Hindawi
BioMed Research International
Volume 2022, Article ID 3787818, 29 pages
https://doi.org/10.1155/2022/3787818

Review Article

Phytochemistry and Biological Properties of *Salvia verbenaca* L.: A Comprehensive Review

Hanae Naceiri Mrabti,[1] **Naoual El Menyiy**,[2] **Saoulajan Charfi**,[3] **Mohammed Saber**,[4] **Saad Bakrim**,[5] **Reema A. Alyamani**,[6] **Abdur Rauf**,[7] **Ahmed M. H. Ali**,[8,9] **Emad M. Abdallah**,[9] **Naserddine El Omari**,[10] **Abdelhakim Bouyahya**,[11] **and Hamza Assaggaf**[12]

[1]*Laboratory of Pharmacology and Toxicology, Bio Pharmaceutical and Toxicological Analysis Research Team, Faculty of Medicine and Pharmacy, Mohammed V University in Rabat, BP 6203 Rabat, Morocco*
[2]*Laboratory of Pharmacology, National Agency of Medicinal and Aromatic Plants, Taounate, 34025, Morocco*
[3]*Biology and Health Laboratory, Department of Biology, Faculty of Science, Abdelmalek-Essaadi University, Tetouan, Morocco*
[4]*Laboratory of Nanotechnology, Materials and Environment, Department of Chemistry, Faculty of Science, Mohammed V University in Rabat, Morocco*
[5]*Molecular Engineering, Valorization and Environment Team, Polydisciplinary Faculty of Taroudant, Ibn Zohr University, Agadir, Morocco*
[6]*Faculty of Applied Medical Sciences, Clinical Nutrition Department, Umm Al-Qura University, Makkah 24381, Saudi Arabia*
[7]*Department of Chemistry, University of Swabi, Khyber Pakhtunkhwa (KP), Pakistan*
[8]*Department of Zoology and Entomology, Faculty of Science, Assiut University, Assiut, Egypt*
[9]*Department of Science Laboratories, College of Science and Arts, Qassim University, Ar Rass, Saudi Arabia*
[10]*Laboratory of Histology, Embryology, and Cytogenetic, Faculty of Medicine and Pharmacy, Mohammed V University in Rabat, Morocco*
[11]*Laboratory of Human Pathologies Biology, Department of Biology, Faculty of Sciences, and Genomic Center of Human Pathologies, Faculty of Medicine and Pharmacy, Mohammed V University in Rabat, Morocco*
[12]*Department of Laboratory Medicine, Faculty of Applied Medical Sciences, Umm Al-Qura University, Makkah 24381, Saudi Arabia*

Correspondence should be addressed to Abdur Rauf; mashaljcs@yahoo.com

Received 4 February 2022; Accepted 10 May 2022; Published 24 May 2022

Academic Editor: Dorota Formanowicz

The family Lamiaceae contains several plants used in traditional medicine to fight against different diseases. *Salvia verbenaca* L. (*S. verbenaca*) is one of the Lamiaceae species distributed around the Mediterranean regions. This plant exhibits different bioactive properties, including antibacterial, anticancer, antioxidant, antileishmanial, antidiabetic, immunomodulatory, and wound healing. This review was conducted to revise previous studies on *S. verbenaca* addressing its botanical description, geographical distribution, and phytochemical, pharmacological, and toxicological properties. Moreover, the main pharmacological actions of *S. verbenaca* major compounds were well investigated. Literature reports have revealed that *S. verbenaca* possesses a pivotal role in medicinal applications. The findings of this work noted that *S. verbenaca* was found to be rich in chemical compound classes such as terpenoids, phenolics, fatty acids, sterols, and flavonoids. Numerous studies have found that *S. verbenaca* essential oils and extracts have a wide range of biological effects. These results support the potential pharmacological properties of *S. verbenaca* and its traditional uses. This analysis can constitute a scientific basis for further refined studies on its pure secondary metabolites. Therefore, the outcome of the present work may support the perspective of identifying new therapeutical applications with detailed pharmacological mechanisms of *S. verbenaca* to prevent the development of some diseases such as neurodegenerative disorders. However, toxicological investigations into *S. verbenaca* are needed to assess any potential toxicity before it can be further used in clinical studies.

1. Introduction

Since the beginning of time, medicinal plants have been and continue to be the primary source of medicine [1]. *Salvia verbenaca* L. (*S. verbenaca*) is a medicinal herb belonging to the family Lamiaceae, which is the most representative genus of *Salvia* [2, 3]. This plant is endemic to the Mediterranean region, including Morocco, Canaries Islands, Algeria, Tunisia, Libya, Egypt, and Cyprus, and has also spread to Europe and Asia [4]. In traditional medicines, *S. verbenaca* has been used to fight against numerous diseases; several ancient and current investigations revealed that *S. verbenaca* presents a chemical diversity in terms of chemical composition according to the chemical characteristics of the extracts from various parts. Indeed, *S. verbenaca* contains numerous secondary metabolites that belong to a wide variety of phytochemical classes [5]. *S. verbenaca* terpenoids have been revealed to have a large diversity due to several factors, including genetic, ecological, environmental, edaphic, and diverse plant parts [6]. An antibacterial potential against a wide range of gram-positive and gram-negative bacteria has been documented [7–11]. Consequently, the antibacterial efficacy of extracts and essential oils (EO) from *S. verbenaca* was remarkable against gram-positive bacteria compared to the gram-negative bacteria. Furthermore, *S. verbenaca* was found to have an antioxidant effect against free radical damage [12] and significantly reduce the level of intracellular reactive oxygen species (ROS) [13, 14]. According to previous studies, the anticancer properties of *S. verbenaca* extracts and essential oils have also been reported [15–19]. The antiparasitic properties of *S. verbenaca*, in particular, antileishmanial effects, have been investigated elsewhere [20].

Besides, *S. verbenaca* was reported to have an inhibitory effect of xanthine oxidase [21] and a healing effect on burns [22]. Furthermore, *S. verbenaca* revealed immunomodulatory effects [23]. Furthermore, the toxicological tests found that the ethanolic extract of *S. verbenaca* did not cause any toxic symptoms or death in rats [24].

The objective of the current article was to provide a general review of *S. verbenaca* such as botanical description, geographical distribution, phytochemistry, and pharmacological properties. Hopefully, this analysis could be a scientific basis for further refined studies on pure compounds from *S. verbenaca* that may lead to the identification of new therapeutical applications.

2. Research Methodology

All data about *S. verbenaca* (botanical description, taxonomy, destruction, phytochemical, and pharmacological properties) were collected using several databases like Web of Science, Google Scholar, Scopus, ScienceDirect, SpringerLink, Wiley Online, PubMed, and SciFinder and were reviewed in order to compile literature on *S. verbenaca*. The structures of the chemical profiles were identified in *S. verbenaca*, and the ChemDraw Pro 8.0 software was used to create the illustrations.

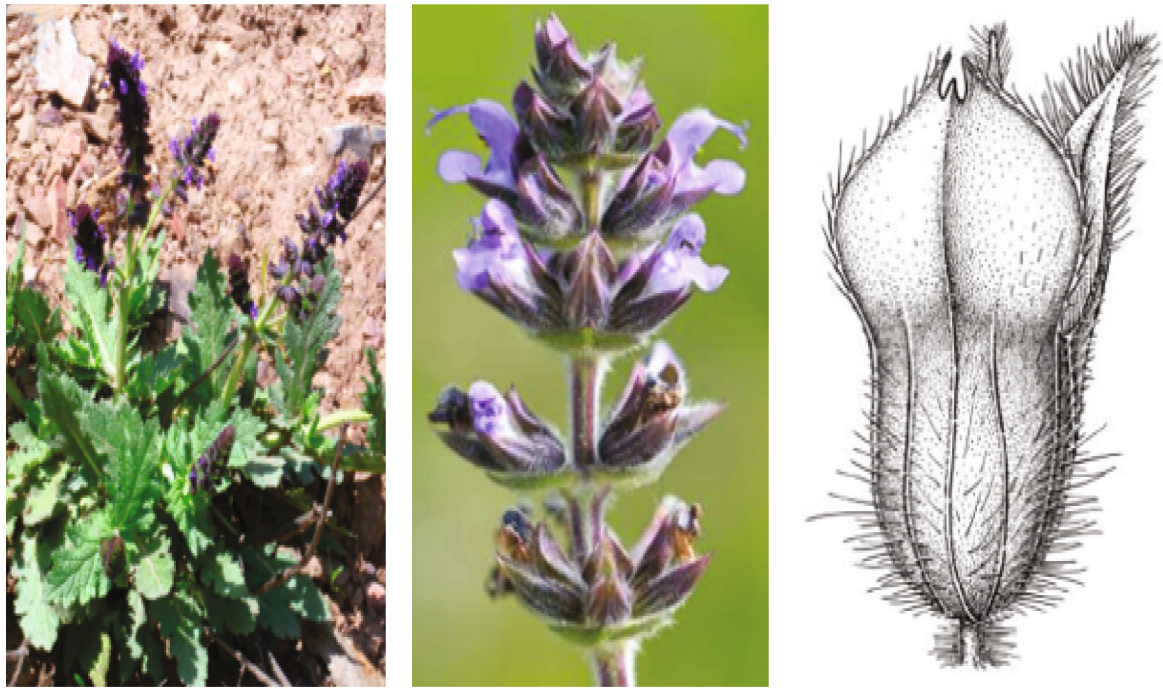
2.1. Botanical Description. S. verbenaca is a perennial herb that reaches between 10 and 50 cm (in height), hairy at the top, odorous, more or less glandular at the top. It grows in the dry lawns, the slopes, and at the edges of the paths. The slightly branched stems carry bunches of dark blue flowers in spring. Leaves are oblong, 2-3 cm broad, crenelated or incised-lobed, with the upper stalkless (Figure 1). The flowers are quite small, pale blue or whitish, in whorls usually close together, forming a fairly short cluster; the fruiting calyx with almost closed lips, bristling with spread hairs; the corolla is 10–15 mm, twice as long as the calyx, with wide lips, very uneven, the upper one compressed and curved in a false shape, and the style with little or prominent point [25].

2.2. Geographic Distribution. S. verbenaca has a very wide geographical distribution around the Mediterranean region, including Morocco, Algeria, Tunisia, Canaries, Egypt, Libya, Turkey, Cyprus, Transcaucasia, and Western and Southern Europe. It is also grown in South West Africa, North America, and Australia [5].

2.3. Ethnomedicinal Uses. The ethnobotanical investigations into *S. verbenaca* revealed its wide applications in folkloric medicine to treat numerous disorders as listed in Table 1. In Morocco, its application in folk medicinal systems includes the treatment of some digestive disorders such as abdominal colics [26–28]. The most commonly used part of the plant is the aerial part, which is prepared by infusion before being used to treat respiratory problems and genitourinary and skin diseases [27]. Dried leaves are also used for the treatment of wounds, burns, and abscesses [29]. Aerial parts are utilized in decoction or infusion to treat diabetes [30].

2.4. Phytochemistry. Like all medicinal plants belonging to the family Lamiaceae, *S. verbenaca* contains numerous secondary metabolites with different classes, such as flavonoids, terpenoids, alkaloids, and phenolic acids. Currently, several analytical investigations using different technical tools (GC, GC-SM, GC-MS, GC-FID, HPLC, 1D and 2D NMR, IR, UV, 1H NMR, and 13C NMR) have been applied to identify and isolate bioactive compounds from medicinal plants. Indeed, investigations into the chemical constituents of *S. verbenaca* revealed the presence of terpenoids, phenolics, fatty acids, flavonoids, and sterols (Table 2). As listed in Table 2, the chemical content of *S. verbenaca* was investigated in different areas with various medicinal applications by using different analytical tools. The results are different according to numerous factors, such as the study area, plant part used, and adopted methodology.

The terpenoids contained in the essential oils of *S. verbenaca* L. mostly consist of α-pinene, β-pinene, sabinene, 1,8-cineole, β-phellandrene, linalool, p-cymene, linalyl acetate, E-β-ocimene, (Z)-β-ocimene, tricyclene, camphor, 1,10-di-epi-cubenol, epi-13-manool, cis-muurola-3,5-diene, δ-selinene, *trans*-sabinene hydrate acetate, β-caryophyllene, viridiflorol, and germacrene D [31–33] (Table 1, Figure 2).



(a) (b) (c)

Figure 1: *Salvia verbenaca* L.: (a) whole plant; (b) aerial part; (c) flowers.

Table 1: Some medicinal applications of *S. verbenaca*.

Part used	Preparation	Traditional application	Ref.
Aerial part	Decoction, infusion	Diabetes	[30]
Leaf	Decoction, powder	Abdominal colics, cold, fever, healing	[26]
Leaf	Powder	Wound treatment	[29]
Leaf	Decoction, infusion	Genitourinary, skin, digestive, and respiratory problems	[27]
Aerial part	No information	Digestive problems	[28]
Leaf, whole plant	Powder	Healing of burns, wounds, and abscesses	[29]

NI: no information.

Belloum et al. [36] evaluated the volatile contents of the essential oil of *S. verbenaca* aerial parts using GC-MS and GC. In this sense, they recorded the presence of many terpenoids like germacrene D (20.5%), β-phellandrene (3.8%), α-copaene (10.4%), β-caryophyllene (3.8%), epi-α-cadinol (11.6%), and 1,10-di-epi-cubenol (20.9%). These compounds were the major terpenoids identified in *S. verbenaca* L. as reported elsewhere [31]. Moreover, in Spain, Taârit et al. [34] identified camphor (38.94%), 13-epi-manool (5.61%), and caryophyllene oxide (7.28%), from the essential oils of its seeds. A Greek study on *S. verbenaca* aerial parts has identified (E)-caryophyllene (16.1%) and β-phellandrene (30.3%) [34]. Moreover, Khemkham et al. [35] revealed *cis*-muurola-3,5 diene (14.6%) in the dried aerial parts of *S. verbenaca* as a major compound.

Al-Jaber et al. [25] compared the different parts of *S. verbenaca* volatile compounds collected from two locations in Jordan. Monoterpene hydrocarbons dominated the emission profile of stem, sepal, and leaf samples from the Mediterranean zone (68.0%, 33.7%, and 42.2%, respectively). Oxygenated monoterpenes controlled the production and emission of flowering components, including preflowering buds, fully grown flowers, and petals. Also, Taârit et al. [33] showed that the major compounds in EOs in *Salvia* aerial parts from the three Algerian regions were the monoterpene hydrocarbons and oxygenated sesquiterpenes. Additionally, the influence of collecting locations and phenophases on the production and chemical composition of *S. verbenaca* L. essential oils was examined by Farhat et al. [6]. In this study, it was reported that at the floral stage, monoterpene hydrocarbons (31.9%) prevail, whereas oxygenated sesquiterpenes (27.5%) predominate at the early fruiting stage. Sesquiterpene hydrocarbons were the most abundant chemical class at late fruiting (28.2%). Furthermore, Al-Jaber [32] reported that *S. verbenaca* EO was primarily composed of oxygenated monoterpenes (61.32%), with the monoterpene alcohol linalool serving as the sole monoterpene alcohol, whereas the essential oil obtained from the air-dried plant was primarily composed of sesquiterpene hydrocarbons (62.66%), with germacrene D serving as the major component (25.92%).

Table 2: Chemical composition of various parts of *S. verbenaca*.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
Aerial parts (dry)	Tunisia	Rass Zebib (subhumid)	Flowering period	EO	1,8-Cineole (9.7%), p-cymene (8.4%), α-pinene (5.4%), γ-terpinene (3.1%), beta-caryophyllene (5.3%), viridiflorol (7.3%), epi-13-manool (4.7%), thymol (3.7%), limonene (2.8%), camphor (2.7%)	GC and GC-MS	[6]
Aerial parts (dry)	Tunisia	Bir Mroua (subhumid)	Flowering period	EO	β-Caryophyllene (15.3%), germacrene D (7.1%), epi-13-manool (6.2%), α-copaene (6.1%), α-humulene (4.3%), α-cadinol (3.9%), viridiflorol (3.4%), p-cymene (3.3%), δ-cadinene (3.1%), p-cymen-8-ol (2.6%)	GC and GC-MS	[31–33]
Aerial parts (dry)	Tunisia	Beja (higher semiarid)	Flowering period	EO	β-Caryophyllene (15.3%), α-humulene (3.0%), viridiflorol (11.6%), 1,8-cineole (3.3%), germacrene D (3.3%), (Z)-β-ocimene (4.0%), T-cadinol (1.9%), p-cymene (2.8%), thymol (2.7%), epi-13-manool (2.5%)	GC and GC-MS	[6, 31]
Aerial parts (dry)	Tunisia	Tunis (higher semiarid)	Flowering period	EO	Viridiflorol (17.7%), 1,8-cineole (8.5%), α-pinene (4.6%), p-cymene (5.2%), β-caryophyllene (5.5%), thymol (4.4%), epi-13-manool (4.0%), α-humulene (2.4%), α-thujone (3.6%), γ-terpinene (2.4%)	GC and GC-MS	[31, 33, 34]
Aerial parts (dry)	Tunisia	Touiref (moderate semiarid)	Flowering period	EO	α-Pinene (15.9%), camphor (4.7%), 1,8-cineole (12.8%), viridiflorol (10.0%), (Z)-β-ocimene (5.4%), camphene (2.6%), β-caryophyllene (5.3%), thymol (4.2%), p-cymene (4.2%), α-thujone (3.4%)	GC and GC-MS	[31, 33, 35]
Aerial parts (dry)	Tunisia	Bou Arada (moderate semiarid)	Flowering period	EO	1,8-Cineole (9.4%), p-cymene (8.7%), viridiflorol (8.3%), α-pinene (4.9%), thymol (2.7%), β-caryophyllene (4.9%), α-humulene (3.5%), γ-terpinene (3.0%), α-thujone (3.0%), epi-13-manool (3.6%)	GC and GC-MS	[31–33]
Aerial parts (dry)	Tunisia	Sers (lower semiarid)	Flowering period	EO	α-Pinene (14.7%), viridiflorol (10.8%), β-caryophyllene (4.6%), (Z)-β-ocimene (4.5%), epi-13-manool (2.8%), thymol (4.4%), p-cymene (4.1%), camphor (3.5%), α-thujone (2.9%), 1,8-cineole (10.9%)	GC and GC-MS	[31–33]
Aerial parts (dry)	Tunisia	Enfidha (lower semiarid)	Flowering period	EO	Viridiflorol (10.5%), camphor (2.9%), epi-13-manool (10.5%), 1,8-cineole (8.7%), p-cymene (8.3%), α-terpineol (3.0%), α-pinene (4.5%), thymol (4.2%), γ-	GC and GC-MS	[31–33]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
					terpinene (3.2%), bornyl acetate (3.2%)		
Aerial parts (dry)	Tunisia	Chott Meriem (higher arid)	Flowering period	EO	p-Cymene (14.2), α-pinene (9.6), γ-terpinene (5.1), camphene (3.9), viridiflorol (5.1), limonene (3.4), epi-13-manool (3.2), thymol (2.5), 1,8-cineole (12.8)	GC and GC-MS	[31–33]
Aerial parts (dry)	Tunisia	Hencha (higher arid)	Flowering period	EO	Viridiflorol (10.0%), bicyclogermacrene (2.3%), germacrene D (5.6%), 1,8-cineole (4.9), epi-13-manool (4.7%), α-thujone (3.2%), β-pinene (3.0%), camphor (2.9%), α-humulene (2.5%), β-caryophyllene (7.2%)	GC and GC-MS	[31–33]
Aerial parts (dry)	Spain	Murcia	Flowering stage	EO	p-Cymene (11.4%), 1,8-cineole (7.7%), viridiflorol (7.0%), camphene (2.7%), β-caryophyllene (4.5%), β-pinene (2.7%), γ-terpinene (4.0%), epi-13-manool (3.9%), camphor (3.7%), α-pinene (8.1%)	GC and GC-MS	[6]
Aerial parts (dry)	Spain	Murcia	Early fruiting stage	EO	Caryophyllene oxide (12.4%), bornyl acetate (3.2%), viridiflorol (9.1%), β-caryophyllene (5.6%), p-cymene (5.6%), α-pinene (4.0%), epi-13-manool (2.3%), thymol (2.0%), β-ionone (2.0%), 1,8-cineole (6.3%)	GC and GC-MS	[6]
Aerial parts (dry)	Spain	Murcia	Late fruiting stage	EO	β-Caryophyllene (14.2%), α-thujone (8.2%), 8-cineole (4.7%), epi-13-manool (7.1%), bornyl acetate (3.5%), α-humulene (6.7%), 1 α-pinene (4.3%), caryophyllene oxide (3.0%), β-pinene (2.8%), viridiflorol (13.5%)	GC and GC-MS	[6]
Aerial parts	Algeria	Bechar	April 2011	EO	Epi-α-cadinol (11.6%), β-caryophyllene (11.33%), bicyclogermacrene (10.9%), γ-cadinene (7.9%), *cis*-muurola-4(14),5-diene (7.8%), muurola-3,5-diene (5.2%), spathulenol (3.0%), *cis*-calamenene (2.0), α-humulene (1.9), 1,10-di-epi-cubenol (20.9%)	GC and GC-MS	[31]
Aerial parts (fresh)	Jordan	Shafa-Badran-Amman	Flowering period (April to May 2011)	EO	Linalool (61.32%), β-elemene (1.50%), (Z)-β-ocimene (4.03%), β-eudesmol (3.66%), spathulenol (3.40%), *E*-β-ocimene (2.63%), β-caryophyllene (2.98%), α-copaene (2.50%), γ-cadinene (1.55%), bicyclogermacrene (5.94%)	GC-MS and GC-FID	[32]
	Jordan			EO		GC and GC-MS	[32]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
Aerial parts (dry)		Shafa-Badran-Amman	Flowering period (April to May 2011)		Linalool (30.72%), bicyclogermacrene (14.70%), β-caryophyllene (7.42%), germacrene D (25.92%), α-copaene (5.13%), isopentyl isovalerate (0.97%), δ-cadinene (2.05%), (Z)-β-ocimene (1.18%), spathulenol (1.58%), α-gurjunene (1.07%)		
Stem	Jordan	Mediterranean	Full maturation period	EO	*Z*-β-Ocimene (32.6%), *trans*-sabinene hydrate acetate (14.5%), α-gurjunene (6.0%), β-bourbonene (1.5%), *E*-β-ocimene (7.8%), sabinene (2.9%), α-phellandrene (3.1%), germacrene D (1.6%), α-pinene (9.3%), β-pinene (8.1%)	GC-MS and GC-FID	[32]
	Jordan	Irano-Turanian	Full maturation period	EO	*trans*-Sabinene hydrate acetate (38.1%), *E*-caryophyllene (9.1%), δ-selinene (5.2%), β-gurjunene (2.5%), sabinene (4.8%), $\delta\alpha$-copaene (4.1%), γ-gurjunene (2.9%), cadinene (4.3%), β-selinene (2.2%), germacrene D (13.3%)	GC and GC-MS	[32]
Leaves	Jordan	Mediterranean	Full maturation period	EO	*trans*-Sabinene hydrate acetate (30.2%), β-bourbonene (7.7%), E-β-ocimene (4.3%), α-pinene (3.0%), α-gurjunene (13.8%), β-selinene (2.8%), δ-cadinene (2.5%), β-pinene (2.4%), myrcene (2.0%), Z-β-ocimene (17.1%)	GC and GC-MS	[32]
Leaves	Jordan	Irano-Turanian	Full maturation period	EO	δ-Selinene (21.5%), *E*-caryophyllene (11.4%), terpinolene (4.3%), α-copaene (9.6%), sabinene (9.0%), *Z*-β-ocimene (4.8%), β-cubebene (4.4%), δ-cadinene (2.7%), *cis*-β-guaiene (2.0%), germacrene D (19.8%)	GC and GC-MS	[32]
Preflower	Jordan	Mediterranean	Full maturation period	EO	*trans*-Sabinene hydrate acetate (56.5%), α-pinene (6.5%), myrcene (1.5%), *E*-β-ocimene (4.3%), α-gurjunene (3.2%), β-pinene (5.3%), sabinene (1.2%), *trans*-β-guaiene (1.0%), limonene (0.7%), *Z*-β-ocimene (13.5%)	GC and GC-MS	[32]
Preflower	Jordan	Irano-Turanian	Full maturation period	EO	Sabinene (42.7%), α-thujene (7.2%), γ-terpinene (6.1%), *E*-β-ocimene (1.9%), α-terpinene (3.6%), β-pinene (3.2%), β-phellandrene (6.8%), terpinolene (1.6%), limonene (1.0%), *trans*-sabinene hydrate (20.4%)	GC and GC-MS	[32]
Flower	Jordan	Mediterranean		EO		GC and GC-MS	[32]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
			Full maturation period		*trans*-Sabinene hydrate acetate (58.6%), *E*-β-ocimene (5.3%), α-pinene (5.2%), sabinene (1.1%), β-pinene (4.9%), α-phellandrene (1.4%), α-gurjunene (1.0%), camphene (0.4%), isobornyl acetate (0.4%), *Z*-β-ocimene (18.8%)		
	Jordan	Irano-Turanian	Full maturation period	EO	Sabinene (37.5%), *Z*-β-ocimene (9.9%), α-thujene (4.6%), myrcene (4.2%), β-pinene (3.9%), *E*-β-ocimene (8.9%), γ-terpinene (3.0%), *E*-caryophyllene (1.9%), α-terpinene (1.4%), *trans*-sabinene hydrate (20.0%)	GC and GC-MS	[32]
Petal	Jordan	Mediterranean	Full maturation period	EO	*trans*-Sabinene hydrate acetate (87.0%), *E*-β-ocimene (1.5%), germacrene D (1.0%), α-phellandrene (0.5%), β-pinene (0.3%), α-gurjunene (1.7%), n-nonane (0.2%), myrcene (0.2%), β-selinene (0.2%), *Z*-β-ocimene (7.1%)	GC and GC-MS	[32]
Petal	Jordan	Irano-Turanian	Full maturation period	EO	*trans*-Sabinene hydrate (18.8%), *E*-β-ocimene (9.9%), γ-terpinene (2.9%), germacrene D (9.6%), β-copaene (4.1%), α-copaene (3.2%), *E*-caryophyllene (13.9%), β-selinene (2.9%), γ-gurjunene (2.8%), *Z*-β-ocimene (9.6%)	GC and GC-MS	[32]
Sepal	Jordan	Mediterranean	Full maturation period	EO	*trans*-Sabinene hydrate acetate (36.6%), β-pinene (14.0%), 8-cineole (3.9%), *Z*-β-ocimene (4.5%), 1 δ-elemene (2.8%), β-cedrene (8.7%), sabinene (2.7%), camphene (1.9%), β-cubebene (1.9%), α-pinene (18.1%)	GC and GC-MS	[32]
Sepal	Jordan	Irano-Turanian	Full maturation period	EO	*trans*-Sabinene hydrate (58.8%), terpinolene (5.0%), *E*-β-ocimene (4.1%), p-methyl-acetophenone (3.2%), germacrene D (3.1%), *Z*-β-ocimene (4.9%), δ-selinene (2.0%), γ-terpinene (1.7%), δ-cadinene (1.3%), *E*-caryophyllene (5.6%)	GC and GC-MS	[32]
Aerial parts	Algeria	Mogheul	April 2011	EO	Germacrene D (20.5%), β-caryophyllene (3.8%), beta-cubebene (2.7%), δ-cadinene (2.6%), 1,10-di-epi-cubenol (2. 6%), γ-cadinene (2.5%), (E)-β-farnesene (3.5%), bicyclogermacrene (2.2%), α-muurolol (2.1%), α-copaene (10.4%), β-phellandrene (3.8%)	GC and GC-MS	[36]
Seeds	Spain	—	—	EO		GC-MS and GC-FID	[33]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
					Camphor (38.94%), 13-*epi*-manool (5.61%), -***d***-elemene (3.93%), beta-eudesmol (3.76%), *n*-undecane (2.65%), *α*-terpinyl acetate (4.77%), linalyl acetate (2.53%), neryl acetate (2.40%), *α*-terpineol (2.03%), caryophyllene oxide (7.28%)		
Aerial parts	Greece	Crete Island	Blossoming (April 2004)	EO	Beta-phellandrene (30.3%), methyl ester of 6-octadecenoic acid (15.0%), camphor (7.0%), (*Z*)-*β*-ocimene (6.6%), fenchone (9.4%), isopropyl ester (7.8%), aromadendrene (4.0%), *α*-humulene (3.7%), (*E*)-caryophyllene (16.1%)	GC and GC-MS	[34]
Aerial parts (fresh)	Sicily	Piano Battaglia	Full flowering stage (July 2009)	EO	Hexadecanoic acid (23.1%), ethyl hexadecanoate (2.6%), benzaldehyde (7.3%), 9,12,15-octadecatrienal (2.9%), limonene (2.0%), (*E*)-*β*-ionone (1.9%), (*Z*)-9-octadecenoic acid (11.9), phenyl acetaldehyde (1.5%), (*E*)-caryophyllene (1.2%), *β*-phellandrene (5.9%)	GC and GC-MS	[8]
Aerial parts	Algeria	Djelfa	March 2019	EO	*cis*-Muurola-3,5-diene (14.6%), unknown (10.5%), bicyclogermacrene (6.8%), bicycloelemene (4.3%), *γ*-cadinene (4.8%), *β*-pinene (4.2%), 2,3-dehydro-1,4-cineol (3.7%), *α*-cubebene (3.0%), *α*-pinene (2.8%), *γ*-amorphene (10.5%)	GC and GC-MS	[35]
Leaves and flowers (dried)	Turkey	Kütahya-Gediz	2016-2017	EO	Linalyl acetate (81.97%), *β*-myrcene (2.73%), *n*-pentanal (0.42%), beta-ocimene (0.39%), hexanal (0.34%), *α*-pinene (0.34%), limonene (1.14%), *trans*-caryophyllene (0.32%), *β*-pinene (0.31%), linalool (8.66%)	GC and GC-MS	[37]
Aerial parts (wild)	Sicily	Piano Battaglia	Full flowering stage (July 2009)	EO	Hexadecanoic acid (23.1%), benzaldehyde (7.3%), b-phellandrene (5.9%), limonene (2.0%), 9,12,15-octadecatrienal (2.9%), ethyl hexadecanoate (2.6%), caryophyllene oxide (1.9%), (*E*)-*b*-ionone (1.9%), spathulenol (1.7%), (*Z*)-9-octadecenoic acid (11.1%)	GC and GC-MS	[19]
Aerial parts (cultivated)	Sicily	Piano Battaglia	July 2010	EO	Hexadecanoic acid (11.0%), (*E*)-*b*-ionone (3.9%), (*Z*)-9-octadecenoic acid (5.6%), *b*-phellandrene (4.1%), caryophyllene oxide (2.8%), (*E*)-caryophyllene (3.8%), methyl hexadecanoate (3.8%), carvacrol	GC and GC-SM	[19]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
					(2.4%), spathulenol (2.0%), hexahydrofarnesyl acetone (9.7%)		
Fruits	Tunisia	Sabelet Ben Ammar	Full fruit ripening stage	EO	β-Caryophyllene (23.1%), camphene (6.5%), α-humulene (5.6%), germacrene D (3.5%), viridiflorol (4.3%), 1-octen-3-ol (3.9%), (*E*)-β-ocimene (1.5%), 1,8-cineole (3.0%), manool (1.1%), caryophyllene oxide (15.9%)	GC and GC-MS	[33]
Stems	Tunisia	Sabelet Ben Ammar	Full fruit ripening stage		Camphor (10.9%), terpinolene (6.6%), methyl eugenol (6.1%), α-pinene (5.9%), α-thujone (3.1%), 1,8-cineole (5.8%), caryophyllene oxide (4.5%), aromadendrene (3.6%), epi-13-manool (2.3%), viridiflorol (10.3%)	GC and GC-MS	[33]
Leaves	Tunisia	Sabelet Ben Ammar	Full fruit ripening stage		epi-13-Manool (13.7%), camphor (3.9%), caryophyllene oxide (3.9%), α-pinene (3.4%), p-cymen-8-ol (3.7%), terpinen-4-ol (3.6%), 1,8-cineole (3.0%), eugenol (2.8%), (*E*)-β-ocimene (2.6%), manool (11.0%)	GC and GC-MS	[33]
Aerial parts	Tunisia	Sabelet Ben Ammar	Full fruiting stage (April 2007)	EO	Viridiflorol (21.6%), methyl eugenol (9.4%), α-terpineol (5.3%), spathulenol (3.7%), β-caryophyllene (7.1%), caryophyllene oxide (2.4%), epi-13-manool (2.2%), germacrene D (1.9%), eugenol (1.8%), camphene (17.6%)	GC and GC-MS	[33]
Aerial parts	Tunisia	Sers	Full fruiting stage (April 2007)		(*Z*)-β-ocimene (29.5%), beta-thujone (7.9%), α-pinene (5.5%), tricyclene (5.1%), 18-cineole (1.9%), α-calacorene (2.5%), terpinen-4-ol (2.1%), germacrene D (3.1%), β-caryophyllene (1.8%), β-phellandrene (8.2%)	GC and GC-MS	[33]
Aerial parts	Tunisia	Somaa			Tricyclene (18.8%), nonane (10.3%), terpinolene (7.3%), -terpineol (2.2%), bornyl acetate (4.9%), camphor (2.9%), α-terpinyl acetate (3.5%), limonene (2.3%), α β-eudesmol (2.2%), methyl eugenol (7.7%)	GC and GC-MS	[33]
Seeds	Tunisia	Sabelet Ben Ammar	Full ripeness (April 2007)	EO	Camphor (33.83%), caryophyllene oxide (10.11%), octane (4.78%), 13-epi-manool (3.57%), hexanal (2.46%), β-bisabolene (1.84%), α-terpineol (3.24%), tricyclene (5.54%), α-copaene (3.19%), α-thujene (13.36%)	GC-MS and GC-FID	[33]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
Seeds	Tunisia	Sabelet Ben Ammar	Full ripeness (April 2007)	Lipid extraction	Palmitic acid (9.25%), stearic acid (2.48%), linolenic acid (45.89%), arachidic acid (0.20%), C18:3n-3/C18:2n-6 (1.67%), SFA (11.93%), USFA (88.07%), oleic acid (14.67%), linoleic acid (27.39%), palmitoleic acid (0.12%)	GC and GC-MS	[33]
Seeds	Tunisia	Sers	Full ripeness (April 2007)	EO	β-Pinene (48.08%), epi-cubebol (10.74%), β-eudesmol (1.00%), α-bisabolol (2.97%), caryophyllene oxide (2.90%), spathulenol (0.93%), eugenol (0.97%), geraniol (0.95%), borneol (1.97%), germacrene D (2.09%)	GC and GC-MS	[33]
Seeds	Tunisia	Sers	Full ripeness (April 2007)	Lipid extraction	Palmitic acid (9.63%), oleic acid (14.14%), linoleic acid (23.79%), linolenic acid (42.84%), SFA (18.35%), USFA (81.65%), stearic acid (4.22%), arachidic acid (4.50%), C18:3n-3/C18:2n-6 (1.53%), palmitoleic acid (0.89%)	GC and GC-MS	[33]
Seeds	Tunisia	Somaa	Full ripeness (April 2007)	EO	Octane (27.39%), δ-cadinene (5.77%), p-cymene (1.64%), camphor (3.53%), bicyclogermacrene (1.86%), β-pinene (3.74%), α-terpineol (1.38%), limonene (0.79%) n-nonane (18.01%), epi-cubebol (9.02%)	GC and GC-MS	[33]
Seeds	Tunisia	Somaa	Full ripeness (April 2007)	Lipid extraction	Palmitic acid (12.11%), stearic acid (3.02%), linoleic acid (25.33%), arachidic acid (1.30%), SFA (16.43%), linolenic acid (41.71%), oleic acid (15.51%), USFA (83.57%), C18:3n-3/ C18:2n-6 (1.65%), palmitoleic acid (1.02%)	GC and GC-MS	[33]
Aerial part	Algeria	Bordj Bou Arreridj	Flowering stage (spring April-May)	Crude extract (CrE)	Flavonoids (08.40 ± 0.32 mg EQ/ g E), polyphenols (177.56 ± 2.51 mg EGA/g E)	Spectrophotometrically	[21]
Aerial part	Algeria	Bordj Bou Arreridj		Chloroform extract (ChE)	Flavonoids (14.87 ± 0.81 mg EQ/ g E), polyphenols (156.81 ± 1.57 mg EGA/g E)	Spectrophotometrically	[21]
Aerial part	Algeria	Bordj Bou Arreridj		Ethyl acetate extract (EAE)	Flavonoids (28.81 ± 0.38 mg EQ/ g E), polyphenols (661.78 ± 4.00 mg EGA/g E)	Spectrophotometrically	[21]
Aerial part	Algeria	Bordj Bou Arreridj		Aqueous extract (AqE)	Flavonoids (06.74 ± 0.14 mg EQ/ g E), polyphenols (123.18 ± 4.20 mg EGA/g E)	Spectrophotometrically	[21]
Aerial part	Algeria	Laghouat	May 2004	80% (v/v) aqueous methanol	Flavonoids (3.04 ± 0.01 mg RE/g dw), total phenols (7.2 ± 0.04 mg GAE/g dw), flavonols (0.85 ± 0.001 mg QE/g dw)	Spectrophotometrically	[12]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
Aerial part	Algeria	Setif and Batna	2016	Decoction	Total phenols (129.02 ± 2.67 mg GAE/g DW), total flavonoid contents (18.62 ± 0.06 mg QE/g DW), total tannin contents (73.80 ± 2.23 mg TAE/g DW) Total carotenoid contents (0.92 ± 0.041 mg/g DW) Total chlorophyll A (1.21 ± 0.02 mg/g DW) Total chlorophyll B (2.48 ± 0.04 mg/g DW)	Spectrophotometrically	[13]
Aerial part	Algeria	Setif and Batna	2016	Methanol extract (85%)	Total phenols (190.16 ± 1.74 mg GAE/g DW) Total flavonoid contents (23.50 ± 0.71 mg QE/g DW) Total tannin contents (118.88 ± 1.25 mg TAE/g DW) Total carotenoid contents (0.58 ± 0.005 mg/g DW) Total chlorophyll A (1.67 ± 0.02 mg/g DW) Total chlorophyll B (0.63 ± 0.01 mg/g DW)	Spectrophotometrically	[13]
Aerial part	Turkey	Artvin	06th September 2004	Methanol extracts	Rosmarinic acids (29.30 ± 0.24 $\mu g\,mg^{-1}$)	Spectrophotometrically	[38]
					Rosmarinic acids (26.12 ± 0.73 $\mu g\,mg^{-1}$)	HPLC	[6]
Aerial parts	Tunisia	Tunis (higher semiarid)	Flowering stage (March and April 2008)	Methanolic extracts	*Phenolic acids* p-Hydroxybenzoïc acids (229.87 ± 8.60 $\mu g/g$), p-coumaric acid (77.65 ± 5.67 $\mu g/g$), rosmarinic acid (1688.01 ± 63.42 $\mu g/g$), vanillic acid (20.21 ± 0.46 $\mu g/g$), caffeic acids (97.29 ± 2.86 $\mu g/g$), ferulic acids (40.41 ± 3.32 $\mu g/g$) *Phenolic diterpenes* Carnosic acids (63.52 ± 15.30 $\mu g/g$), methyl carnosate contents (633.37 ± 11.66 $\mu g/g$), carnosol (25.52 ± 7.27 $\mu g/g$) *Flavonoids* Naringenins (940.41 ± 22.50 $\mu g/g$), cirsiliols (73.16 ± 1.72 $\mu g/g$), luteolins (13.84 ± 2.62 $\mu g/g$), apigenins (3.01 ± 0.69 $\mu g/g$), naringins (57.30 ± 3.55 $\mu g/g$), hesperidins (21.74 ± 3.2 $\mu g/g$), genkwanins (2.80 ± 0.72 $\mu g/g$)	HPLC-UV	[6]
Aerial parts	Tunisia	Bir Mroua (subhumid)	Flowering stage (March and April 2008)	Methanolic extracts	*Phenolic acids* p-Hydroxybenzoïc acids (382.79 ± 11.98 $\mu g/g$), caffeic acid (191.19 ± 27.72 $\mu g/g$), rosmarinic acid (2503.96 ± 224.40 $\mu g/g$), p-coumaric acid (133.78 ± 1.88 $\mu g/g$), ferulic acid (72.89 ± 0.86 $\mu g/$	HPLC-UV	[6]

Table 2: Continued.

Part used	Country	Harvest site	Harvest season	Extracts/ essential oils	Chemical composition	Analysis	References
					g), vanillic acid (14.51 ± 0.46 μg/g) *Phenolic diterpenes* Carnosic acids (67.95 ± 3.73 μg/g), carnosols (32.09 ± 1.46 μg/g) *Flavonoids* Naringenins (1402.07 ± 5.17 μg/g), luteolins (21.14 ± 2.03 μg/g), hesperidins (84.48 ± 4.67 μg/g), apigenins (13.56 ± 0.51 μg/g), cirsiliols (53.18 ± 3.15 μg/g), genkwanins (2.53 ± 0.57 μg/g), naringins (36.79 ± 2.83 μg/g) *Phenolic acids* p-Hydroxybenzoic acids (51.18 ± 3.76 μg/g), caffeic acids (50.77 ± 3.04 μg/g), ferulic acids (74.55 ± 16.66 μg/g), p-coumaric acids (22.51 ± 0.84 μg/g), rosmarinic acids (475.74 ± 7.45 μg/g), vanillic acids (9.59 ± 0.91 μg/g)		
Aerial parts	Tunisia	Hencha (higher arid)	Flowering stage (March and April 2008)	Methanolic extracts	*Phenolic diterpenes* Methyl carnosate (1159.73 ± 41.68 μg/g), carnosic acids (55.47 ± 1.60 μg/g) *Flavonoids* Naringenins (254.82 ± 22.14 μg/g), cirsiliols (57.89 ± 3.81 μg/g), luteolins (51.65 ± 2.42 μg/g), apigenins (23.95 ± 1.00 μg/g), genkwanins (2.65 ± 0.12 μg/g), hesperidins (24.19 ± 1.21 μg/g), naringins (20.26 ± 0.50 μg/g)	HPLC	[6]
Aerial parts (dried)	Saudi Arabia	Assir	18th February 2001	Alcoholic extract	Verbenacines and salvinines	1D and 2D NMR	[39]
Roots (dried)	Algeria	Batna	—	Acetone extract	6,7-Dehydroroyleanones, cryptanol, sitosterols, campesterols, 6-hydroxysalvonolones, microstegiols, stigmasterols	IR, UV, 1H 13C NMR, and NMR	[40]

Chemical heterogeneity of EOs was isolated from three distinct *S. verbenaca* tissues (leaves, twigs, and stem). In this regard, the EO of *S. verbenaca* from the fruits contains the highest concentrations of -caryophyllene (23.1%) and caryophyllene oxide (15.9%), while the EO from the stems contains the highest concentrations of camphor and viridiflorol and, and in comparison, the leaf oil contains the highest concentrations of epi-13-manool and manool [33].

Regarding phenolic acid compounds, several phenolic compounds were identified in the *S. verbenaca* methanolic extract, which was the phenolic acid with six compounds: p-hydroxybenzoic acid, vanillic acid, rosmarinic acid, p-coumaric acid, caffeic acid, phenolic diterpenes, and ferulic acid, with three compounds: carnosol, carnosic acid, and methyl carnosate [6] (Table 1, Figure 3). In Turkey, Tepe et al. [38] extracted rosmarinic acid from the dried methanolic extracts of this plant.

Moreover, Farhat et al. [6] have identified several flavonoids in methanol extract from aerial parts of Tunisian *S. verbenaca L* such as luteolin, apigenin, genkwanin, cirsiliol, naringenin, hesperidin, and naringin (Table 1, Figure 4).

Certain fatty acids were found in *S. verbenaca* (Table 1). Taârit et al. [33] identified approximately eight constituents (oleic acid, linoleic acid, arachidic acid, linolenic acid, palmitic acid, stearic acid, palmitoleic acid, and ethyl palmitate) (Figure 5). Russo et al. [19] isolated several interesting fatty acids from essential oils of *S. verbenaca* aerial parts,

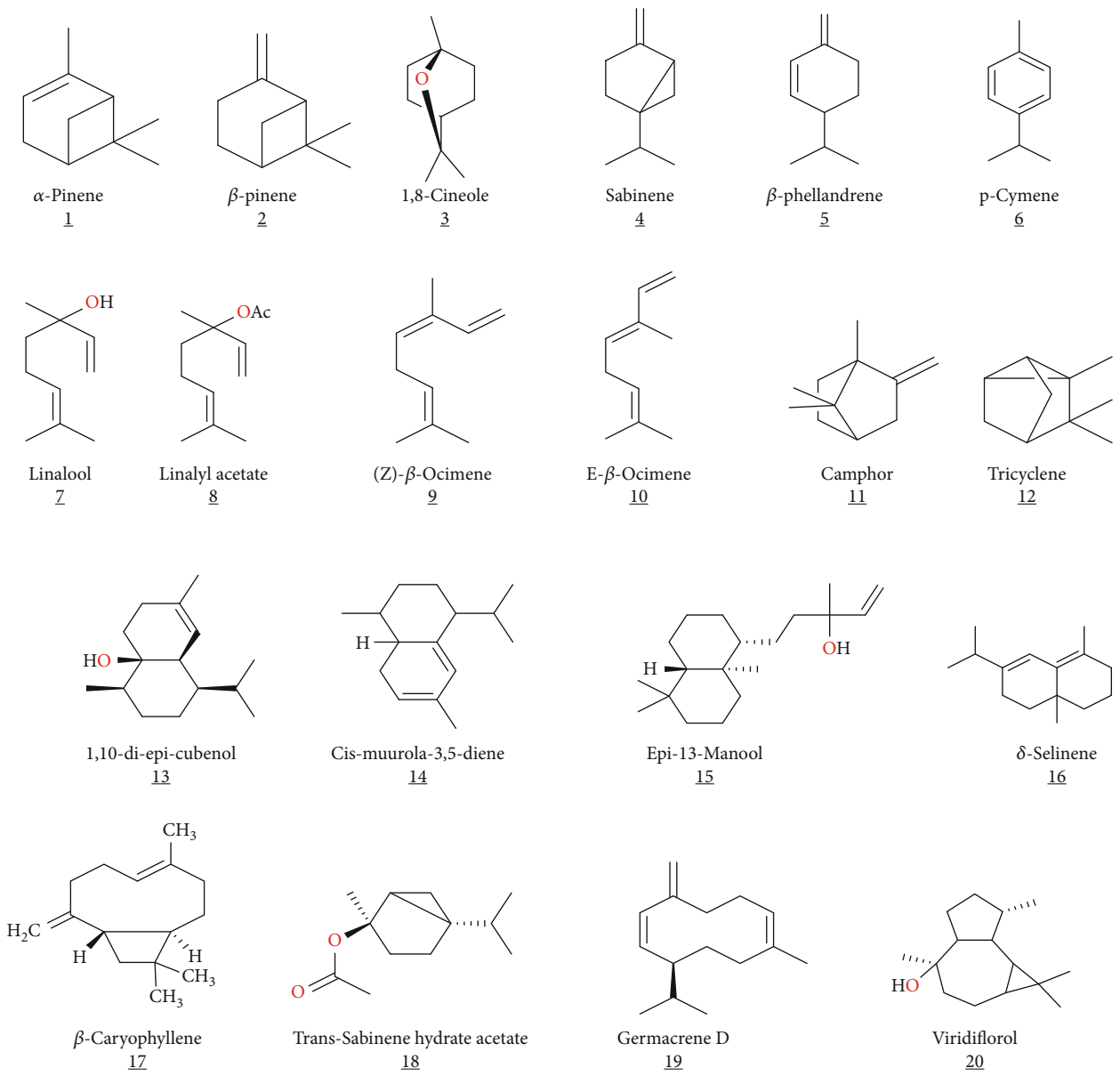


Figure 2: Terpenoid structures identified from *S. verbenaca* EO.

including (Z)-9-octadecenoic acid (oleic acid), hexadecanoic acid (palmitic acid), methyl hexadecanoate (methyl palmitate), and ethyl hexadecanoate (ethyl palmitate).

Additionally, Kabouche et al. [40] on the roots of *S. verbenaca* allowed the isolation of other secondary metabolites including five sterols (campesterol, stigmasterol, sitosterol, 6-hydroxysalvonolone, and microstegiol) and two diterpenes (6,7-dehydroroyleanone, cryptanol). Ahmed et al. [39] isolated two new diterpenes, namely, verbenacine and salvinine, from *S. verbenaca* aerial parts (Table 1, Figure 6).

2.5. Bioeffective Properties. Different parts of *S. verbenaca* exhibit the presence of several bioactive molecules of antibacterial, antileishmanial, antioxidant, and anticancer activities (Figure 7).

2.5.1. Antibacterial Activity. The EOs and other organic extracts of *S. verbenaca* showed effective antibacterial effects against various gram-negative and gram-positive bacteria [7, 8, 10]. The inhibition zone diameter of *S. verbenaca* extracts and EOs and/or the minimum inhibitory concentration (MIC) are presented in (Table 3).

In Turkey, Sarac and Ugur [10] investigated the antibacterial potential of the ethanol extract from *S. verbenaca* aerial parts; they found that the extract showed a weak antibacterial activity, with IZD between 9 and 11 mm against the gram-positive bacteria *Staphylococcus epidermidis* (MU 30) ($\Phi = 9$ mm), *Bacillus subtilis* (ATCC 6633) ($\Phi = 9$ mm), *S. aureus* (MU 44) ($\Phi = 10$ mm), *S. aureus* (MU 38) ($\Phi = 9$ mm), and *S. aureus* (ATCC 25923) ($\Phi = 11$ mm), and no activity was seen against *Streptococcus mutans* (CNCTC8/77) and *Micrococcus luteus* (NRRL B-4375) and

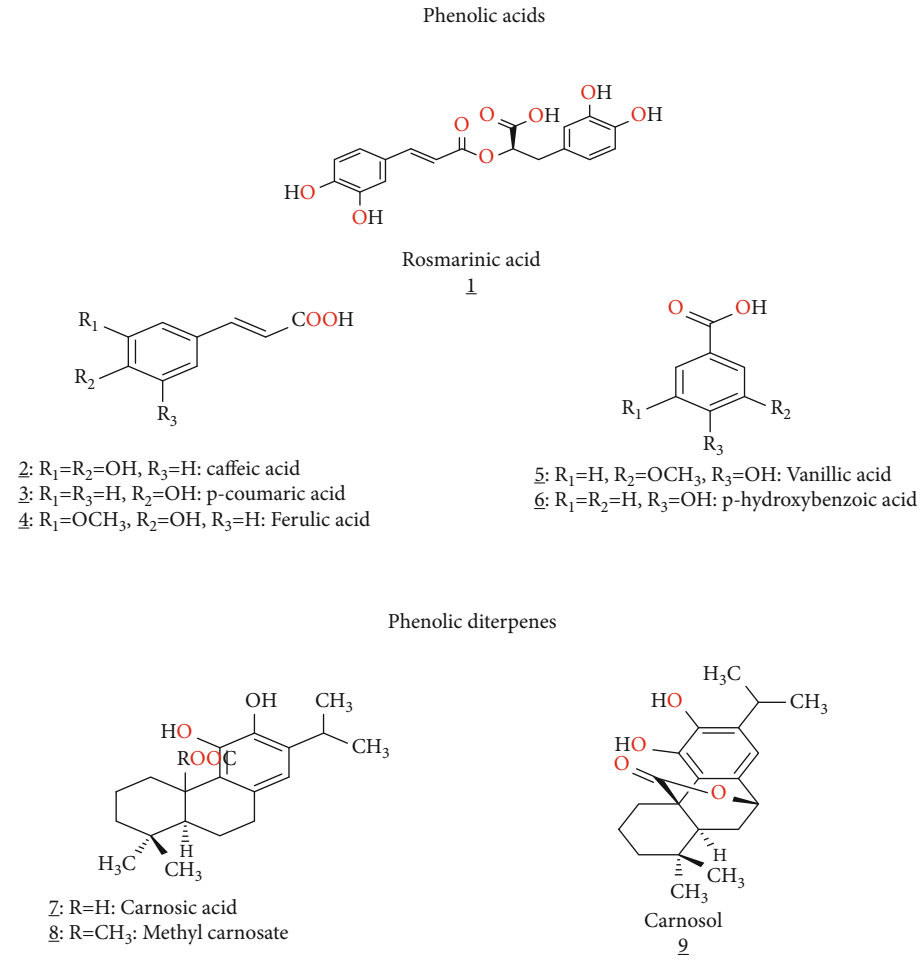


Figure 3: Phenolic acids and phenolic diterpenes isolated from *S. verbenaca*.

nor gram-negative bacteria, *P. fluorescens* (MU87), *Escherichia coli* (ATCC25922), *Pseudomonas stutzeri* (MU70), *Pseudomonas aeruginosa* (ATCC27853), *Stenotrophomonas maltophilia* (MU64), *Chryseomonas luteola* (MU65), and *S. maltophilia* (MU99). Moreover, the ethanolic extract prepared from 12 *S. verbenaca* exhibited lower antimicrobial activity than the methanolic extracts, as found by Kostić et al. [9].

The investigation of the methanol extract from aerial parts of Tunisian *S. verbenaca* demonstrated that the extract had a high antibacterial potential (MIC = 500 μg/mL) against six bacteria isolated from the mouths of patients [42]. However, a South African extract of *S. verbenaca* that was made with methanol and chloroform had strong antibacterial properties against *Klebsiella pneumoniae*, *Bacillus cereus*, *Escherichia coli*, and *Staphylococcus aureus* [11]. Moreover, Belkhiri et al. [21] compared the antibacterial potential of four fractions from the methanol extract of Algerian *S. verbenaca*: chloroform extract, crude extract, aqueous extract, and ethyl acetate extract. They have found that the antibacterial efficacy increases with the concentration of the extract. Al-Zereini [7] also found that the ethyl acetate extract prepared from the leaves of *S. verbenaca* from Jordan had dose-dependent antibacterial properties against *Bacillus brevis* (ATCC 9999) and *Bacillus subtilis* (ATCC 6633). On the other hand, the extract had no effect on *Klebsiella pneumoniae* (ATCC 13883), *Staphylococcus aureus* (ATCC 43300), and *Escherichia coli* (ATCC 25922). Canzoneri et al. [8] found that the EO of *S. verbenaca* aerial parts has potential antibacterial effects, and this activity is much higher against gram-positive bacteria than gram-negatives.

2.5.2. Antioxidant Activity. The antioxidant potential of *S. verbenaca* extracts was investigated by several researchers [12, 21, 23, 38, 42–44], and Table 4 summarizes the majority of the investigations that were carried out on different parts of *S. verbenaca*, collected from different regions.

Kostić et al. [41] evaluated the antioxidant potential of different *S. verbenaca* extracts using the beta-carotene/linoleic acid system and DPPH assay. They found that the methanol extract had the highest activity in the DPPH method, while the ethanolic extract obtained by ultrasound extraction was the most active metabolite of beta-carotene/linoleic acid. The antioxidant activity of hydromethanolic extract prepared from stems and leaves of Moroccan species was carried out by Khlifi et al. [44]. The results showed that the extract had a significant antioxidant effect at 100 μg/mL,

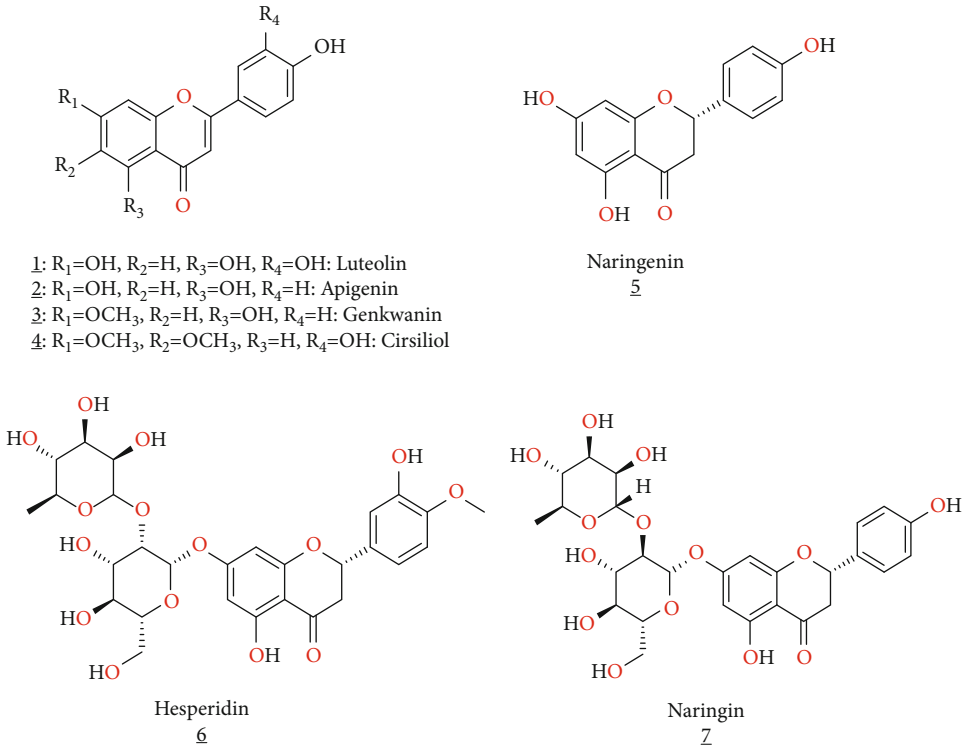


Figure 4: Flavonoids of *S. verbenaca* extracts.

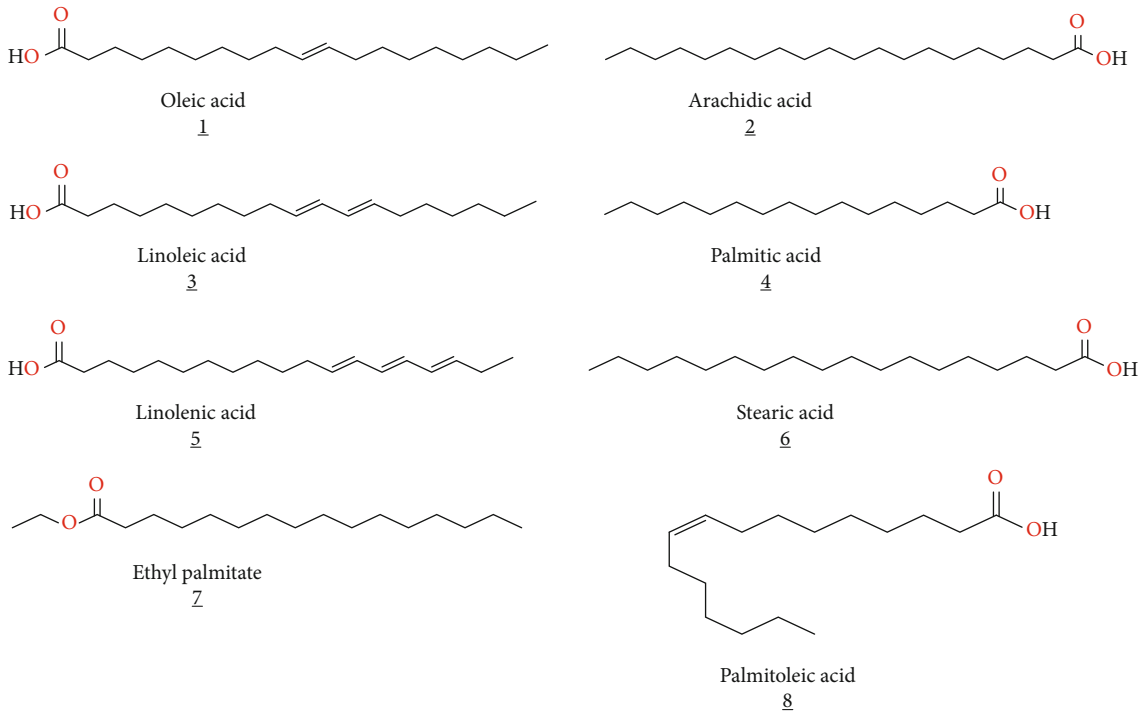


Figure 5: Some fatty acids isolated from *S. verbenaca* extracts.

with a strong inhibition of oxygen consumption compared to previous studies [38].

The antioxidant potential of Tunisian *S. verbenaca* extracts was also studied [42], and the results showed that methanolic extract from aerial parts had lower activity (IC_{50} = 86.9 μg/mL) compared to the positive control, which was the trolox (IC_{50} = 23.12 μg/mL) using the DPPH assay. In addition, it was reported that the antioxidant activity over 20 minutes using the ABTS assay increased with time, but was still four times lower than the activity of trolox.

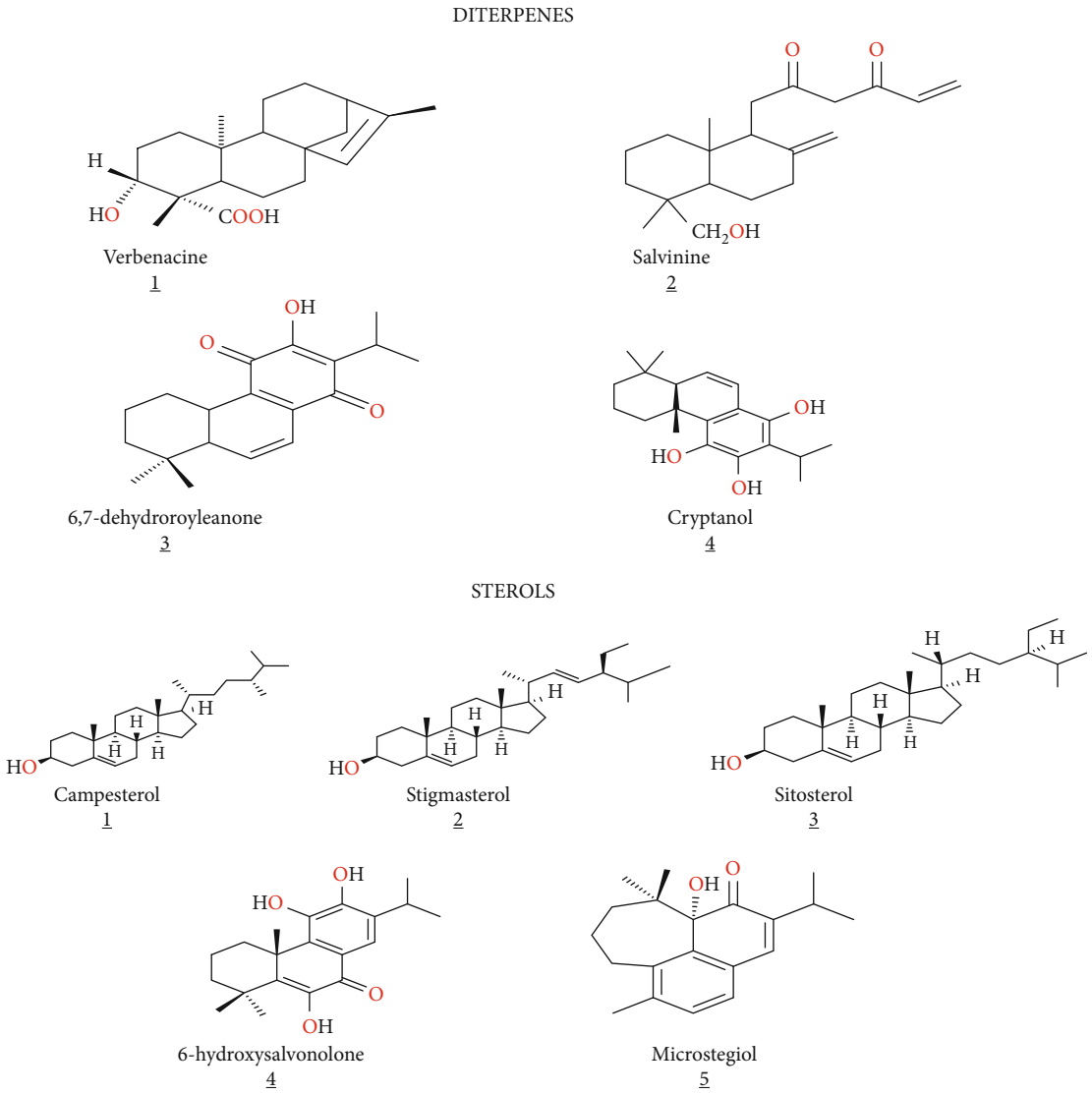


Figure 6: Structure of compounds isolated from *S. verbenaca*.

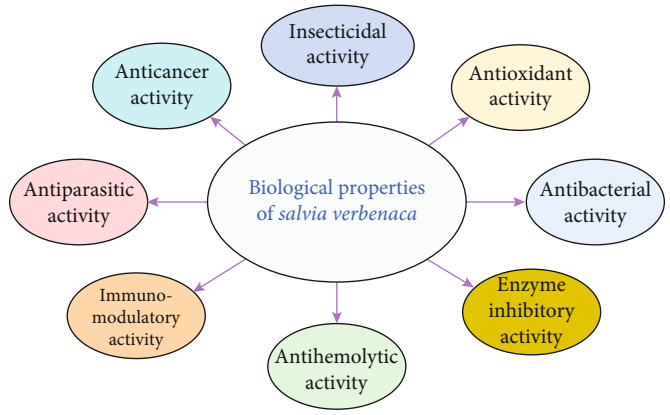


Figure 7: Pharmacological properties of *S. verbenaca*.

Table 3: Antibacterial potential of *S. verbenaca* extracts and EOs.

Plant section	Extracts	Methodology	Tested bacterial strains	Antibacterial results	Ref.
Aerial parts	Ethanolic extract	Disc diffusion method dose (20 μL)	Gram positive *Staphylococcus aureus* (ATCC 25923) *Micrococcus luteus* (NRRL B-4375) *Staphylococcus aureus* (MU 44) *Staphylococcus aureus* (MU 38) *Staphylococcus epidermidis* (MU 30) *Bacillus subtilis* (ATCC 6633) *Streptococcus mutans* (CNCTC 8/77) Gram negative *Escherichia coli* (ATCC 25922) *Pseudomonas aeruginosa* (ATCC 27853) *Stenotrophomonas maltophilia* (MU 99) *Chryseomonas luteola* (MU65) *Pseudomonas fluorescens* (MU 87) *Stenotrophomonas maltophilia* (MU 64) *Pseudomonas stutzeri* (MU 70)	Φ = 11 mm No inhibition Φ = 10 mm Φ = 9 mm Φ = 9 mm Φ = 9 mm No inhibition No inhibition No inhibition No inhibition No inhibition No inhibition No inhibition No inhibition	[10]
Not specified	Methanolic extract (80%) Ethanolic extract (80%)	Not specified	Not specified	The 80% methanol extract prepared using ultrasound extraction showed the highest antimicrobial activity	[41]
Aerial parts	Methanolic extract	Minimum inhibitory concentration	Gram positive *Micrococcus sedentarius* (L7B5) *Staphylococcus xylosus* (IP8166) *Corynebacterium* gr. C (L3C3) *Staphylococcus cohnii* (L6S3) *Corynebacterium* gr. D2 (L19C1) *Micrococcus luteus* (L1C5) *Corynebacterium xerosis* (IP5216) *Staphylococcus epidermidis* (L1S2) *Staphylococcus intermedius* (IP8160) *Corynebacterium* gr. B (L16C3) Gram negative	MIC = 500 μg/mL MIC > 1000 μg/mL MIC = 500 μg/mL MIC = 500 μg/mL MIC = 500 μg/mL MIC > 1000 μg/mL MIC = 500 μg/mL MIC = 500 μg/mL MIC > 1000 μg/mL MIC > 1000 μg/mL	[42]

Table 3: Continued.

Plant section	Extracts	Methodology	Tested bacterial strains	Antibacterial results	Ref.
Aerial parts	Methanol : chloroform (1 : 1, *v*/*v*) extract	Microdilution assay	*Acinetobacter* sp. (LH5DC1) *Moraxella* sp. (LH7SV1) *Alcaligenes* sp. (LH4TV1) *Pseudomonas cepacia* (V6108) *Pseudomonas aeruginosa* (V5791)	MIC = 700 μg/mL MIC > 1000 μg/mL MIC > 1000 μg/mL MIC > 1000 μg/mL MIC > 1000 μg/mL Gram positive *Bacillus cereus* (ATCC 11778) *Staphylococcus aureus* (ATCC 25923) Gram negative *Klebsiella pneumoniae* (NTCC 9633) *Escherichia coli* (ATCC 8739) MIC = 2.0 mg/mL MIC = 3.0 mg/mL MIC = 2.0 mg/mL MIC = 8.0 mg/mL	[17]
Aerial parts	Methanolic extract subfractions: Crude extract (CrE) Chloroform extract (ChE) Ethyl acetate extract (EAE) Aqueous extract (AqE)	Disc diffusion method Dose (3 mg and 6 mg/disc)	Gram positive *Staphylococcus aureus* (ATCC 52952)	EAE Φ (3 mg/disc) = 12 mm Φ (6 mg/disc) = 16 mm ChE Φ (3 mg/disc) = 11 mm Φ (6 mg/disc) = 10 mm CrE Φ (3 mg or 6 mg/disc) = 11 mm AqE: no inhibition	[21]
			Bacillus cereus (ATCC 10876)	EAE Φ (3 mg/disc) = 13 mm Φ (6 mg/disc) = 15 mm ChE Φ (3 mg/disc) = 11 mm Φ (6 mg/disc) = 15 mm CrE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 12 mm AqE: no inhibition	
			Enterococcus faecalis (ATCC 49452)	EAE Φ (3 mg/disc) = 12 mm Φ (6 mg/disc) = 14 mm ChE Φ (3 mg/disc) = 09 mm Φ (6 mg/disc) = 12 mm CrE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 11 mm AqE: no inhibition EAE Φ (3 mg/disc) = 10 mm	

Table 3: Continued.

Plant section	Extracts	Methodology	Tested bacterial strains	Antibacterial results	Ref.
				Φ (6 mg/disc) = 14 mm ChE Φ (3 mg/disc) = 8.0 mm Φ (6 mg/disc) = no inhibition CrE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 12 mm AqE: no inhibition	
			Gram negative *Escherichia coli* (ATCC 25922)	EAE Φ (3 mg/disc) = 11 mm Φ (6 mg/disc) = 14 mm ChE Φ (3 mg/disc) = 09 mm Φ (6 mg/disc) = 12 mm CrE and AqE No inhibition	
			Pseudomonas aeruginosa (ATCC 27853)	EAE Φ (3 mg/disc) = 12 mm Φ (6 mg/disc) = 15 mm ChE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 13 mm CrE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 9 mm AqE: no inhibition	
			Citrobacter freundii (ATCC 8090)	EAE Φ (3 mg/disc) = 12 mm Φ (6 mg/disc) = 14 mm ChE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 14 mm CrE Φ (3 mg/disc) = 11 mm Φ (6 mg/disc) = no inhibition AqE: no inhibition	
			Acinetobacter baumannii (ATCC 19306)	EAE Φ (3 mg/disc) = 10 mm Φ (6 mg/disc) = 15 mm ChE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 14 mm CrE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 10 mm AqE: no inhibition	
			Proteus mirabilis (ATCC 35659)	EAE Φ (3 mg or 6 mg/disc) = 13 mm ChE Φ (3 mg/disc) = no inhibition Φ (6 mg/disc) = 13 mm CrE and AqE No inhibition	
			Salmonella typhi (ATCC 13311)	No inhibition	
Leaves	Ethyl acetate extract				[7]

Table 3: Continued.

Plant section	Extracts	Methodology	Tested bacterial strains	Antibacterial results	Ref.
Aerial parts	Essential oil	Agar diffusion test Dose (100 μg and 300 μg/disc) Microbroth dilution assay	Gram positive *Bacillus brevis* (ATCC 9999)	MIC = 50 μg/mL	[8]
			Bacillus subtilis (ATCC 6633)	MIC = 50 μg/mL	
			Staphylococcus aureus (ATCC 43300)	No inhibition	
			Gram negative *Klebsiella pneumoniae* (ATCC13883)	No inhibition	
			Escherichia coli (ATCC 25922)	No inhibition	
		Broth dilution method	Gram positive *Bacillus subtilis* (ATCC6633)	MIC = 50 μg/mL	
			Staphylococcus aureus (ATCC 25923)	MIC = 100 μg/mL	
			Staphylococcus epidermidis (ATCC 12228)	MIC = 50 μg/mL	
			Streptococcus faecalis (ATTC 29212)	MIC = 100 μg/mL	
			Gram negative *Escherichia coli* (ATCC25922)	MIC > 100 μg/mL	
			Proteus vulgaris (ATCC13315)	MIC > 100 μg/mL	
			Klebsiella pneumoniae (ATCC10031)	MIC > 100 μg/mL	
			Pseudomonas aeruginosa (ATCC27853)	MIC > 100 μg/mL	

Φ: diameter of inhibition.

Additionally, Farhat et al. [6] studied the efficacy of the collection sites on the antioxidant capacity of methanolic extract prepared from postdistilled aerial parts of Tunisian species. They found that the site had a significant effect on the antioxidant potential by the DPPH, ABTS, and FRAP methods. Likewise, activity was shown to be substantially linked with total phenolic content.

The antioxidant activity of some extracts of *S. verbenaca* collected from Algeria was mostly studied using the DPPH assay. It was found that the crude extract prepared from aerial parts had good antioxidant activity that increased with increasing the extract concentration [14]. The scavenging activity was 95% at a concentration of 0.1 mg/mL. Also, the methanol extract of *S. verbenaca* aerial parts revealed a high reducing power in the FRAP test [43] using the DPPH assay. Additionally, it was cited that the methanol extract had a beneficial effect against free-radical damage and exhibited a 5-fold more inhibitory effect than the standard antioxidant trolox ($IC_{50} = 72.63\,\mu M$) [12]. They also observed that the radical scavenging activity had no significant correlation with the phenolic content and a low correlation with the flavonoid content. Belkhiri et al. [21] investigated the antioxidant potential of some fractions of the methanol extracts using the DPPH method, metal chelating activity, and reducing power assay, and all extracts showed potent antioxidant activity [13]. The cupric ion reducing capacity (CUPRAC) and Fe^{3+} reducing capacity (phenanthroline assay) of the extracts were investigated, and the findings exhibited that both extracts had high antioxidant capacity, with methanolic extract exhibiting the highest activity [14].

2.5.3. Anticancer Activity. The different organic essential oils and extracts of *S. verbenaca* have been studied for anticancer properties. Numerous laboratory investigations using cell culture have shown that *S. verbenaca* extracts and essential oils have antiproliferative properties (Table 5) against a variety of cancer cell lines [15–19, 23, 45].

Table 4: Antioxidant activity of *S. verbenaca*.

Part used	Extracts	Methods used	Key results	Ref.
Not specified	Methanolic extract (80%) Ethanolic extract (80%)	DPPH assay β-Carotene/linoleic acids	The 80% methanol extract prepared by maceration was highly active The 80% of ethanol extract was the most active	[41]
Aerial parts (stems and leaves)	Hydromethanolic extract	Oxygen consumption	A strong inhibition of oxygen consumption (92%)	[44]
		Conjugated diene formation (CD)	A strong inhibition of CD formation of LDL peroxidation (92%)	
		Thiobarbituric acid reactive substance (TBARS) formation	A strong inhibition of TBARS formation of linolenic acid oxidation (93%)	
Not specified	Methanolic extract	DPPH assay β-Carotene–linoleic acid method	$IC_{50} = 14.30 \pm 1.42\ \mu g/mg$ Percent inhibition = 77.03 ± 0.42%	[38]
Aerial parts	Methanolic extract	DPPH assay	$IC_{50} = 86.9\ \mu g/mL$	[42]
		ABTS assay	IC_{50} at 5 min = 777.3 $\mu g/mL$ TEAC at 5 min = 0.624 IC_{50} at 20 min = 499.5 $\mu g/mL$ TEAC at 10 min = 0.647 TEAC at 20 min = 0.705 TEAC at 15 min = 0.705	
		DPPH method	Sers: $IC_{50} = 24.47 \pm 1.87\ \mu g/mL$ Touiref: $IC_{50} = 25.11 \pm 2.97\ \mu g/mL$ Beja: $IC_{50} = 26.62 \pm 0.8\ \mu g/mL$ Chott Meriem: $IC_{50} = 28.28 \pm 0.16\ \mu g/mL$ Tunis: $IC_{50} = 30.34 \pm 2.28\ \mu g/mL$ Rass Zebib: $IC_{50} = 31.19 \pm 2.25\ \mu g/mL$ Bou Arada: $IC_{50} = 33.47 \pm 4.13\ \mu g/mL$ Bir Mroua: $IC_{50} = 34.70 \pm 2.43\ \mu g/mL$ Hencha: $IC_{50} = 39.85 \pm 3.9\ \mu g/mL$ Enfidha: $IC_{50} = 40.91 \pm 0.5\ \mu g/mL$	
Aerial parts	Methanolic extract from postdistilled plant	ABTS method	Hencha: TEAC = 120.11 ± 6.62 μM trolox/mg Enfidha: TEAC = 134.45 ± 5.27 μM trolox/mg Bir Mroua: TEAC = 139.26 ± 10.59 μM trolox/mg Rass Zebib: TEAC = 144.02 ± 3.4 μM trolox/mg Bou Arada: TEAC = 154.97 ± 6.79 μM trolox/mg Tunis: TEAC = 190.51 ± 6.71 μM trolox/mg Chott Meriem: TEAC = 196.72 ± 1.61 μM trolox/mg Sers: TEAC = 271.51 ± 4.52 μM trolox/mg Beja: TEAC = 282.17 ± 6.58 μM trolox/mg Touiref: TEAC = 287.81 ± 3.65 μM trolox/mg	[6]
		FRAP	Beja: 142.07 ± 1.46 mM Fe^{+2}/mg Sers: 139.09 ± 11.23 mM Fe^{+2}/mg Touiref: 131.86 ± 1.05 mM Fe^{+2}/mg Chott Meriem: 124.27 ± 0.38 mM Fe^{+2}/mg Tunis: 122.33 ± 3.7 mM Fe^{+2}/mg Bou Arada: 120.53 ± 7.53 mM Fe^{+2}/mg Rass Zebib: 118.02 ± 15.25 mM Fe^{+2}/mg Bir Mroua: 109.22 ± 5.04 mM Fe^{+2}/mg Hencha: 104.89 ± 0.37 mM Fe^{+2}/mg Enfidha: 101.46 ± 1.97 mM Fe^{+2}/mg	
Aerial parts	Crude extract	DPPH method	$IC_{50} = 47.50\ \mu g/mL$	[14]
Aerial parts	Methanolic extract	DPPH FRAP	$IC_{50} = 9.79 \pm 0.47\ \mu g/mL$ High reducing power	[43]
Not specified	Methanolic extract	DPPH method	$IC_{50} = 16.92 \pm 0.2\ \mu M$	[12]

Table 4: Continued.

Part used	Extracts	Methods used	Key results	Ref.
Aerial parts	Methanolic extract subfractions: Crude extract (CrE) Chloroform extract (ChE) Ethyl acetate extract (EAE) Aqueous extract (AqE)	DPPH method	EAE: IC_{50} = 0.0086 mg/mL CrE: IC_{50} = 0.0336 mg/mL ChE: IC_{50} = 0.0725 mg/mL AqE: IC_{50} = 0.0389 mg/mL	[21]
		Reducing power method	EAE: EC_{50}: 0.0047 mg/mL CrE: EC_{50}: 0.0453 ± 0.000 mg/mL AqE: EC_{50}: 0.0455 mg/mL	
		Metal chelating method	AqE and CrE reported the highest activity EAE chelation did not exceed 20%	
Aerial parts	Methanolic extracts (85%) (ME) Decoction extract (distilled water) (DE)	DPPH method	ME: IC_{50}: 24.36 ± 1.13 μg/mL DE: IC_{50}: 27.26 ± 1.05 μg/mL	[13]
		ABTS method	ME: IC_{50}: 19.96 ± 1.03 μg/mL DE: IC_{50}: 36.86 ± 1.03 μg/mL	
		Alkaline DMSO superoxide radical scavenging	ME: IC_{50}: 07.77 ± 1.00 μg/mL DE: IC_{50}: 18.78 ± 1.07 μg/mL	
		β-Carotene bleaching	DE: inhibition: 96.12 ± 2.48% ME: inhibition: 82.58 ± 2.39%	
		Reducing power method	DE: EC_{50}: 69.52 ± 3.07 μg/mL ME: EC_{50}: 56.64 ± 4.81 μg/mL	
		Metal chelating activity method	ME: IC_{50}: 70.39 ± 1.13 μg/mL DE: IC_{50}: 109.70 ± 1.72 μg/mL	
		Phenanthroline method	ME: IC_{50}: 27.03 ± 1.54 μg/mL DE: IC_{50}: 40.26 ± 0.59 μg/mL	
		Cupric reducing antioxidant capacity (CUPRAC)	ME: $A_{0.50}$: 14.66 ± 2.51 μg/mL DE: $A_{0.50}$: 33.00 ± 0.30 μg/mL	
Root	Methanolic extract	H2DCF-DA method	Significant reduction in the intracellular reactive oxygen species (ROS) level for both tested values (1 and 10 μg/mL)	[14]

The ethyl acetate extract of *S. verbenaca* leaves produced after maceration was examined using the MDA cell lines MB-231 (human breast adenocarcinoma, ATCC HTB-26). The findings indicated that all extracts produced cytotoxicity in MDA MB-231 breast cancer cells [7]. However, it was proved that *S. verbenaca* leaf extracts possessed cytotoxic effect against HEp-2 (human larynx cancer cells) and Vero (monkey kidney cells) [18]. In another investigation, methanolic extracts of *S. verbenaca*'s aerial component prepared by maceration were evaluated in vitro against four human cancer cell lines, including HCA, HepG2, MCF-7, and HPC. The findings indicate that LC_{50} levels higher than 75 μg/mL were deemed inactive [15]. Additionally, MTT assays were used to determine the cytotoxic activity of several extracts (methanol, hexane, ethyl acetate, n-butanol, and chloroform extracts) obtained from the aerial portion of *S. verbenaca* [16]. Methanol and chloroform extracts of *S. verbenaca* aerial parts were evaluated against colon adenocarcinoma (HT-29), human cancer cell lines (breast adenocarcinoma (MCF-7), human kidney epithelial cell line and glioblastoma (SF-268)) [17]. *S. verbenaca* exhibited more favorable action against MCF-7, with an IC_{50} value of 31.50 13.70 μg/mL, but was inactive versus SF-268 and/or HT-29 cell lines [17].

A cell viability study was performed to avoid any cytotoxic concentration of *S. verbenaca* root extract on THP-1 cells. The MTT assay revealed that the most cytotoxic concentration of the extract was 1000 μg/mL, which caused 70% of cell death and 30% of cell viability [23]. The essential oils of *S. verbena* were investigated for their ability to suppress the proliferation of human tumor cells using the human M14 melanoma cell line and shown significant efficacy [19]. The antiproliferative effect of *S. verbenaca* essential oil may be attributed to active sesquiterpenes in combination with other natural chemicals found in the essential oil components. Indeed, carvacrol and thymol exhibited outstanding anticancer properties through a variety of mechanisms [19].

2.5.4. Antiparasitic Activity. Et-Touys et al. [20] investigated the antileishmanial effects of organic extracts (methanol, n-hexane, and dichloromethane extract) from *S. verbenaca*, and it was reported that the *in vitro* antileishmanial effect which was evaluated on the culture of three Leishmania species such as *Leishmania infantum*, *Leishmania tropica*, and *Leishmania major* was good (Table 6).

Belkhiri et al. [21] additionally observed that *S. verbenaca* has antihemolytic properties. In vitro antihemolytic

Table 5: Anticancer effects of *S. verbenaca*.

Plant part	Tested extract	Cell lines	Major results	Ref.
Leaves	Ethyl acetate	Human breast adenocarcinoma	IC_{50}: 41.3 ± 4.8 μg/mL	[7]
Aerial parts	Methanol	Human colon adenocarcinoma	LC_{50}: 60.4 μg/mL	[15]
		Human hepatoblastoma	LC_{50}: 68.9 μg/mL	
		Human breast cancer cells	LC_{50}: 43.1 μg/mL	
		Human pancreatic carcinoma	LC_{50}: 42.2 μg/mL	
Aerial parts	Hexane	Human embryonal rhabdomyosarcoma cancerous cell lines	IC_{50}: 474.6 ± 1.3 μg/mL	[16]
		Vero (monkey kidney cancerous cell lines)	IC_{50} > 500 μg/mL	
Aerial parts	Ethyl acetate	Human embryonal rhabdomyosarcoma cancerous cell lines	IC_{50} > 500 μg/mL	[16]
		Vero (monkey kidney cancerous cell lines)	IC_{50}: 223.6 ± 1.6 μg/mL	
Aerial parts	*n*-Butanol	Human embryonal rhabdomyosarcoma cancerous cell lines	IC_{50} > 500 μg/mL	[16]
		Vero (monkey kidney cancerous cell lines)	IC_{50} > 500 μg/mL	
Aerial parts	Methanol and chloroform	Breast adenocarcinoma	IC_{50}: 31.5 ± 13.7 μg/mL	[17]
		Colon adenocarcinoma	IC_{50}: 50.0 ± 5.3 μg/mL	
		Glioblastoma	IC_{50} was not calculated	
		Human kidney epithelial cell line	IC_{50}: 20.8 ± 2.5 μg/mL	
Leaves	Methanol	Monkey kidney cells	CC_{50}: 64 μg/mL	[18]
		Human larynx cancer cells	CC_{50} = 64 μg/mL	
Roots	Methanol	Human monocytic leukemia cell line	70% of apoptosis and 30% of viable cells at a 1000 μg/mL concentration	[23]
Aerial parts	Essential oils	Human melanoma cell line	IC_{50} = 8.1 ± 0.6 μg/mL	[19]

Table 6: Antiparasitic activity of *S. verbenaca*.

Activity	Part used	Extract	Parasite	Major results	Ref.
Antileishmanial activity	Whole plant part	*n*-Hexane	*Leishmania major*	IC_{50}: 155.4 μg/mL	[20]
			Leishmania tropica	IC_{50}: 148.2 μg/mL	
			Leishmania infantum	IC_{50}: 14.1 μg/mL	
		Dichloromethane	*Leishmania major*	IC_{50}: 24.5 μg/mL	
			Leishmania tropica	IC_{50}: 33.7 μg/mL	
			Leishmania infantum	IC_{50}: 31.5 μg/mL	
		Methanol	*Leishmania major*	IC_{50} > 1000 μg/mL	
			Leishmania tropica	IC_{50}: 850.7 μg/mL	
			Leishmania infantum	IC_{50} > 1000 μg/mL	
Antimalarial activity	Aerial parts	Methanol chloroform	*Plasmodium falciparum* (FCR-3 strain)	IC_{50}: 23.9 ± 1.1 μg/mL	[11]

activity of *S. verbenaca* extract was determined by inducing oxidative erythrocyte hemolysis. The results indicated that ethyl acetate extract was the most effective in inhibiting hemolysis, followed by crude extract, chloroform extract, and aqueous extract. Additionally, ethyl acetate extract inhibited hemolysis more effectively than vitamin C.

2.5.5. Insecticidal Activity. In most cases, the application of synthetic pesticides is the primary approach for controlling insect pests, which produces excellent effects in a short period of time. Meanwhile, their irrational usage has resulted in global issues such as pollution, nontarget toxicity, biodiversity loss, and the development of pest resistance [46–48]. This need arose from a desire to provide alternatives to synthetic insecticides, which can have negative environmental consequences [49–52]. The insecticidal capabilities of *S. verbenaca* extracts and essential oils have been documented to have potential impact against several pests in previous studies [53]. Insecticidal action has been shown in several experiments using some *Salvia* species [54].

Essential oils from *Salvia* species revealed 100% repellency activity against adults of *Aedes albopictus* [55]. The

Table 7: Other biological activities of *S. verbenaca*.

Activity	Part used	Extracts	Experiment	Major results	Ref.
Antihemolytic	Aerial part	Ethyl acetate	2,2-Azobis (2-amidinopropane) dihydrochloride induces erythrocyte oxidative hemolysis (AAPH)	HT50: 165 min	[21]
		Crude		HT50: 125.1 min	
		Chloroform		HT50: 111.5 min	
		Aqueous		HT50: 111.5 min	
Xanthine oxidase inhibition	Aerial part	Chloroform	Colorimetric approach based on uric acid generation at 295 nm in the presence of 100 mM xanthine in phosphate buffer	IC_{50}: 0.0088 ± 0.0 mg/mL	
		Ethyl acetate		IC_{50}: 0.0165 ± 0.001 mg/mL	
		Crude		IC_{50}: 0.0520 ± 0.003 mg/mL	
		Aqueous		IC_{50}: 0.9800 ± 0.004 mg/mL	
Porcine liver carboxylesterase inhibition	Aerial part	Aqueous methanol	Enzyme inhibition by spectrophotometric assay	CE (carboxylesterase) inactivation with a pI = 5.1 and a Ki value of 38 Mm	[12]
Healing of burns	Leaves	Hexane	Second-degree burn injury induced by a hot metal cylinder in rats	Accelerated healing process with 44.34%	[16]
		Ethyl acetate		Accelerated healing process with 47.55%	
		n-Butanol		Accelerated healing process with 49.16%	
Anticholinesterases	Aerial part	Methanol	Cholinesterase inhibition	Inhibition effect of AChE at 100 μg/mL	[13]
Anti-α-amylase			α-Amylase inhibition	IC_{50}: 01.3 ± 0.08 μg/mL	
Anti-α-glucosidase			α-Glucosidase inhibition	IC_{50} = 150.5 ± 1.4 μg/mL	
Immunomodulatory	Aerial parts	Methanol	Phagocytic activity used carbon clearance rate test	Significantly increased phagocytic index (0.095 ± 0.012) at a dose of 200 mg/kg Increased corrected phagocytic index α (0.095 ± 1.71)	[14]

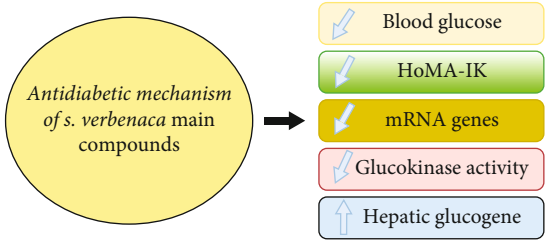


Figure 8: Antidiabetic mechanism insights of *S. verbenaca* main compounds.

oil of *S. verbenaca* drastically shortened the lifespan of *cowpea weevil* and prevented females from laying eggs [56]. Several crude extracts and essential oils from *Salvia* species were tested for pesticide activity against the test pest larvae [57–59]. Insectistatic and insecticidal properties of chloroform extracts from the aerial portions of four Salvia species were examined [60]. *S. verbenaca* extracts are very effective against *Culex quinquefasciatus* mosquitos [61]. Caryophyllene oxide was the major component in the essential oil of *S. verbenaca* with 7.28 [62]. The insecticidal activity and fumigant toxicity of caryophyllene oxide were tested against two insect pests, and it was shown to be effective [63].

2.6. Other Biological Effects. Different extracts from *S. verbenaca* have also exhibited other biological activities such as antihemolytic, immunomodulatory, and enzyme inhibitory effects (Table 7).

2.6.1. Xanthine Oxidase Inhibitory Effect. Xanthine oxidase, abbreviated as XO, is an oxidoreductase that catalyzes the conversion of hypoxanthine to xanthine and xanthine to uric acid. Xanthine oxidase is generally present in the liver and in an inactive form in the blood in humans. A blood test for XO may identify liver impairment because xanthine oxidase is released into the blood in situations of severe liver injury [21].

2.6.2. Burn Recovery Activities. Guaouguaou et al. [24] evaluated the impact of three *S. verbenaca* extracts on the healing of burns in rats using hexane, ethyl acetate, and n-butanol. The results indicated that various *Salvia verbenaca* plant extracts were more effective than silver sulfadiazine (SSD) and that it is the most widely used topical treatment for injury, with healed areas of 29.17% (base), 44.34% (hexane), 47.55% (ethyl acetate), 49.16% (n-butanol), and 41.09% SSD.

Table 8: Toxicological studies of *S. verbenaca*.

Activities	Part used	Extract	Experimental approach	Major results	Ref.
Acute oral toxicity	Aerial parts	*n*-Butanol, hexane, ethyl acetate	Orally delivered at a dose of 2000 mg/kg in a volume of 0.25 mL per 20 g of body weight to mice and examined for 14 days	LD_{50} > 2000 mg/kg body weight	[64]
Acute dermal toxicity	Aerial parts	Hexane, ethyl acetate, *n*-butanol	For 14 days, daily topical application of *S. verbenaca* extracts at a dose of 2000 mg/kg body weight	There are no adverse effects, behavioral problems, or fatalities	[64]
Subchronic dermal toxicity	Aerial parts	Hexane, ethyl acetate, *n*-butanol	For 28 days, daily topical application of *S. verbenaca* extracts at a dose of 2000 mg/kg body weight	There are no harmful symptoms or changes in the amount of water or food consumed There is no lethality There is no change in the parameters of fasting blood circulation There were no morphological alterations in the main vital organs investigated	[64]

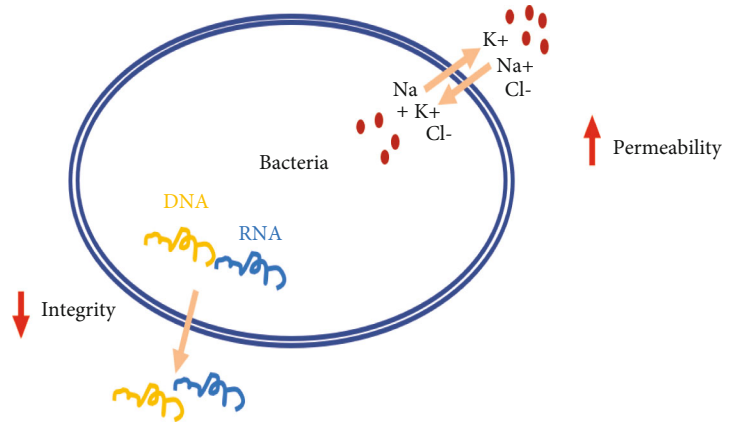


Figure 9: Suggested antibacterial mechanisms of *S. verbenaca* compounds.

2.6.3. In Vitro Antidiabetic Activity. Several earlier studies have shown *S. verbenaca*'s antidiabetic activity *in vitro* [13]. Additional studies are shown in Section 2.8 and Figure 8.

2.6.4. Immunomodulatory Effects. Previous studies investigated the immunomodulatory effects of *S. verbenaca* aerial parts [14]. The carbon clearance rate test was used to determine the immunostimulant potential of this plant on phagocytic activity. The phagocytic index was much higher in rats who were given *S. verbenaca* at a dose of 200 mg/kg than in rats who were not given the herb.

2.7. Toxicological Investigations of S. verbenaca. The toxicological investigations of *S. verbenaca* have not been well studied. However, some studies carried out recently have confirmed the safety of these plant extracts (Table 8). Indeed, a report by Guaouguaou et al. [64] focused on the acute and subchronic effects of *S. verbenaca* toxicity in mice and rats through oral and topical administration. The findings of the acute toxicity of the fractions derived from *S. verbenaca* (n-butanol, hexane, and ethyl acetate) demonstrated that the LD_{50} of this plant after oral administration at 2000 mg kg^{-1} is not deadly [64]. In order to complete the toxicity profile of this plant, more research should be done to find out how toxic it is over a long period of time.

2.8. Pharmacological Properties of S. verbenaca Main Volatile Compounds. Several studies examined the major volatile chemicals found in *S. verbenaca*, including carvacrol, thymol, and linalool. Studies showed that carvacrol has hypoglycemic properties through intrinsic mechanisms such as blood glucose and insulin level lowering [65]. Additionally, carvacrol resulted in a drop in glucose levels. Additionally, these substances were shown to enhance the activity of glucokinase and glucose-6-phosphate dehydrogenase in the liver [66]. Carvacrol inhibits the enzymes α-amylase and alpha-glucosidase *in vitro* [67] and beta-galactosidase *in vitro* [68]. Thymol was also able to normalize blood sugar, plasma insulin, HbA_{1c}, and the insulin resistance index in patients with hyperglycemia [69]. The levels of expression of genes involved in the production of insulin have been studied and reported in STZ-induced diabetic mice [70, 71], and a rise in *Mafa* and *Pdx1* gene expression has been reported. Limonene is another major constituent of *S.*

verbenaca that has been shown to improve glucose homeostasis. Indeed, this substance boosts hepatic glycogen and plasma glucose levels [72] (Figure 8).

The antidiabetic effect has been also revealed by linalool (another main compound of *S. verbenaca*) [73, 74]. Indeed, linalool lowered blood glucose, hemoglobin A1c, fructosamine, interleukin-6, and tumor necrosis factor-α (TNF-α), while it increased insulin levels [74].

The major phytochemical compounds of *S. verbenaca* exhibited remarkable antibacterial effects [75–77]. Rhayour et al. [70] investigated the impact of thymol on gram-positive and gram-negative microorganisms, including *Bacillus subtilis* and *Escherichia coli* [75–78]. Antibacterial activity is demonstrated by modifying cell shape, damaging cell walls and membranes, and limiting the development of some types of bacteria, including *P. aeruginosa* [79]. In addition, limonene was found to be antibacterial because it targeted microorganisms' cytoplasmic membranes, weakened membrane integrity, blocked respiratory enzymes, and lost the proton motive force (Figure 9).

The anticancer properties of the major components in *S. verbenaca* (carvacrol, limonene, and thymol) have also been reported recently [80–82]. Thymol has been shown to have anticancer properties via a variety of mechanisms, including inducing severe DNA damage, including the production of reactive oxygen species (ROS) and subsequent increase in oxidative stress and/or mitochondrial dysfunction, or via the nuclear factor of activated T cell (NFAT-2) route [81]. Additionally, carvacrol increased apoptosis in cells, perhaps via activating mitochondrial apoptotic and signaling pathways [83].

3. Conclusions and Perspectives

S. verbenaca, a medicinal plant used in traditional medicine to cure a variety of ailments, was found to be abundant in bioactive chemicals such as flavonoids, terpenoids, and phenolic acids. Numerous pharmacological studies have demonstrated that *S. verbenaca* extracts and essential oils have extraordinarily beneficial effects on a variety of diseases, including those caused by microbes and those caused by dysregulation of homeostasis. Indeed, this plant demonstrated antibacterial, antidiabetic, anticancer, and immunomodulatory properties via a variety of mechanisms. However, further research should be conducted to find other pharmacodynamic targets. Additionally, pharmacokinetic studies should be conducted to ascertain the absorption, metabolism, and elimination of *S. verbenaca* bioactive components. Additionally, toxicological studies should be conducted to validate the safety of *S. verbenaca* extracts at various doses and delivery methods.

Data Availability

All the data are cited in the main text of this document.

Conflicts of Interest

No potential competing interest was reported by the authors.

Acknowledgments

The authors would like to thank the Deanship of Scientific Research at Umm Al-Qura University for supporting this work by Grant Code 22UQU4331100DSR01.

References

[1] E. M. Abdallah, "Plants: an alternative source for antimicrobials," *Journal of Applied Pharmaceutical Science*, vol. 1, no. 6, pp. 16–20, 2011.

[2] H. I. Al-Jaber, S. M. Obeidat, F. U. Afifi, and H. Musa, "Aroma profile of two populations of *Salvia verbenaca* collected from two bio- geographical zones from Jordan," *Chemistry & Biodiversity*, vol. 17, no. 2, article e1900553, 2020.

[3] G. Bonnier and R. Douin, "La grande flore en couleur de Gaston Bonnier, France, Suisse, Belgique et pays voisins," *Réédition de la flore complète illustrée en couleur de France, Suisse, Belgique, de G. Bonnier et R. Douin, Belin édit*, vol. 4, 1990.

[4] M. Esra, O. Cetin, A. Kahraman, F. Celep, and M. Dogan, "A cytomorphological study in some taxa of the genusSalviaL. (Lamiaceae)," *Caryologia*, vol. 64, no. 3, pp. 272–287, 2011.

[5] M. Z. Afzal-Rafii, "Contribution à l'étude cytotaxonomique du groupe*Salvia verbenaca*L," *Bulletin de la Société Botanique de France. Lettres Botaniques*, vol. 126, no. 1, pp. 79–86, 1979.

[6] M. B. Farhat, J. A. Sotomayor, and M. J. Jordán, "_Salvia verbenaca_ L. essential oil: variation of yield and composition according to collection site and phenophase," *Biochemical Systematics and Ecology*, vol. 82, pp. 35–43, 2019.

[7] A. Russo, V. Cardile, A. C. E. Graziano et al., "Comparison of essential oil components and in vitro anticancer activity in wild and cultivated Salvia verbenaca," *Natural Product Research*, vol. 29, no. 17, pp. 1630–1640, 2015.

[8] M. Canzoneri, M. Bruno, S. Rosselli et al., "Chemical composition and biological activity ofSalvia VerbenacaEssential oil," *Natural Product Communications*, vol. 6, no. 7, article 1934578X1100600725, 2011.

[9] A. Khouchlaa, A. Et-Touys, F. Lakhdar, F. E. Laasri, A. E. Y. El Idrissi, and F. Zaakour, "Ethnomedicinal use, phytochemistry, pharmacology, and toxicology of *Salvia verbenaca* L. : a review," *Biointerface Research in Applied Chemistry*, vol. 12, no. 2, pp. 1437–1469, 2021.

[10] N. Sarac and A. Uğur, *Antimicrobial activities and usage in folkloric medicine of some Lamiaceae species growing in Mugla, Turkey*, Muğla Sıtkı Koçman Üniversitesi, 2007, http://acikerisim.mu.edu.tr/xmlui/handle/20.500.12809/7732.

[11] G. P. P. Kamatou, R. L. Van Zyl, H. Davids, F. R. Van Heerden, A. C. U. Lourens, and A. M. Viljoen, "Antimalarial and anticancer activities of selected South African _Salvia_ species and isolated compounds from *S. radula*," *South African Journal of Botany*, vol. 74, no. 2, pp. 238–243, 2008.

[12] A. Djeridane, M. Yousfi, B. Nadjemi, S. Maamri, F. Djireb, and P. Stocker, "Phenolic extracts from various Algerian plants as strong inhibitors of porcine liver carboxylesterase," *Journal of Enzyme Inhibition and Medicinal Chemistry*, vol. 21, no. 6, pp. 719–726, 2006.

[13] W. Mamache, S. Amira, C. Ben Souici, H. Laouer, and F. Benchikh, "In vitro antioxidant, anticholinesterases, anti-α-amylase, and anti-α- glucosidase effects of Algerian *Salvia aegyptiaca* and *Salvia verbenaca*," *Journal of Food Biochemistry*, vol. 44, no. 11, article e13472, 2020.

[14] M. Nassar, F. Zadri, and S. Slimani, "Assessment of the protective effect of the methnolic extract from *Salvia verbenaca* roots against oxidative damage induced by hydrogen peroxide (H_2O_2)," *Turkish Journal Of Pharmaceutical Sciences*, vol. 18, no. 3, pp. 360–366, 2020.

[15] R. B. Badisa, O. Tzakou, M. Couladis, and E. Pilarinou, "Cytotoxic activities ofSalvia. of the Labiatae family," *Pharmaceutical Biology*, vol. 42, no. 8, pp. 640–645, 2005.

[16] F.-E. Guaouguaou, M. A. A. Bebaha, K. Taghzouti et al., "Cytotoxicological investigation of the essential oil and the extracts of *Cotula cinerea* and *Salvia verbenaca* from Morocco," *BioMed Research International*, vol. 2018, Article ID 7163961, 5 pages, 2018.

[17] G. P. P. Kamatou, S. F. Van Vuuren, F. R. Van Heerden, T. Seaman, and A. M. Viljoen, "Antibacterial and antimycobacterial activities of South African _Salvia_ species and isolated compounds from _S. chamelaeagnea_," *South African Journal of Botany*, vol. 73, no. 4, pp. 552–557, 2007.

[18] A. Latif, H. M. Amer, M. E. Hamad, S. A. R. Alarifi, and F. N. Almajhdi, "Medicinal plants from Saudi Arabia and Indonesia: in vitro cytotoxicity evaluation on Vero and Hep-2 cells," *Journal of Medicinal Plants Research*, vol. 8, no. 34, pp. 1065–1073, 2014.

[19] A. Russo, V. Cardile, A. C. E. Graziano et al., "Comparison of essential oil components and in vitro anticancer activity in wild and cultivated *Salvia verbenaca*," *Natural Product Research*, vol. 29, no. 17, pp. 1630–1640, 2015.

[20] A. Et-Touys, H. Fellah, F. Sebti et al., "In vitro antileishmanial activity of extracts from endemic Moroccan medicinal plant *Salvia verbenaca* (L.) Briq. ssp verbenaca Maire (S. clandestina Batt. non L)," *European Journal of Medicinal Plants*, vol. 16, no. 1, pp. 1–8, 2016.

[21] F. Belkhiri, A. Baghiani, M. M. Zerroug, and L. Arrar, "Investigation of antihemolytic, xanthine oxidase inhibition, antioxidant and antimicrobial properties of *Salvia verbenaca* L. aerial part extracts," *African Journal of Traditional, Complementary and Alternative Medicines*, vol. 14, no. 2, pp. 273–281, 2017.

[22] L. Viegi, K. Ghedira, and K. Ghedira, "Preliminary study of plants used in ethnoveterinary medicine in Tunisia and in Italy," *African Journal of Traditional, Complementary and Alternative Medicines*, vol. 11, no. 3, pp. 189–199, 2014.

[23] M. Nassar, S. Zerizer, Z. Kabouche, A. Kabouche, and S. Bechkri, "Antioxidant and the immunomodulatory activities exhibited by three plants from Lamiaceae family," *International Journal of Pharmacy & Pharmaceutical Sciences*, vol. 7, no. 9, pp. 331–334, 2015.

[24] F.-E. Guaouguaou, K. Taghzouti, M. Oukabli, and N. E. Es-Safi, "The effect of *Salvia verbenaca* extracts for healing of second-degree burn wounds in rats," *Current Bioactive Compounds*, vol. 14, no. 4, pp. 419–427, 2018.

[25] M. Canzoneri, M. Bruno, S. Rosselli et al., "Chemical composition and biological activity of *Salvia verbenaca* essential oil," *Natural Product Communications*, vol. 6, no. 7, article 1934578X1100600, 2011.

[26] E. Abbouyi, P. Ahmed, N. Filali-Ansari, P. S. Khyari, and H. Loukili, "Inventory of medicinal plants prescribed by traditional healers in El Jadida city and suburbs (Morocco)," *International Journal of Green Pharmacy*, vol. 8, no. 4, p. 242, 2014.

[27] I. Slimani, M. Najem, R. Belaidi et al., "Ethnobotanical survey of medicinal plants used in Zerhoun region, Morocco," *International Journal of Innovation and Applied Studies*, vol. 15, no. 4, pp. 846–863, 2016.

[28] A. Daoudi, M. Bammou, S. Zarkani, I. Slimani, J. Ibijbijen, and L. Nassiri, "Étude ethnobotanique de la flore médicinale dans la commune rurale d'Aguelmouss province de Khénifra (Maroc)," *Phytothérapie*, vol. 14, no. 4, pp. 220–228, 2016.

[29] N. Salhi, A. Bouyahya, S. Fettach, A. Zellou, and Y. Cherrah, "Ethnopharmacological study of medicinal plants used in the treatment of skin burns in occidental Morocco (area of Rabat)," *South African Journal of Botany*, vol. 121, pp. 128–142, 2019.

[30] A. Douira and L. Zidane, "Étude ethnobotanique des plantes médicinales utilisées dans le traitement du diabète, et des maladies cardiaques dans la région d'Izarène (Nord du Maroc)," *Journal of Applied Biosciences*, vol. 86, no. 1, pp. 7940–7956, 2015.

[31] M. Aissaoui, P. Chalard, G. Figuérédo et al., "Chemical composition of the essential oil of Salvia verbenaca (L.) Briq. ssp. pseudo-jaminiana (Chev.) M," *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, vol. 5, no. 6, pp. 368–372, 2014.

[32] H. I. Al-Jaber, "Essential oil composition of the aerial parts of fresh and air-dried*Salvia verbenaca*L. growing wild in Jordan," *Journal of Essential Oil Bearing Plants*, vol. 18, no. 3, pp. 718–724, 2015.

[33] M. B. Taârit, K. Msaada, K. Hosni, and B. Marzouk, "GC analyses of Salvia seeds as valuable essential oil source," *Advances in Chemistry*, vol. 2014, Article ID 838162, 6 pages, 2014.

[34] D. Pitarokili, O. Tzakou, and A. Loukis, "Essential oil composition of Salvia verticillata, S. verbenaca, S. glutinosa and S. candidissima growing wild in Greece," *Flavour and Fragrance Journal*, vol. 21, no. 4, pp. 670–673, 2006.

[35] A. Khemkham, S. Belhadj, R. Meddour et al., "HS-SPME-GC/MS analysis of 3 Lamiaceae plants: *Ajuga iva* (L.) Schreb., *Salvia verbenaca* L. and *Thymus algeriensis* Boiss. & Reut," *Journal of Fundamental and Applied Sciences*, vol. 12, no. 2, pp. 700–711, 2020.

[36] Z. Belloum, P. Chalard, G. Figuérédo et al., "Chemical composition of the essential oil of *Salvia verbenaca* (L.) Briq. ssp. clandestina (L.) Pugsl," *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, vol. 5, no. 6, pp. 262–265, 2014.

[37] I. Özdek and H. Fakir, "Determination to leaf and flower volatile components of natural sage taxa (salvia spp.) of murat mountain (Kütahya-Gediz)," *Turkish Journal of Forestry*, vol. 20, no. 4, pp. 433–439, 2019.

[38] B. Tepe, O. Eminagaoglu, H. A. Akpulat, and E. Aydin, "Antioxidant potentials and rosmarinic acid levels of the methanolic extracts of Salvia verticillata (L.) subsp. verticillata and S. verticillata (L.) subsp. amasiaca (Freyn & Bornm.) Bornm," *Food Chemistry*, vol. 100, no. 3, pp. 985–989, 2007.

[39] B. Ahmed, T. A. Al-Howiriny, A. J. Al-Rehaily, and J. S. Mossa, "Verbenacine and salvinine: two new diterpenes from *Salvia verbenaca*," *Zeitschrift für Naturforschung C*, vol. 59, no. 1-2, pp. 9–14, 2004.

[40] A. Kabouche, Z. Kabouche, R. Touzani, and C. Bruneau, "Diterpenes and sterols from the roots of *Salvia verbenaca* subsp. clandestina," *Chemistry of Natural Compounds*, vol. 44, no. 6, pp. 824-825, 2008.

[41] M. Kostić, B. Zlatković, B. Miladinović et al., "Rosmarinic acid levels, phenolic contents, antioxidant and antimicrobial activities of the extracts from *Salvia verbenaca* L. obtained with different solvents and procedures," *Journal of Food Biochemistry*, vol. 39, no. 2, pp. 199–208, 2015.

[42] K. B. H. Salah, M. A. Mahjoub, S. Ammar et al., "Antimicrobial and antioxidant activities of the methanolic extracts of three Salvia species from Tunisia," *Natural Product Research*, vol. 20, no. 12, pp. 1110–1120, 2006.

[43] N. Belmekki and N. Bendimerad, "Antioxidant activity and phenolic content in methanol crude extracts from three Lamiaceae grown in southwestern Algeria," *Journal of Natural Product and Plant Resources*, vol. 2, no. 1, pp. 175–181, 2012.

[44] S. Khlifi, Y. El Hachimi, A. Khalil et al., "In vitroantioxidant properties of *Salvia verbenaca* L. hydromethanolic extract," *Indian Journal of Pharmacology*, vol. 38, no. 4, p. 276, 2006.

[45] W. A. Al-Zereini, "Ononis natrixand*Salvia verbenaca*: two Jordanian medicinal plants with cytotoxic and antibacterial activities," *Journal of Herbs, Spices & Medicinal Plants*, vol. 23, no. 1, pp. 18–25, 2017.

[46] S. J. Yu, S. N. Nguyen, and G. E. Abo-Elghar, "Biochemical characteristics of insecticide resistance in the fall armyworm, *Spodoptera frugiperda* (J.E. Smith)," *Pesticide Biochemistry and Physiology*, vol. 77, no. 1, pp. 1–11, 2003.

[47] G. J. Devine and M. J. Furlong, "Insecticide use: contexts and ecological consequences," *Agriculture and Human Values*, vol. 24, no. 3, pp. 281–306, 2007.

[48] C. A. Farnsworth, M. G. Teese, G. Yuan et al., "Esterase-based metabolic resistance to insecticides in heliothine and spodopteran pests," *Journal of Pesticide Science*, vol. 35, no. 3, pp. 275–289, 2010.

[49] R. Pavela and T. Chermenskaya, "Potential insecticidal activity of extracts from 18 species of medicinal plants on larvae of Spodoptera littoralis–Short Communication," *Plant Protection Science*, vol. 40, no. 4, pp. 145–150, 2010.

[50] R. Pavela, "Possibilities of botanical insecticide exploitation in plant protection," *Pest Technology*, vol. 1, no. 1, pp. 47–52, 2007.

[51] J. Pretty and Z. P. Bharucha, "Integrated pest management for sustainable intensification of agriculture in Asia and Africa," *Insects*, vol. 6, no. 1, pp. 152–182, 2015.

[52] S. M. Hamed, A. A. Abd, N. A.-R. El-Rhman, and I. B. M. Ibraheem, "Role of marine macroalgae in plant protection & improvement for sustainable agriculture technology," *Beni-Suef University Journal of Basic and Applied Sciences*, vol. 7, no. 1, pp. 104–110, 2018.

[53] N. C. Cárdenas-Ortega, M. M. González-Chávez, R. Figueroa-Brito et al., "Composition of the essential oil of Salvia ballotiflora (Lamiaceae) and its insecticidal activity," *Molecules*, vol. 20, no. 5, pp. 8048–8059, 2015.

[54] Z. R. Karahroodi, S. Moharramipour, and A. Rahbarpour, "Investigated repellency effect of some essential oils of 17 native medicinal plants on adults Plodia interpunctella," *American-Eurasian Journal of Sustainable Agriculture*, vol. 3, pp. 181–185, 2009.

[55] B. Conti, G. Benelli, M. Leonardi et al., "Repellent effect of Salvia dorisiana, S. longifolia, and S. sclarea (Lamiaceae) essential oils against the mosquito Aedes albopictus Skuse (Diptera: Culicidae)," *Parasitology Research*, vol. 111, no. 1, pp. 291–299, 2012.

[56] R. A. Fatiha, R. Kada, M. A. Khelil, and J. Pujade-Villar, "Biological control against the cowpea weevil (Callosobruchus chinensis L., Coleoptera: Bruchidae) using essential oils of some medicinal plants," *Journal of Plant Protection Research*, vol. 54, no. 3, pp. 211–217, 2014.

[57] H. Cetin, I. Cinbilgel, A. Yanikoglu, and M. Gokceoglu, "Larvicidal activity of some Labiatae (Lamiaceae) plant extracts from Turkey," *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, vol. 20, no. 12, pp. 1088–1090, 2006.

[58] B. Hosseini, A. Estaji, and S. M. Mehdi, "Fumigant toxicity of essential oil from'Salvia leriifolia'(benth) against two stored product insect pests," *Australian Journal of Crop Science*, vol. 7, no. 6, pp. 855–860, 2013.

[59] Z. Ulukanli, S. Karabörklü, M. Cenet, O. Sagdic, I. Ozturk, and M. Balcilar, "Essential oil composition, insecticidal and antibacterial activities of Salvia tomentosa Miller," *Medicinal Chemistry Research*, vol. 22, no. 2, pp. 832–840, 2013.

[60] M. A. Zavala-Sánchez, S. P. Gutiérrez, D. Romo-Asunción, N. C. Cárdenas-Ortega, and M. A. Ramos-López, "Activity of fourSalviaspecies againstSpodoptera frugiperda(J.E. Smith) (Lepidoptera: Noctuidae)," *Southwestern Entomologist*, vol. 38, no. 1, pp. 67–73, 2013.

[61] R. Pavela, "Larvicidal effects of some Euro-Asiatic plants against Culex quinquefasciatus Say larvae (Diptera: Culicidae)," *Parasitology Research*, vol. 105, no. 3, pp. 887–892, 2009.

[62] M. Taarit, K. Ben, K. Msaada, N. B. Hosni, B. M. Amor, and M. E. Kchouk, "Chemical composition of the essential oils obtained from the leaves, fruits and stems of*Salvia verbenaca*L. from the northeast region of Tunisia," *Journal of Essential Oil Research*, vol. 22, no. 5, pp. 449–453, 2010.

[63] P. Liu, X.-C. Liu, H.-W. Dong, Z.-L. Liu, D. Shu-Shan, and Z.-W. Deng, "Chemical composition and insecticidal activity of the essential oil of Illicium pachyphyllum fruits against two grain storage insects," *Molecules*, vol. 17, no. 12, pp. 14870–14881, 2012.

[64] F.-E. Guaouguaou, K. Taghzouti, M. Oukabli et al., "Acute and subchronic oral and dermal toxicological studies of*Salvia verbenaca*extracts in mice and rats," *Journal of Herbs, Spices & Medicinal Plants*, vol. 25, no. 1, pp. 33–42, 2019.

[65] K. G. Woon, J. H. Kyung, K. I. M. Do Yeon, and C. S. Hyun, "Beneficial effects of carvacrol on insulin resistance in high fat diet-induced diabetic mice," *Fall General Meeting and Academic Conference.*, vol. 1, pp. 281–281, 2013.

[66] M. Ezhumalai, T. Radhiga, and K. V. Pugalendi, "Antihyperglycemic effect of carvacrol in combination with rosiglitazone in high-fat diet-induced type 2 diabetic C57BL/6J mice," *Molecular and Cellular Biochemistry*, vol. 385, no. 1, pp. 23–31, 2014.

[67] S. Govindaraju and P. Indra Arulselvi, "Characterization of Coleus aromaticusessential oil and its major constituent carvacrol forin vitroantidiabetic and antiproliferative activities," *Journal of Herbs, Spices & Medicinal Plants*, vol. 24, no. 1, pp. 37–51, 2018.

[68] J. Wang, X. Hu, W. Ai et al., "Phytol increases adipocyte number and glucose tolerance through activation of PI3K/Akt signaling pathway in mice fed high-fat and high-fructose diet," *Biochemical and Biophysical Research Communications*, vol. 489, no. 4, pp. 432–438, 2017.

[69] S. Saravanan and L. Pari, "Role of thymol on hyperglycemia and hyperlipidemia in high fat diet-induced type 2 diabetic C57BL/6J mice," *European Journal of Pharmacology*, vol. 761, pp. 279–287, 2015.

[70] K. Rhayour, T. Bouchikhi, A. Tantaoui-Elaraki, K. Sendide, and A. Remmal, "The mechanism of bactericidal action of oregano and clove essential oils and of their phenolic major

components onEscherichia coliandBacillus subtilis," *Journal of Essential Oil Research*, vol. 15, no. 5, pp. 356–362, 2003.

[71] A. S. Brujeni, "Thymol effect on the expression of Mafa and Pdx1 genes in streptozotocin-induced diabetic rats," *Razi Journal of Medical Sciences*, vol. 26, no. 10, 2019.

[72] R. Murali and R. Saravanan, "Antidiabetic effect of d-limonene, a monoterpene in streptozotocin-induced diabetic rats," *Biomedicine & Preventive Nutrition*, vol. 2, no. 4, pp. 269–275, 2012.

[73] T. A. More, B. R. Kulkarni, M. L. Nalawade, and A. U. Arvindekar, "Antidiabetic activity of linalool and limonene in streptozotocin-induced diabetic rat: a combinatorial therapy approach," *International Journal of Pharmacy & Pharmaceutical Sciences*, vol. 6, no. 8, pp. 159–163, 2014.

[74] B. Deepa and C. V. Anuradha, "Linalool, a plant derived monoterpene alcohol, rescues kidney from diabetes-induced nephropathic changes via blood glucose reduction," *Diabetologia Croatica*, vol. 40, no. 4, 2011.

[75] W. Churklam, S. Chaturongakul, B. Ngamwongsatit, and R. Aunpad, "The mechanisms of action of carvacrol and its synergism with nisin against _Listeria monocytogenes_ on sliced bologna sausage," *Food Control*, vol. 108, article 106864, 2020.

[76] A. Duarte, Â. Luís, M. Oleastro, and F. C. Domingues, "Antioxidant properties of coriander essential oil and linalool and their potential to control *Campylobacter* spp," *Food Control*, vol. 61, pp. 115–122, 2016.

[77] K. Hąc-Wydro, M. Flasiński, and K. Romańczuk, "Essential oils as food eco-preservatives: model system studies on the effect of temperature on limonene antibacterial activity," *Food Chemistry*, vol. 235, pp. 127–135, 2017.

[78] M. K. Swamy, M. S. Akhtar, and U. R. Sinniah, "Antimicrobial properties of plant essential oils against human pathogens and their mode of action: an updated review," *Evidence-based Complementary and Alternative Medicine*, vol. 2016, 21 pages, 2016.

[79] X. Liu, J. Cai, H. Chen et al., "Antibacterial activity and mechanism of linalool against *Pseudomonas aeruginosa*," *Microbial Pathogenesis*, vol. 141, article 103980, 2020.

[80] J. Baranauskaite, A. Kubiliene, M. Marksa et al., "The influence of different oregano species on the antioxidant activity determined using HPLC postcolumn DPPH method and anticancer activity of carvacrol and rosmarinic acid," *BioMed Research International*, vol. 2017, 7 pages, 2017.

[81] M. T. Islam, A. B. R. Khalipha, R. Bagchi et al., "Anticancer activity of thymol: a literature-based review and docking study with emphasis on its anticancer mechanisms," *IUBMB Life*, vol. 71, no. 1, pp. 9–19, 2019.

[82] K. Sekhar, A. R. Chandra, M. N. Bobby, and J. R. Kanala, "A review on anticancer potential of natural drugs: hispolon and limonene," *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 11, pp. 3253–3263, 2018.

[83] K. Fan, X. Li, Y. Cao et al., "Carvacrol inhibits proliferation and induces apoptosis in human colon cancer cells," *Anti-Cancer Drugs*, vol. 26, no. 8, pp. 813–823, 2015.