 168]
Antioxidant activity	*Satureja avromanica* Maroofi	[22]
	Satureja bachtiarica Bunge	[28, 32, 100, 154]
	Satureja boissieri Hausskn. ex Boiss.	[36]
	Satureja cilicica P. H. Davis	[39, 40, 41]
	Satureja cuneifolia Ten.	[44, 25, 151]
	Satureja hortensis L.	[51, 52, 58, 100]
	Satureja icarica P. H. Davis	[65]
	Satureja intermedia C. A. Mey.	[66, 100]
	Satureja intricata Lange	[69, 171]
	Satureja kermanica Payandeh, Bordbar & Mirtadz.	[72]
	Satureja kermanshahensis Jamzad	[74]
	Satureja khuzistanica Jamzad	[77, 86, 84]
	Satureja kitaibelii Wierzb. ex Heuff.	[92-93, 95-96]
	Satureja laxiflora K. Koch	[100]
	Satureja macrantha C. A. Mey.	[101, 103]
	Satureja metastasiantha Rech. f.	[104]
	Satureja montana L.	[93, 108-109, 123, 157, 172]
	Satureja montana subsp. *macedonica* (Formánek) Baden	[106]
	Satureja montana subsp. *montana*	[109, 120]
	Satureja montana subsp. *variegata* (Host) P. W. Ball	[106, 120]
	Satureja mutica Fisch. & C. A. Mey.	[132, 154]
	Satureja parnassica Heldr. & Sartori ex Boiss.	[134]
	Satureja pilosa Velen.	[139]
	Satureja sahendica Bornm.	[142, 146]
	Satureja spicigera (K. Koch) Boiss.	[151-152, 154]
	Satureja subspicata Bartl. ex Vis.	[157, 159]
	Satureja thymbra L.	[134, 160, 163-165]
	Satureja visianii Šilic	[172]
	Satureja × delpozoi Sánchez-Gómez, J. F. Jiménez & R. Morales	[171]

Biological utliziation of the genus *Satureja*

Anticholinergic activity	*Satureja avromanica* Maroofi	[22]
	Satureja bachtiarica Bunge	[30]
	Satureja cuneifolia Ten.	[45]
	Satureja isophylla Rech.f.	[70]
	Satureja khuzistanica Jamzad	[81]
	Satureja kitaibelii Wierzb. ex Heuff.	[97]
	Satureja macrantha C. A. Mey.	[101]
	Satureja metastasiantha Rech. f.	[104]
	Satureja montana L.	[110, 116]
	Satureja montana subsp. *montana*	[109, 122]
	Satureja montana subsp. *variegata* (Host) P. W. Ball	[122]
	Satureja pilosa Velen.	[139]
	Satureja thymbra L.	[160, 163]
Antidiabetic activity	*Satureja avromanica* Maroofi	[22]
	Satureja bachtiarica Bunge	[29]
	Satureja cuneifolia Ten.	[45, 46]
	Satureja khuzistanica Jamzad	[84, 88]
	Satureja kitaibelii Wierzb. ex Heuff.	[95, 96]
	Satureja thymbra L.	[160]
Antiepileptic/anticonvulsant activity	*Satureja bachtiarica* Bunge	[25]
	Satureja edmondi Briq.	[49]
	Satureja hortensis L.	[56]
Antispasmodic activity	*Satureja hortensis* L.	[59]
	Satureja montana L.	[111]
Antidepressant/anxiolytic activity	*Satureja bachtiarica* Bunge	[31]
	Satureja montana L.	[117]
Anti-inflammatory activity	*Satureja hortensis* L.	[50, 57, 62]
	Satureja khuzistanica Jamzad	[82, 91, 177]
	Satureja kitaibelii Wierzb. ex Heuff.	[95]
	Satureja montana L.	[115]
	Satureja pilosa Velen.	[140]
	Satureja sahendica Bornm.	[144]
	Satureja thymbra L.	[63]
Analgesic/antinociceptive activity	*Satureja cuneifolia* Ten.	[176]
	Satureja hortensis L.	[57]
	Satureja khuzistanica Jamzad	[177]
	Satureja montana L.	[127]
	Satureja thymbra L.	[63]
Larvicidal activity	*Satureja bachtiarica* Bunge	[33]
	Satureja cilicica P. H. Davis	[42]
	Satureja cuneifolia Ten.	[42]
	Satureja hortensis L.	[42, 54]
	Satureja khuzistanica Jamzad	[83]
	Satureja montana L.	[42]
	Satureja montana subsp. *montana*	[125]
	Satureja spicigera (K. Koch) Boiss.	[42]
	Satureja thymbra L.	[42]

Insecticidal activity/fumigant toxicity	*Satureja bachtiarica* Bunge	[34]
	Satureja hortensis L.	[53, 155]
	Satureja intermedia C. A. Mey.	[68]
	Satureja isophylla Rech.f.	[61]
	Satureja khuzistanica Jamzad	[34, 147]
	Satureja montana L.	[121, 126, 138]
	Satureja parnassica subsp. *parnassica*	[126]
	Satureja sahendica Bornm.	[147]
	Satureja spicigera (K. Koch) Boiss.	[150, 155]
	Satureja spinosa L.	[138]
	Satureja thymbra L.	[126, 166, 169-170]
Anticholesterolemic activity	*Satureja cuneifolia* Ten.	[47]
Cardioprotective activity	*Satureja hortensis* L.	[55, 60]
Wound healing activity	*Satureja khuzistanica* Jamzad	[76, 79]
	Satureja mutica Fisch. & C. A. Mey.	[132]
	Satureja pilosa Velen.	[140]
	Satureja sahendica Bornm.	[144]
Fertility disorders	*Satureja khuzistanica* Jamzad	[87, 90]
	Satureja montana L.	[107, 113, 118]
Anti-aging activity	*Satureja macrantha* C. A. Mey.	[101]
Diuretic activity	*Satureja montana* subsp. *montana*	[105]
Antiviral	*Satureja montana* subsp. *variegata* (Host) P. W. Ball	[119]
	Satureja spicigera (K. Koch) Boiss.	[152]
	Satureja thymbra L.	[171]

5.1. Antibacterial Activity of Satureja Genus

The in vitro antibacterial activity of the *Satureja* genus examined both Gram-negative and Gram-positive bacteria concurrently. The 32 taxa of *Satureja* genus' with a broad spectrum, including *Bacillus* spp., *Staphylococcus* spp., *Enterococcus* spp., *Listeria* spp., *Streptococcus* spp. and *Pseudomonas aeruginosa* strains. Among these studies, it was determined that essential oils of the *Satureja* genus were generally reported [19, 23, 24, 28, 32, 35, 43, 44, 48, 58, 64, 67, 74, 86, 94, 99, 100-104, 109, 114, 128, 132, 133, 135-137, 142, 143, 145, 149, 156, 158, 161, 162, 164, 168, 173-175]. The essential oils of the genus *Satureja* predominantly contain oxygenated monoterpenes, primarily thymol and carvacrol. The majority of publications indicate that the carvacrol serves as the primary indicator of antibacterial activity. As estimated, the *Satureja* taxa with elevated levels of thymol and carvacrol had significant antibacterial activity. On the other hand, Askun and colleagues demonstrated the activity of petroleum ether, ethyl acetate, and methanol extracts of *Satureja aintabensis* P.H. Davis against four strains of *M. tuberculosis* with the minimal inhibitory concentrations value of 12.5-100 µg /mL by broth microdilution method and attributed this activity to rosmarinic acid [20]. In another study, which was conducted by Aćimović et al., the water extract of *Satureja kitaibelii* Wierzb. ex Heuff.'s antibacterial activity against *Bacillus cereus*, *Staphylococcus aureus*, *Enterococcus faecalis* and *Listeria monocytogenes* was shown, and the activity was attributed to elevated amounts of syringic and caffeic acid (37.88, 18.06, and 10.04 mg/g, respectively) [95].

5.2. Antifungal Activity of Satureja Genus

In most of the prior studies reported before, it was observed that the in vitro antibacterial and antifungal activities of the *Satureja* genus were generally tested together. Only in a few studies, the in vitro antifungal activity evaluation was focused. Both essential oil and the extracts of the 27 taxa of *Satureja* genus's antifungal activity against a broad spectrum were reported [19, 32, 35, 36, 38, 43, 44, 64, 67, 73, 85, 86, 89, 94, 95, 99-102, 108, 109, 114, 116, 120, 128-130, 138, 143, 145, 148, 157, 158, 162, 164, 167, 168, 174]. The anti-fungal activity of the essential oil of *S. hortensis*, *S. khuzistanica*, and *S. spicigera* against four post-harvest pathogenic fungi (*Rhizopus stolonifer*, *Penicillium digitatum*, *Aspergillus niger*, and *Botrytis cinerea*) was shown by Nebigol. According to the results, *S. khuzistanica* essential oil was detected as the strongest and its potential for use in decreasing the incidence of post-harvest diseases of the strawberry fruit [85]. The antifungal activity against three fungi namely; *Candida albicans* ATCC 10231, *Saccharomyces cerevisiae*, *Yarrowia lipolytica*) of *Satureja boissieri* extract was reported by Aras et al. [36], where the main phenolic components such as hesperidin and rosmarinic acid were reported. The *S. montana* L. and *S. subspicata* methanolic and ethanolic extracts' anti-fungal activity against *Candida albicans*, *Candida dubliniensis*, *Candida krusei*, *Candida glabrata*, *Candida parapsilosis*, and *Microsporum gypseum* was repored by Kremer et al. [157]. In another study, nanoencapsulated *Satureja kermanica* essential oil/extract using the chitosan biopolymer (SKEO-CSN) / (SKEX-CSN)'s in vitro antifungal activity against *Fusarium oxysporum*, *Alternaria alternata*, *Botrytis cinerea*, *Sclerotinia sclerotiorum*, *Rhizoctonia solani*, and *Pythium aphanidermatum* strains was reported by Payandeh et al. [73] where the *S. kermanica* essential oil antifungal inhibitory activity was attributed to the relatively high amounts of thymol (46.54%) and carvacrol (30.54%) content. The SKEO-CSN was determined to be complete inhibition (100%) of the radial growth rate, enhancing the inhibition from 65% to 84.2% to 100% across all tested fungi. The strong antifungal activity of *Satureja* genus essential oils is ascribed to thymol and carvacrol compounds, as is the antibacterial activity.

5.3. In vitro Cytotoxic Activity of Satureja Genus

Overall, 18 *Satureja* species namely*; S. atropatana, S. avromanica, S. bachtiarica, S. boissieri, S. cilicica, S. hortensis, S. intermedia, S. isophylla, S. kermanica, S. khuzistanica, S. kitaibelii, S. macrantha, S. montana, S. montana* subsp. *pisidia, S. parnassica, S. sahendica, S. spicigera, S. thymbra)* cytotoxic activities were reported for their in vitro cytotoxicity of the extracts and/or essential oils were evaluated using a variety of cell lines such as PC-3, A-495, Panc-1, KYSE, Vero, JET 3, K562, HepG-2, MCF-7, A-549 and HT29/219.

S. avromanica's cytotoxic effect against the A495 cell line was evaluated by Kiziltas [22]. The strong activity was mainly attributed to the phenolic compounds of the extract-rosmarinic acid (19961.31 mg/kg), hederagenin (18895.43 mg/kg) and hesperidin (11409.60 mg/kg) [22].

S. bachtiarica (IC_{50}: 28.3 μg /mL) and *S. hortensis* (IC_{50}: 52 μg /mL) water extract activity on K562 cell line was reported by Esmaeilbeig et al. [26]. The *S. bachtiarica's* viability, migration, invasion, and clonogenic potential of MDAMB-231 and U87-MG cells was also evaulated in both two and three dimensional cell culture models by Zavareh et al. [27]. The cytotoxic activity of *S. hortensis* extracts against HepG-2, MCF-7, A-549, and Panc-1 cell lines were reported by Huwaimel et al. *S. hortensis* extract was determined as the most active against this cell line with an IC_{50} value of 113.05 μg/mL [61].

S. boissieri essential oil's cytotoxic effect on the human colorectal adenocarcinoma (HT-29) cell line was shown by Oke-Altuntas et al [37]. *p*-cymene, thymol and spathulenol compounds were also isolated by them as pure terpenoids, and their cytotoxic activity was examined on HT-29 cell line at the concentrations of 10, 50 and 100 µg/mL by real time cell analyzer xCELLigence method. *p*-cymene and thymol with remarkable cytotoxic effects against the HT-29 cell line, and the activity of the *S. boissieri* essential oil was attributed, respectively [37].

S. cilicica essential oil's low cytotoxic effect against the MCF-7 cell line (IC_{50} value of 268 μg /mL) was reported by Arabacı et al. The *S. cilicica* essential oil's major compounds, p-cymene (17.68%), carvacrol (14.02%), γ-terpinene (11.23 %) and thymol (8.76%) were also detected noticeably at relatively lower amounts [41].

S. intermedia essential oil's cytotoxic effect against KYSE cell line (IC_{50} values of 156 μg /mL) [67] and *S. montana* essential oil's strong cytotoxic effects against A549, HeLa, MDA-MB-453, K562 cell lines were published [123, 124, 128, 129]. The cytotoxic effect of *S. montana* ssp. *pisidica* essential oil's cytotoxic activity on MDA-MB-361, MDA-MB-453, HeLa, LS174 and MRCS cells were also reported.

S. isophylla extracts strong cytotoxic activities against MCF-7, AsPC-1, and PC-12 cancer cell lines with relatively low cytotoxic activity ACHN cell lines was reported by Aghaaliakbari et al. [70].

The methanolic extract of *S. kermanica'*s cytotoxicity against the MCF-7 cell line was measured as 1251.088 µg /mL by Hassanabadi et al. [72]. *S. khuzistanica* extract's cytotoxic effects on the HT29 and HeLa cell lines and the essential oil's cytotoxicity against A2780 and PC-3 cells were reported [78, 80, 81].

Satureja kitaibelii methanolic extract's cytotoxicity against the MRC5 cell line [98] and *S. macrantha* essential oil's and ethanolic extract's cytotoxic effect against MCF-7, HDF and HT-29 were evaluated [101].

S. thymbra and S. parnassica essential oils' cytotoxic activity against MCF-7, A549, HepG2 and Hep3B cell lines resulted in that the *S. thymbra* essential oil was with stronger antioxidant and antiproliferative capacity when tested on MCF-7 cells compared to *S. parnassica* essential oil. The essential oils' strong activities were attributed to their carvacrol and thymol contents. [134]. *S. thymbra* essential oil's cytotoxicity also against HCT-116 cell line (IC_{50} 2.45 +/- 0.21 µg /mL) was demonstrated by Khalil et al. [168].

S. sahendica essential oil's *in-vitro* cytotoxicity against MCF7, Vero, SW480 and JET 3 cell lines in a dose-dependent manner with an IC_{50} value 15.6, 15.6, 125, and 250 µg/mL, respectively, was reported by Yousefzadi et al. [143]. Essential oil of *S. spicigera*'s cytotoxicity against four cancerous cell lines namely the HT29/219, Caco (2), NIH-3T3, and T47D were evaluated by Gohari et al. [153].

5.4. Antioxidant Activity of Satureja Genus

The studies which evaulated the antioxidant activity of the *Satureja* genus were presented in the Table 2. Overall 29 taxa of the *Satureja* species were reported for their potential antioxidant activity in the literature. Among these studies, to assess the antioxidant capacity of the species from different perspectives, at least two or more methods were typically were combined: *β*-carotene bleaching assay, DPPH, ABTS, TBARS, superoxide, and nitric oxide (NO) free radical scavenging tests, and ferric reducing antioxidant power (FRAP) assay were as frequently used in order to detect the antioxidant potency of the species.

According to these studies, the antioxidant activity clearly were observed in *Satureja* essential oils is due to the high amounts of carvacrol and thymol constituents of them. In parallel to this, the strong antioxidant capacity of the *Satureja* extracts was correlated with the elevated content of polar phenolic compounds. For instance, the *S. hortensis, S. bachtiarica, S. laxiflora and S. intermedia* essential oils' radical scavenging and antioxidant activity were reported using DPPH and FRAP assays by Jafari et al [100]. The thymol (24.54-38.75%) and carvacrol (32.07-42.51%) were determined as the most abundant compounds of the essential oils [100]. The *S. montana* essential oil's strong antioxidant activity and its' major compounds carvacrol (306 g/L), thymol (141 g/L), and carvacrol methyl ether (63 g/L) were reported by Serrano et al. Also, hot water extract of *S. montana*'s high phenolic content with strong antioxidant activity was demonstrated in the same study [108]. In another study, *Satureja montana* subsp. *kitaibelii*'s petroleum ether, chloroform, ethyl acetate and *n*-butanol extracts were prepared and, the *n*-butanol extract was showed as the best antioxidant active fraction of it. According to those results, it was understood that the antioxidant activities of the *Satureja montana* subsp. *kitaibelii* extracts and their total phenolic content showed a strong correlation [93]. Because of their strong antioxidant potential, the genus of *Satureja* taxa might be considered to be one of the important source for daily consumption of human diet.

5.5. Anticholinergic Activity and Alzheimer's Disease

Alzheimer's disease is a chronic neurodegenerative disorder of the brain, marked by oxidative stress, dementia, and memory deficits in the elderly. The cholinesterase inhibitors, which enhance acetylcholine levels and improve cholinergic transmission at the synaptic cleft, serve as a crucial role in the treatment of Alzheimer's disease. The suppression of cholinergic enzymes by certain medicinal plants is primarily ascribed to their phenolic compounds [22]. 13 taxa of the *Satureja* genus' acetylcholinesterase (AChE) and butyrylcholinesterase (BChE) inhibitory activities were investigated in the literature.

The ethanolic extract of *S. avromanica*'s acetylcholinesterase (AChE) inhibition (IC_{50}: 1.909 µg /mL) was evaulated by Kiziltas. Additionally, with the molecular docking studies the extract's activity was linked to the hesperidin, hederagenin, and rutin components [22].

The methanolic extract of *S. bachtiarica*'s amelioration of beta-amyloid-induced memory impairment and cholinergic deficit in a rat model of Alzheimer's disease was demonstrated by Soodi et al. [30].

S. cuneifolia water and methanol extracts *in-vitro* inhibition of AChE and BChE were reported by Taslimi et al. Water and methanol extracts of *S. cuneifolia's* IC_{50} values were detected as 93.58 µg/mL (r^2: 0.9895) and 63.69 µg/mL (r^2: 0.9821) for AChE, respectively. Morever, these values were detected as 53.72 µg/mL (r^2: 0.9916) and 23.17 µg/mL (r^2: 0.9757) for BChE respectively [45].

S. isophylla n-hexane, chloroform, ethyl acetate, and methanol extracts inhibition of AChE and BChE were evaluated by Aghaaliakbari et al. [70].

S. khuzistanica essential oil's inhibition of AChE (IC_{50}: 377.14 ± 2.36 µg/mL) and BChE (IC_{50}: 251.37 ± 1.88 µg/mL) were showed by Ezatpour et al., and they claimed that the anticholinesterase activity was attributed to the carvacrol content of the essential oil with molecular docking simulation [81].

The essential oil, exudate fraction and methanolic extract of *S. kitaibelii'*s inhibition of acetylcholinesterase enzyme were reported by Nikolova et al. According to those data, it was determined that the exudate fraction of *S. kitaibelii* was reported as the most potent AChE inhibitory activity with IC_{50} value of 0.18 µg/mL [97].

The essential oil and ethanolic extract of *S. macrantha*'s inhibition of AChE and BChE activity were tested by Akdeniz et al. It was understood that the *S. macrantha* was shown to have low inhibition of acetylcholinesterase enzyme but also have high inhibition of butyrylcholinesterase enzyme [101].
The *S. metastasiantha* essential oil's acetylcholinesterase (30% inhibition at 200 µg/mL) and butyryl-cholinesterase (18.1% inhibition at 200 µg/mL) inhibition effects were determined by Carikci et al. [104].

The methanol-aqueous extract of *S. montana*'s moderate effects on cognition abilities in rat models of acute and chronic stress were shown by Vilmosh et al [110]. In another study, *S. montana* essential oil's AChE inhibitory activity was demonstrated by Silva et al., *S. montana* essential oil's strong inhibition of AChE was assessed as a potential indicator for the control of Alzheimer's disease. In addition, the supercritical non-volatile fractions, which contain the highest amounts of (+)-catechin, chlorogenic, vanillic, and protocatechuic acids, were also determined to significantly inhibit BChE [116]. *S. montana* ssp. *montana* essential oil's strong anticholinesterase activity was shown by Mihajilov-Krstev et al. [109]. The *S. montana* subsp. montana (IC_{50}: 488.88 nL/mL) and *S. montana* subsp. *variegata* (IC_{50}: 872.04 nL/mL) essential oils inhibition of AChE in a dose-dependent manner were demonstrated by Les et al. [122].

Dichloromethane, acetone and methanol extracts of leaves and branches of *S. pilosa*'s AChE inhibition were determined by Kınoğlu et al. According to results, the highest AChE inhibition was measured in leaf methanol extract (IC_{50}: 41.2 +/- 5.6 µg/mL) and the highest BChE inhibition was determined in leaf dichloromethane extract (IC_{50}: 52.3 +/- 8.6 µg/mL) [139].

The essential oil and methanolic extract of *S. thymbra*'s cholinesterase inhibitory effects against acetylcholinesterase and butyrylcholinesterase were shown in the literature [160, 163]. When the studies were evaluated, it was understood that the effects of *Satureja* taxas on Alzheimer's disease are remarkable; more detailed studies are needed on this subject.

5.6. Antidiabetic Activity of Satureja Genus

Diabetes mellitus is a metabolic disease characterized by high blood glucose amounts (hyperglycemia) and the inability of the pancreas to secrete or stimulate insulin. The enzymes α-glycosidase and α-amylase hydrolyze polysaccharides, altering them into simple sugar units and/or monosaccharides. Since they regulate the blood glucose levels, inhibition of these two enzymes is thought to be a treatment option for diabetes mellitus [22]. According to the literature survey, it was determined that the 6 taxa of the *Satureja* genus's antidiabetic properties were evaluated.

The ethanolic extract of *S. avromanica*'s inhibition of α-glycosidase (IC_{50}: 0.701 μg /mL), and α-amylase (IC_{50}: 0.517 μg /mL) enzymes were determined by Kiziltas. Also, the activity of the extract was attributed with the hesperidin, hederagenin and rutin components by molecular docking analysis [22].

The hydroalcoholic extract of the *S. bachtiarica*'s antidiabetic effects through modulation of oxidative stress and expression of GLUT2 and GLUT4 was reported with an *in vivo* study by Joudaki et al. [29].

S. cuneifolia methanol and water extracts antidiabetic properties via in vitro *α*-glycosidase and *α*-amylase inhibition were demonstrated by Taslimi et al. [45]. In another study, the *S. cuneifolia* extract blended with sodium alginate (SA) /polyethylene glycol (PEG) scaffolds for the potential treatment of diabetic ulcer was reported by Ilhan et al. [46].

Essential oil of *S. khuzistanica* of beneficial effects on the antioxidant enzymes activity in alloxan-induced Type 1 diabetic rats was demonstrated by Ahmadvand [84]. *S. khuzestanica* supplement's influence on metabolic parameters of hyperlipidemic patients with Type 2 Diabetes Mellitus was investigated in a double-blind randomized controlled trial by Vosough-Ghanbari et al. According to the results obtained, usage of *S. khuzestanica* as a supplement to the drug regimen of diabetic Type 2 patients with hyperlipidemia was recommended by researchers [88].

S. kitaibelii extracts antihyperglycemic activity was also showed in the literature by several studies [95, 96]. The α-glucosidase enzyme inhibition of the *S. thymbra* was carried out by Kirkan et al. [160].

5.7. Anti-inflammatory Activity of Satureja Genus

The anti-inflammatory activity of the *S. hortensis, S. khuzistanica, S. kitaibelii*, *S. montana*, *S. pilosa, S. sahendica* and *S. thymbra* which belong to the *Satureja* genus, were investigated in the literature (Table 2).

The anti-inflammatory activity of aqueous extracts of *S. hortensis* (250 mg/kg) in a rabbit model of rhinosinusitis was reported by Uslu et al. [50]. In another study, hydroalcoholic and polyphenolic extracts and essential oil of *S. hortensis* seeds' anti-inflammatory activity were examined with the carrageenan-induced rat paw edema test by Hajhashemi et al. According to researchers, all three fractions were determined as strong agents to reduce paw edema in the carrageenan test [57]. The administration of ethanolic extract of *S. hortensis*'s anti-inflammatory activity in a mouse model of ulcerative colitis was reported by Rocha et al. *S. hortensis* extract decreasing several markers for intestinal injury, including the nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2 or prostaglandin-endoperoxide synthase) expression, was proven [62].

The hydroalcoholic extract of *S. khuzistanica*'s anti- inflammatory activity was tested by using the carrageenan- induced rat paw edema. The results indicated that similar anti-inflammatory effects were reported between *S. khuzistanica* hydroalcoholic extract (150 mg/kg; i.p.) and indomethacin (4 mg/kg; i.p.) in the carrageenan assay [177]. The anti-inflammatory activity of *S. khuzistanica* essential oil was shown in the experimental mouse model of inflammatory bowel disease, which is acetic acid-induced colitis by Ghazanfari et al. [91].

The water extract of *S. kitaibelii'*s high anti-inflammatory activity was shown with protein denaturation bioassay using egg albumin by Aćimović et al. [95].

The methanolic extract of *S. montana*'s anti-inflammatory activity was measured by using COX-1, COX-2, 5-LOX, and MPO inhibition assays. According to the results, the extract was shown to have higher anti-inflammatory potency against the reference drug with IC_{50} values for COX-2 (0.17 μg/mL), LOX (9.25 μg/mL), MPO (9.50 ng/mL) and COX-1 (10.21 μg/mL) [115].

The anti-inflammatory activity of *S. pilosa* extracts was investigated with a leukocyte cell adhesion assay by Panagiotidou et al. According to results, the anti-inflammatory activity of *S. pilosa* extracts was not significant [140].

In a study evaluated by Omarizadeh et al., it was demonstrated that the dermal application of *S. sahendica* essential oil accelerates wound healing by upregulating the expression of IGF-1, IL-10, FGF-2, VEGF, TGF-beta, and CXCL-1; shortening the inflammatory stage, and enhancing the proliferative phase [144].

The anti-inflammatory activity of *S. thymbra* essential oil was investigated by Karabay-Yavasoglu et al. It was understood that *S. thymbra* essential oil showed no anti-inflammatory activity in either mice or rats [63].

5.8. Analgesic / Antinociceptive Activity of Satureja Genus

According to the literature investigation, it was determined that the following species belong to the genus of Satureja taxa: *S. cuneifolia, S. hortensis, S. khuzistanica, S. montana* and *S. thymbra*'s analgesic/ antinociceptive activities were reported (Table 2).

S. cuneifolia essential oil's analgesic activity was reported using the tail-flick method in mice by Aydın et al. The analgesic activity was attributed to the carvacrol amount of the essential oil [176]. Hydroalcoholic and polyphenolic extracts and essential oil of *S. hortensis* seeds's analgesic activity were determined with acetic acid and formalin tests in male mices by Hajhashemi et al. The results indicate that the hydroalcoholic extract markedly decreased pain responses in both the early and late stages of the formalin test, whereas the polyphenolic extract and essential oil were effective only in the late phase of the formalin test [57].

S. khuzistanica is endemic to Iran and has been used as an analgesic and antiseptic agent in traditional medicine in Iran. The hydroalcoholic extract of the plant's antinociceptive activity was showed with the formalin test by Amanlou et al. *S. khuzistanica* extract's antinociceptive activity was detected in a dose-dependent (10- 150 mg/ kg; i. p.) manner at the second phase of the formalin test which was comparable with morphine (3 mg/ kg; i. p.). The strong activity was also attributed to the carvacrol and tannin content of the *S. khuzistanica* [177].

The chronic administration of dry extract of *S. montana* (250 and 500 mg/kg b.w.)'s moderate analgesic effects in the different animal pain models were shown by Vilmosh et al. The active compounds of the plant, rosmarinic acid (15 mg/kg b.w.) and carvacrol (500 mg/kg b.w.)'s analgesic effect were also demonstrated [127].

The antinociceptive activity of the *S. thymbra* essential oil was tested by the formalin test in mice and by the light tail-flick and hot-plate methods in rats by Karabay-Yavasoglu et al. The authors indicated that the *S. thymbra* essential oil demonstrated an antinociceptive effect in both the early (50 and 100 mg/kg) and late phases (25, 50, and 100 mg/kg) of the formalin test; however, no significant antinociceptive effect in the tail-flick test was observed [63].

5.9. Larvicidal Activity of Satureja Genus

The essential oil of *S. bachtiarica, S. cilicica, S. cuneifolia, S. hortensis, S. khuzistanica, S. montana, S. montana* subsp. *montana, S. spicigera* and *S. thymbra* taxons larvicidal activities were evaluated in the literature. Among these researches, larvicidal activity of the essential oils was tested against *Anopheles stephensi, Culex quinquefasciatus, Leptinotarsa decemlineata* and *Culex quinquefasciatus*.

S. bachtiarica essential oil's larvicidal activity against two mosquito vector, *Anopheles stephensi* and *Culex quinquefasciatus* was shown by Soleimani-Ahmadi et al. The LC_{50} and LC_{90} values for *An. stephensi* larvae were 24.27 ppm and 54.24 ppm, respectively, whereas for *Cx. quinquefasciatus*, they were 44.96 ppm and 114.45 ppm after 24 hours of exposure [33].

The essential oil of *S. cilicica, S. cuneifolia, S. hortensis, S. spicigera, S. thymbra* and *S. montana*'s larvicidal activity on the adults and larvae of Colorado potato beetle (*Leptinotarsa decemlineata*) was tested by Usanmaz-Bozhuyuk et al. Among the six oils that were evaluated, *S. thymbra* essential oil demonstrated efficacy across all examined biological periods. The findings of this study indicate that the essential oils from the examined *Satureja* species may serve as bio-larvicides and insecticides for *L. decemlineata* larvae and adults [42]. In another study, *S. hortensis* essential oil's larvicidal activitiy on *Anopheles stephensi* was demonstrated by Kazempour et al. [54].

The essential oil of *S. khuzistanica*'s larvicidal activity against *Leptinotarsa decemlineata* (Say). was examined by Saroukolai et al. According to the results, it was determined that the *S. khuzestanica* essential oil was very effective on the 4th instar larvae and adults (LC_{50} = 23.36 and 167.96 ppm, respectively) [83].

S. montana subsp. *montana* essential oil's larvicidal activity against the filariasis vector *Culex quinquefasciatus* with (LC_{50} = 25.6 µL./L) was shown by Benelli et al. According to the results, the researchers indicated that the larvicidal efficacy can be improved by producing basic binary combinations of essential oils, such as *S. montana* subsp. *montana* and *Aloysia citriodora* in a 1:1 ratio, which demonstrated increased larvicidal toxicity (LC_{50} = 18.3 µL/L) [125].

5.10. Insecticidal Activity / Fumigant Toxicity of Satureja Genus

According to the literature survey, it was determined that the 11 taxons—*S. bachtiarica, S. hortensis, S. intermedia, S. isophylla, S. khuzistanica, S. montana, S. parnassica subsp. parnassica, S. sahendica, S. spicigera, S. spinosa* and *S. thymbra*—insecticidal activity/fumigant toxicity were evaluated. Essential oils were utilized as target agents in most of the studies. Numerous studies have demonstrated that a taxon's essential oils have a greater activity on insects than extracts.

The fumigant toxicity of *S. bachtiarica* and *S. khuzestanica* essential oils' on the tomato leafminer, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) was demonstrated by Rahmani et al. [34]. In another study, the insecticidal activity of the *S. khuzestanica* and *S. sahendica* extracts' against *Bemisia tabaci* (Hemiptera: Aleyrodidae) was demonstrated by Moghadam et al. [147].

The *S. hortensis* extracts obtained with supercritical CO_2's insecticidal activity against larvae of *Musca domestica*, *Spodoptera littoralis*, *Culex quinquefasciatus* and *Leptinotarsa decemlineata* and on adults of *M. domestica* was reported by Pavela et al. [53]. The *S. hortensis* and *S. spicigera* essential oils' insecticidal effect on *Sitophilus granarius* (L.) (Coleoptera: Curculionidae) demonstrated by Yildirim et al. [155]. In another study, the fumigation of *S. hortensis* and *S. intermedia* essential oils' on *Tribolium castaneum* (Coleoptera: Tenebrionidae) was investigated by Ebadollahi et al. It was determined that applying 55.15 µL/L of *S. hortensis* and 58.82 µL/L of *S. intermedia* essential oils could result in a maximum significant mortality of 94.72% and 92.97% within 72 hours, respectively [68]. Also, the *S. spicigera* essential oil's insecticidal effectiveness on *Halyomorpha halys* nymphs and adults was reported by Gokturk [150].

S. isophylla essential oil's fumigant toxicity on *Aphis fabae* Scop. (Hemiptera: Aphididae) was reported by Hasanshahi et al. [71].

The 0.2% aqueous extract of *S. montana*'s insecticidal activity on *Trialeurodes vaporariorum* (Hemiptera: Aleyrodidae) with 68.33 % mortality after 96 h was shown by Šućur et al. [121].

S. spinosa, *S. parnassica* subsp. *parnassica*, *S. thymbra* and *S. montana* essential oils' insecticidal effect on *Culex pipiens* larvae (Diptera: Culicidae) was shown by Michaelakis et al. [126].

The insecticidal activity on adult *Hyalomma marginatum* (Acari: Ixodidae), *Drosophila melanogaster* and *Anopheles gambiae* of *S. thymbra* essential oil' was also demonstrated in the literature. The strong activity was attributed to the high content of carvacrol and thymol compounds in the essential oil [166, 169-170].

5. 11. The Other Activities of Satureja Genus

In addition to the aforementioned activities, as demonstrated in Table 2, numerous different activities of the *Satureja* genus members have been documented. *S. hortensis*, *S. khuzestanica* and *S. montana* are the taxa that are most frequently investigated among them. Because of the high number of reports under this topic, it is not achievable to discuss all biological activity studies of *Satureja* taxa here. According to the literature survey, the antiepileptic/ anticonvulsant, antispasmodic, antidepressant/anxiolytic, anticholesterolemic, cardioprotective, wound healing, anti-aging, diuretic and antiviral activities of the *Satureja* genus were discussed in the literature.

6. Phytochemistry

6. 1. Essential Oil

When the chemical composition of the essential oil of the *Satureja* genus was examined, it was determined that it mainly contained carvacrol, thymol, *p*-cymene and *γ*-terpinene. The summaries of studies on the essential oil analysis of some species of the *Satureja* genus are below.

Satureja aintabensis grows mainly in the Gaziantep region in Türkiye and its essential oil composition was examined in detail and its main components were reported as *p*-cymene (59.0%) and thymol (17.5%) [19]. In a study on the chemical composition of the essential oil of the species *Satureja avromanica* recorded in Türkiye, the main components were reported as *n*-pentacosane (23.8%), spatulenol (11.5%), α-bourbonene (11.3%) and n-docosane (11.0%) in an Iranian study [178]. In another study by Hooshidari and his team, the volatile oil content was reported as thymol (83.9%), carvacrol (5.2%), and *p*-cymene (3.9%) [179].

The main components of the volatile oil of *Satureja boissieri*, another species distributed in the Upper Euphrates and Middle Euphrates basins, were reported to be carvacrol (21.3%-44.8%), *p*-cymene (23.2%-35.5%), γ-terpinene (6.5%-26.4%) and thymol (2.3%-18.9%) [35, 37, 180]. Cacan and his team investigated the fatty acids of the essential oils of some *Satureja* species, including *Satureja boissieri*, and reported that *Satureja boissieri* contained high levels of linolenic acid, palmitic acid and linoleic acid [181].

A study conducted by Abou Baker et al., the major compounds of the *S. hortensis* essential oil were detected as carvacrol (48.51%) and γ-terpinene (36.63%), followed by ρ-cymene (3.93%) and terpinolene (2.42%) [58]. The fatty acid content of *S. hortensis* leaves, flowers and seeds were investigated by Kökten et al. and palmitic and linoleic acids were determined as the major components [182]. In a study conducted by Maral and his colleagues from Çukurova University on *Satureja cilicica*, which is endemic to the Mediterranean region (Cilicia), it was reported that the essential oil contents and antioxidant properties of some *Origanum, Thymbra, Zizipora, Thymus* species collected from Ermenek would be compared with *Satureja cilicica*, however, the essential oil components of other plants were reported in the study, but the *Satureja cilicica* content was not given. It was reported that only the amount of essential oil was determined as 1.64% [183]. Schulz et al. [184] determined the chemical content of the essential oil of *Satureja* species, including *S. cilicica*, collected from Türkiye by ATR/FT-IR and NIR FT-Raman spectroscopy. The main components were determined as carvacrol (19%), thymol (23%), p-cymene (20%), γ-terpinene (13%). The main components of 12 different *S. cuneifolia* samples collected from the south of Italy were determined as linalool, borneol, and α-pinene by GC-MS. In addition, in order to obtain information about the effect of precipitation rates on the amounts of components, the components of plants irrigated with different amounts of water were investigated, and it was reported that increasing the amount of water in the soil was associated with the emergence of the borneol chemotype, while decreasing the amount of water was associated with the presence of linalool and α-pinene [185].

The two subspecies of *S. montana* (*S. montana* subsp. *variegata* and subsp. *montana*) essential oils' chemical constituents were detected by Caprioli et al. The major compounds were determined as carvacrol (22.5%), p-cymene (17.6%), thymol (17,4%) in the subsp. variegata, and carvacrol (61.9%), *p*-cymene (9,9%) and γ-terpinene (8.2%) in the subsp. *montana*. The primary chemical difference between the subsp. *montana* and subsp. *variegata* was the carvacrol:thymol ratio, which was significantly higher in the subsp. *montana* [106]. *S. khuzistanica* essential oil's major compound was measured as carvacrol (94.16%) by Abbasloo et al. [82]. In another study, *S. hortensis, S. spicigera* and *S. khuzistanica* essential oils' major compounds were analyzed by Farzaneh et al. Carvacrol (48%), γ-terpinene (24.2%) and p-cymene (11.7%) were detected as the primary compounds of *S. hortensis* essential oil while the main compenents of *S. khuzistanica* essential oil's were carvacrol (48%), p-cymene (18.5%) and γ-terpinene (11%). Thymol (29.5%), p-cymene (23.4%), γ-terpinene (15.2%), carvacrol (9.6%) and carvacrol methyl ether (8.5%) were measured as the major compounds of the *S. spicigera* essential oil. Carvacrol, γ-terpinene, and *p*-cymene were identified as the predominant recurring components in the three essential oils, whereas thymol and carvacrol methyl ether were exclusively present in *S. spicigera* among the main components, with thymol constituting one-third of all components in this species [138].

6.2. Phenolic Acids

According to the literature survey, it was determined that the *Satureja* genus extracts were rich in phenolic acids. The phenolic acids such as rosmarinic acid, salvianolic acid A, fumaric acid, quinic acid, caffeic acid, *p*-coumaric acid, vanillic acid, protocatechuic acid, ferulic acid, chlorogenic acid, lithospermic acid and gallic acid of the *Satureja genus* were reported in the literature [36, 38, 65, 186-187]. For instance; the rosmarinic acid (4364 ± 214 ppb) was measured as one of the major compounds of the *S. boissieri* extract by Aras et al. [36]. Shanaida was also conducted a limited number of HPLC analyses of *S. hortensis* collected in Ukraine in 2018 and measured rosmarinic acid as the main component [186]. Kınoğlu et al. separated the leaf and branch parts of *S. pilosa* and performed secondary metabolite screening of DCM, Acetone, MeOH extracts by LC-HRMS. The rosmarinic acid was reported as the main component of extracts [139]. In 2012, Askun and colleagues investigated the phenolic compounds of *S. icarica* in their study on some *Satureja* species. Gallic acid, caffeic acid, *p*-coumaric acid, ferulic acid, rosmarinic acid were detected in the methanol extract of the plant [38]. It was determined that the most abundant phenolic acid detected in *Satureja* taxa is rosmarinic acid.

6.3. Flavonoids and Related Compounds

The high content of the flavonoids and the related compounds of the *Satureja* genus was reported in the literature. The flavonoids and related compounds such as naringin, hesperidin, eriodictyol, quercetin, naringenin, luteolin, apigenin, catechin, rutin, quercetagetin-3.6-dimethylether, cyanidine chloride, epicatechin, luteolin-5-*O*-glucoside, luteolin-7-*O*-glucoside, 5,4dihydroxy-3 methoxyflavanone-7-(6-*O*-α-L-rhamnopyranosyl)-β-D-glucopyranoside, luteolin 7,4-di-*O*-glucuronide, kaempferol, hyperoside, luteolin 7-*O* rutinoside, aromadendrin, apigenin 7-O-glycoside of the *Satureja* genus was detected in the literature [36, 38, 65, 186-187]. For instance, in a study evaluated by Aras et al., the phenolic compounds of *S. boissieri* leaf extract was detected by UHPLC-ESI-MS/MS. The hesperidin (5051 ± 247 ppb) was measured as the major compound of the *S. boissieri* extract. Also, the high content of this compound was attributed to the effective biological activity [36]. In addition to the rosmarinic acid, the luteolin-7-*O*-rutinoside was determined as the main component in the methanol extract of *S. icarica* with LC-HRMS analysis by Kınoğlu et al. The antioxidant activity of the plant was also evaluated by them, and the activity of the plant was attributed to the compounds [65]. Catechin, epicatechin, vitexin, rutin, naringin, hesperidin, apigenin-7-glucoside, eriodictyol, quercetin, naringenin, luteolin and apigenin were detected in the methanol extract of the plant by Askun et al. [38]. In a study conducted by Nikolova and Dzhurmanski on 28 plants cultivated in Bulgaria in 2014, data belonging to *S. pilosa* which is endemic to Bulgaria, were discussed. In the study, flavonoids and flavonoid glycosides of the methanol extract of the plant were investigated and it was stated that trace amounts of apigenin and luteolin 7-O-glycoside were determined [187]. When the studies in the literature were examined, it was understood that the biological activities of *Satureja* genus are generally associated with the flavonoid compounds they contain.

6.4. Other Secondary Metabolites

The literature survey indicates that, in addition to essential oils, phenolic acids, and flavonoids, some other phytochemicals such as triterpene acids, phytosterols, tocopherols and alkane homologues have been often documented. For instance, *S. spicigera* collected from the northwest of Iran was determined by chromatographic and spectral methods and *β*-sitosterol, ursolic acid and oleanolic acid were identified [153]. Lagouri and Boskou were detected four known homologues of tocopherol, *α*-, *β*-, *γ*- and *δ*-, in the *S. thymbra* leaf extract [188]. The methanolic extract of *S. atropatana*'s chemical compounds were identified by Morardi et al. They were detected two triterpenes: ursolic acid and oleanolic acid with a phytosterol: β -sitosterol [21].

7. As Food Source

Satureja genus, especially *S. thymbra* [189] and *S. montana,* is consumed as a winter tea for respiratory system disorders and to strengthen the immune system. Honey obtained from hives located around the fields where the *Satureja* genus is cultivated is consumed. The essential oils of *Satureja* genus can be utilized as flavoring agents in the food industry and are currently a compelling source of natural antimicrobials for food preservation, owing to their antibacterial, antifungal, and antioxidative properties. Carvacrol is the among the major compounds of the *Satureja* genus and is Generally Recognized as Safe (GRAS) for flavoring [190]. It was also determined that extracts of *Satureja* genus rich in phenolic acids (majorly rosmarinic acid) and flavonoids and related compounds (such as hesperidin and rutin) possessing antibacterial, antifungal and antioxidant activity. Extracts of *S. thymbra* were evaluated as natural antioxidants to extend the shelf life of fried potato chips. It was understood that the incorporation of the natural antioxidants into the packaging material results in active packaging that effectively prolongs the shelf life of the fried food [191].

8. Other Applications

S. kitaibelii extract is standardized in Serbia to the rosmarinic acid compound and produced in tablet and capsule form for use in respiratory diseases and digestive disorders. This product is not currently commercially available [192]. The extract and essential oil of *S. hortensis* with the extract, hydrosol and essential oil of *S. montana* are used in the cosmetic industry for fragrance and skin conditioning according to the CosIng - Cosmetics Ingredients, European Commission [193]. The genus *Satureja* is quite promising for the veterinary sector as well as the industries mentioned above. A veterinary dietary supplement prepared from *S. hortensis* extract at a concentration of 400 mg/kg was used as a natural feed addition to help broiler chickens maintain their growth and enhance their health [194]. *S. hortensis* essential oil can also be utilized in reducing the prevalence of important poultry diseases such as colibacillosis and salmonellosis or decreasing the severity of these diseases due to its antimicrobial and anti-biofilm properties. *Satureja* genus essential oils can be used as a poultry feed additive for both prevention and therapy [195].

7. Conclusion

In conclusion, the genus *Satureja* exhibits considerable potential as a natural resource for the pharmaceutical, cosmetic, food and veterinary industries. The taxa of the *Satureja* genus are important in terms of the compounds they contain with their biological activities. They also have great potential, especially in the development of new functional foods, beverages, cosmetics, and veterinary products in economic terms, with the development of innovative products.

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