Review Article

Ethnopharmacology, Phytochemistry, and Pharmacological Properties of *Thymus satureioides* Coss.

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*Thymus satureioides* Coss. (Lamiaceae) is a Moroccan medicinal plant locally known as “Azkouni” or “Zaitra.” It is widely used in traditional medicine to treat various ailments, including hypertension, diabetes, cold, fever, dermatological and circulatory disorders, immune problems, bronchitis, nociception, cooling, pharyngitis, cough, and influenza. The current review aims to critically summarize the literature on ethnopharmacological uses, chemical profile, and pharmacological investigations of *T. satureioides* in order to provide data support and scientific evidences for further investigations. Electronic databases such as Scopus, PubMed, Web of Science, SciFinder, ScienceDirect, Google Scholar, and Medline were used to gather data on *T. satureioides*. Chemical characterization of *T. satureioides* essential oils (EOs) and extracts allowed to identify a total of 139 bioactive compounds, mainly belonging to the terpenoids, phenolic acids, and flavonoids classes. *T. satureioides* especially its essential oils exhibited numerous biological activities such as antibacterial, antifungal, anti-inflammatory, antioxidant, antidiabetic, anticancer, antiparasitic, and hypolipidemic activities. In light of these findings, further studies to transmute the traditional application of *T. satureioides* into scientific-based information are strongly required. Additional *in vivo* pharmacological studies are recommended to validate the results of the *in vitro* studies. Moreover, comprehensive preclinical and clinical trials on the pharmacological mechanisms of action of this plant and its bioactive compounds on molecular targets should be performed. Finally, more efforts must be focused on toxicological assessments and pharmacokinetic studies, in order to ensure the safety and the efficiency of *T. satureioides*.

1. Introduction

*Thymus satureioides* Coss. is a perennial shrub (10–60 cm in height) belonging to the Lamiaceae family and the genus *Thymus* [1, 2]. *T. satureioides* is an endemic Moroccan medicinal plant locally known as “Azkouni” or “Zaitra” [3]. This species is widely distributed in the arid and semiarid habitats of the Moroccan High Atlas and Anti-Atlas [1, 4].

In Morocco, *T. satureioides* has been extensively used in folk medicine against numerous diseases, including arterial hypertension, diabetes, cold, fever [5, 6], dermatological and immune problems, digestive ailments [1, 7, 8], and metabolic disorders [9]. Ethnopharmacological investigations showed that *T. satureioides* is used for the treatments of bronchitis, skin ailments, nociception, circulatory disorders, urogenital problems, nervous and visual ailments, cooling, pharyngitis, cough, influenza, and as an antispasmodic agent [5, 10–12]. Phytochemical analysis of *T. satureioides* essential oils and extracts enabled to identify numerous bioactive compounds belonging to several chemical classes, including terpenoids, phenolic acids, and flavonoids classes. *T. satureioides* especially its essential oils exhibited numerous biological activities such as antibacterial, antifungal, anti-inflammatory, antioxidant, antidiabetic, anticancer, antiparasitic, and hypolipidemic activities. In light of these findings, further studies to transmute the traditional application of *T. satureioides* into scientific-based information are strongly required. Additional *in vivo* pharmacological studies are recommended to validate the results of the *in vitro* studies. Moreover, comprehensive preclinical and clinical trials on the pharmacological mechanisms of action of this plant and its bioactive compounds on molecular targets should be performed. Finally, more efforts must be focused on toxicological assessments and pharmacokinetic studies, in order to ensure the safety and the efficiency of *T. satureioides*. 
However, the targeted mechanisms of these pharmacological properties have been poorly investigated.

Although numerous studies reported the ethnomedicinal properties and pharmacological effects of *T. satureioides*, to the best of our knowledge, no review was published to summarize these reports and suggest the future pharmacological applications of this plant. Therefore, this review was designed to critically summarize all published works on ethnomedicinal uses, phytochemistry, and pharmacological properties of *T. satureioides*. The current paper aims to provide data support and prospect concerning future research studies on the biological potential of *T. satureioides*.

2. Research Methodology

All published works about the ethnomedicinal uses, phytochemical composition, and biological activities of *T. satureioides* were collected, examined, and reported in the present review. An extensive bibliometric survey from different scientific databases such as ScienceDirect, PubMed, Scopus, Web of Science, SpringerLink, Google Scholar, and Medline was used to extract all relevant papers. A total of 79 peer-reviewed papers published in English and French languages were selected to compose this review. The data provided in case reports, editorial/letters, patents, conference papers, and symposiums were excluded because they were considered scientifically unreliable. The search keywords used were “*T. satureioides*, phytochemical composition of *T. satureioides*, *T. satureioides* EOs, biological activities of *T. satureioides*, the antimicrobial activity of *T. satureioides*, ethnomedicinal study of *T. satureioides*, and the antioxidant effect of *T. satureioides*”. ChemDraw Ultra 12.0 Software was used to draw the chemical structures. IUPAC names of the reported chemical compounds were checked using PubChem databases (pubchem.ncbi.nlm.nih.gov).

3. Results and Discussion

3.1. Botany, Ecology, and Biogeographic Distribution. *T. satureioides* is a bushy perennial shrub (10–60 cm in height) with erect branches [1, 2] (Figure 1). Its leaves are opposite, linear, or lanceolate, curled at the edges, grayish on top, and tomentose at the base. The flowers are grouped into ovoid glomerules. The corolla is bilabiate (1/2 cm) with pink top, and tomentose at the base. The flowers are grouped into opposite, linear, or lanceolate, curled at the edges, grayish on top, and tomentose at the base. The flowers are grouped into opposite, linear, or lanceolate, curled at the edges, grayish on top, and tomentose at the base. The flowers are grouped into opposite, linear, or lanceolate, curled at the edges, grayish on top, and tomentose at the base.

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*T. satureioides* is an endemic Moroccan plant, geographically found in the Mediterranean, Thermomediterranean, and Mesomediterranean series, in forest clearings, scrub, matorrals, and low and medium mountains up to 2200 m altitude [3, 27]. This species grows on siliceous limestone substratum and rocky to moderately earthy soils in the High Atlas and Anti-Atlas of Morocco. From a climatic point of view, *T. satureioides* is located in the arid to subhumid bioclimate, with hot, temperate, and fresh variants [3].

3.2. Ethnomedicinal Use. *T. satureioides* is one of the medicinal plants commonly used in Moroccan folk medicine to treat many pathological disorders, including diabetes, arterial hypertension, digestive ailments, cold, fever, and respiratory problems [5, 6].

Several ethnomedical and ethnopharmacological surveys reported these practices and showed that the medicinal use of *T. satureioides* depends on the plant’s part used (Table 1). The aerial parts of *T. satureioides* were used as a decoction and infusion to treat gastric disorders, chills, cold, fever, and headaches [11], as well as arterial hypertension and diabetes [5, 28]. In addition, Mouhajir et al. [35] showed that the aerial part decoction is used as food disinfectant and against cold and colic.

The whole plant is used to treat dermatological disorders, immune problems, digestive ailments, intestinal troubles, colds, and coughs [7, 8, 29]. The leaves of *T. satureioides* are mainly known to be used against metabolic disorders, in particular diabetes [9, 12, 31], as well as for the treatments of bloating and diarrhea [32] or against cooling, pharyngitis, cough, and influenza [10].

Other ethnopharmacological studies reported that *T. satureioides* was also used as an antispasmodic and antinociceptive agent, and for the treatment of bronchitis, skin ailments, circulatory disorders, urogenital problems, nervous and visual ailments, and menstruation pains [1, 5, 11, 12, 33].

3.3. Phytochemistry. Phytochemical screening of *T. satureioides* EOs and extracts revealed the presence of a total of 139 bioactive compounds, which can be grouped into three main chemical classes, including terpenoids, phenolic acids, and flavonoids (Table 2).

3.3.1. Phenolic Compounds. Thanks to their phenolic group, the phenolic compounds such as phenolic acids, flavonoids, tocopherols, and tannins are considered as an important group of bioactive compounds that are responsible for a wide range of biological properties such as antimicrobial [51, 52], antioxidant [53] anticancer [54], and litholytic activities [55]. Besides their pharmacological potential, the phenolic compounds, particularly flavonoids, are involved in many physiological processes; they are included in the regulation and protection of vascular plants against several biotic and abiotic stresses [56–58].

There are few studies investigating the chemical composition of *T. satureioides* extracts. In fact, the phenolic profile of *T. satureioides* remains not well identified.
Khouya et al. [24] have examined the phenolic composition of the *T. satureioides* aqueous extracts and reported that they contain high levels of phenolic compounds, which are represented by rosmarinic acid as major phenolic acid and luteolin-7-glycoside and hesperetin as major flavonoids. Another study showed that *T. satureioides* aqueous extracts were rich in total polyphenols (456.73 ± 6.94 mg caffeic acid equivalent/g of dry plant) and in flavonoid group (172.79 ± 2.12 mg rutin equivalent/g of dry plant) with rosmarinic acid, hesperetin, and luteolin-7-glucoside as major phenolic compounds [13]. However, other molecules such as ursolic acid and oleanolic acids were identified in the chloroform extract of *T. satureioides* [14].

In a recent study, Tebaa et al. [59] showed that the aqueous extracts of *T. satureioides* aerial parts are rich in total polyphenols (285 ± 34.82 μg gallic acid equivalent/mL aqueous extract), in total flavonoids (25.83 ± 4 μg catechin equivalent/mL aqueous extract) and in total tannins (0.032 ± 0.002 μg tannic acid equivalents/mL aqueous extract).

Table 1: Ethnomedicinal use of *T. satureioides*.

| Study area                        | Parts used  | Preparation method         | Medicinal use                                                                 | References |
|----------------------------------|-------------|-----------------------------|-------------------------------------------------------------------------------|------------|
| Agadir-Ida-Ou Tanane (Morocco)   | Aerial parts| Infusion, decoction, cataplasms, and fumigation | Gastrointestinal complaints, influenza, colds, fever, headaches, affections of the annex glands of the digestive tract, respiratory problems, and menstruation pain in women | [5]        |
| Agadir-Ida-Ou-Tanane Province (Southwest Morocco) | Whole plant, flowers, leaves, and stems | Infusion | Respiratory, digestive, skin, circulatory, genital, nervous, visual, and urinary problems | [12]       |
| Beni Mellal (Morocco)            | Leaves      | Decoction and infusion      | Diabetes                                                                       | [28]       |
| High Atlas mountains (Morocco)   | Whole plant | Powder                      | Gastrointestinal ailments (stomach ache and intestinal trouble) and respiratory disorders such as colds and coughs | [29]       |
| Haouz-Rhamna region (Morocco)    | Leaves      | Decoction and infusion      | Diabetes                                                                       | [9]        |
| Er-Rich region (High Atlas of Morocco) | Aerial parts | Decoction and infusion | Gastric disorders, chills, cold, fever, headaches, digestive infections, and pain, and it is also used as an antispasmodic agent | [11]       |
| Er-Rich region                   | Aerial parts| Fumigation                  | Respiratory diseases, digestive ailments                                       | [11]       |
| Agadir region (Morocco)          | Leaves      | Infusion                    | Diabetes                                                                       | [30]       |
| Chitouka Ait Baha and Tiznit (Morocco) | Leaves | Infusion, maceration, and powder | Diabetes                                                                       | [31]       |
| Western Middle Atlas region (Morocco) | Leaves and stems | Infusion       | Gastrointestinal disorders (bloating, diarrhea)                               | [32]       |
| Zagora (Morocco)                 | Leaves      | Decoction and powder        | Diabetes and used as antinociceptive agent                                     | [33]       |
| Azilal (Morocco)                 | Aerial parts| Fumigation, infusion        | Digestive ailment, colds, and coughs                                          | [34]       |
| Seksaoua region, Western High Atlas (Morocco) | Leaves | Decoction | Cooling, pharyngitis, cough, and influenza                                     | [10]       |
| Morocco                          | Leaves, aerial part | Decoction, infusion | Coughs and bronchitis                                                          | [1]        |
| Beni Mellal region (Morocco)     | Whole plant | Infusion                    | Gastrointestinal ailments                                                       | [8]        |
| Berber Peoples of Morocco        | Aerial parts| Infusion                    | Treatment of cold and colic and as food disinfectant                           | [35]       |
| Marrakech (Morocco)              | Aerial parts| Decoction                   | Digestive ailments                                                             | [36]       |
| Errachidia Province (Morocco)    | Leaves, flower | Decoction             | Arterial hypertension                                                           | [37]       |
| Tata Province, Morocco           | Aerial part | Decoction                   | Hypotensive, digestive ailments, diabetes, colds                               | [6]        |
| Region of Middle Oum Rbia (Morocco) | Whole plant, leaves | Not reported    | Dermatological, immune, and digestive and respiratory ailments                | [7]        |

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| No. | Compounds                        | Parts used                | Extracts                                           | References |
|-----|----------------------------------|---------------------------|---------------------------------------------------|------------|
| 1   | Apigenin                         | Leaves                    | Alcohol                                           | [38]       |
| 2   | Luteolin                         | Leaves, Aerial parts      | Alcohol, methanol                                 | [14, 38]   |
| 3   | Eriodictyol                      | Leaves                    | Methanol                                          | [14]       |
| 4   | Thymonin                         | Leaves                    | Methanol                                          | [14]       |
| 5   | Quercetin                        | Aerial parts              | Crude extracts, ethyl acetate, methanol           | [39]       |
| 6   | Hesperetin                       | Aerial parts              | Crude extracts, ethyl acetate, methanol, aqueous  | [13, 27, 39]| |
| 7   | Luteolin-3′-O-glucuronide        | Leaves                    | Methanol                                          | [14]       |
| 8   | Apigenin-7-O-glucoside           | Aerial parts              | Dichloromethane                                   | [39]       |
| 9   | Hyperoside                       | Aerial parts              | Dichloromethane, ethyl acetate, methanol          | [39]       |
| 10  | Luteolin-7-O-glucoside           | Leaves, Aerial parts      | Aqueous, methanol                                 | [13, 14, 24]| |
| 11  | Eriodictyol-7-O-glucoside        | Leaves                    | Methanol                                          | [14]       |
| 12  | Caffeic acid                     | Aerial parts, Leaves      | Alcohol, ethyl acetate, methanol                  | [38, 39]   |
| 13  | p-Coumaric acid                  | Leaves                    | Alcohol                                           | [38]       |
| 14  | Ferulic acid                     | Leaves                    | Alcohol                                           | [38]       |
| 15  | Rosmarinic acid                  | Aerial parts              | Crude extracts                                    | [27, 39]   |
| 16  | Chlorogenic acid                 | Leaves                    | Alcohol                                           | [38]       |
| 17  | Ursolic acid                     | Leaves                    | Chloroform                                        | [14]       |
| 18  |oleanolic acids                   | Leaves                    | Chloroform                                        | [14]       |
| 19  | (E)-Linalool oxide               | Aerial parts              | EOs                                               | [40]       |
| 20  | (E)-p-Menthan-2-one              | Aerial parts              | EOs                                               | [40]       |
| 21  | (E)-Sabine hydrate               | Aerial parts              | EOs                                               | [40]       |
| 22  | (E)-Verbenol                     | Aerial parts              | EOs                                               | [40]       |
| 23  | (E)-γ-Ocimene                    | Flowering top             | EOs                                               | [41]       |
| 24  | (Z)-Dihydrocarvone               | Aerial parts              | EOs                                               | [40]       |
| 25  | (Z)-Sabine hydrate               | Aerial parts              | EOs                                               | [40]       |
| 26  | 1,10-di-epi-Cubenol              | Whole plant, aerial parts | EOs                                               | [19, 41]   |
| 27  | 1,8 Cineole                      | Aerial parts              | EOs                                               | [40]       |
| 28  | Thymol methyl ether (2-Isopropyl-5-methylnisol) | Aerial parts | EOs                                               | [40]       |
| 29  | 3-Octanol                        | Whole plant, aerial parts | EOs, petroleum ether, ethyl acetate              | [19, 23, 41]| |
| 30  | 3-Tetradecen-5-ynne              | Leaves                    | EOs                                               | [42]       |
| 31  | 3-Thujen-2-one                   | Aerial parts              | EOs                                               | [16]       |
| 32  | 3-β-Carene                       | Aerial parts              | EOs                                               | [40]       |
| 33  | Alloaromadendrene                | Aerial parts, flowering top | EOs                                           | [40, 41]   |
| 34  | Alloocimene                      | Aerial parts              | Petroleum ether, EOs                              | [23, 43]   |
| 35  | Aromadendrene                    | Aerial parts              | EOs                                               | [40]       |
| 36  | Bicyclogermacrene                | Flowering top, aerial parts | EOs                                           | [41, 44]   |
| 37  | Bornol                           | Aerial parts, flowering top | EOs, petroleum ether, ethyl acetate              | [23, 41, 45]| |
| 38  | Bornyl acetate                   | Aerial parts, flowering top | EOs, petroleum ether, ethyl acetate              | [23, 41, 45]| |
| 39  | Bornyl formate                   | Aerial parts              | EOs                                               | [16]       |
| 40  | Calamenene                       | Aerial parts              | EOs                                               | [40]       |
| 41  | Calarene                         | Aerial parts              | EOs, petroleum ether, ethyl acetate              | [23, 43]   |
| 42  | Camphene                         | Aerial parts, whole plant, flowering top | EOs, petroleum ether, ethyl acetate | [19, 41, 46]| |
| 43  | Camphene hydrate                 | Aerial parts              | EOs                                               | [44]       |
| 44  | Camphenilone                     | Aerial parts              | EOs                                               | [44]       |
| 45  | Camphor                          | Aerial parts, flowering top | EOs                                           | [41, 47]   |
| 46  | Carvacrol (5-isopropyl-2-methylphenol) | Aerial parts, flowering top | EOs, petroleum ether, ethyl acetate | [23, 41, 47]| |
| 47  | Carvacrol methyl ether           | Aerial parts              | EOs, petroleum ether, ethyl acetate              | [15, 21, 23]| |
| 48  | Carvenone                        | Aerial parts              | EOs, petroleum ether, ethyl acetate              | [23, 44]   |
| 49  | Carveol                          | Aerial parts              | EOs                                               | [40]       |
| 50  | Carvone                          | Aerial parts              | EOs                                               | [40]       |
| 51  | Caryophyllene oxide              | Aerial parts              | EOs, petroleum ether, ethyl acetate              | [23, 40]   |
| 52  | Cedrene oxide                    | Aerial parts              | EOs                                               | [48]       |
| 53  | cis-Linalool oxide               | Aerial parts, flowering top | EOs                                           | [43, 44]   |
| 54  | cis-Ocimene                      | Aerial parts              | EOs                                               | [44]       |
| 55  | cis-α-Bisabolene                 | Leaves                    | EOs                                               | [42]       |
| No. | Compounds                        | Parts used                              | Extracts                        | References          |
|-----|----------------------------------|-----------------------------------------|---------------------------------|---------------------|
| 56  | Copaene                          | Aerial parts                            | EOs                             | [40]                |
| 57  | Crithmene                        | Aerial parts                            | EOs                             | [47]                |
| 58  | Dehydro-p-cymene                 | Aerial parts                            | EOs                             | [40]                |
| 59  | Dihydrocarvone 1                 | Aerial parts                            | EOs                             | [40]                |
| 60  | Dihydrocarvone 2                 | Aerial parts                            | EOs                             | [40]                |
| 61  | Dodecamethylcyclohexasiloxane    | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 62  | Eucalyptol                       | Leaves                                  | EOs                             | [42]                |
| 63  | Eugenol                          | Aerial parts, whole plant               | EOs                             | [19, 44]            |
| 64  | Fenchone                         | Flowering top                           | EOs                             | [16]                |
| 65  | Geraniol formate                 | Aerial parts                            | Ethyl acetate                   | [23]                |
| 66  | Geranyl linalool                  | Aerial parts                            | EOs                             | [40]                |
| 67  | Germacrene-D-4-ol                | Flowering top                           | EOs                             | [41]                |
| 68  | Germacrene                       | Aerial parts                            | EOs                             | [15]                |
| 69  | Guai-3,9-diene                   | Aerial parts                            | Petroleum ether, EOs            | [23, 43, 48]        |
| 70  | Guaiazulene                      | Aerial parts                            | EOs                             | [40]                |
| 71  | Hexahydroindan                   | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 72  | Hotrienol                        | Leaves                                  | EOs                             | [42]                |
| 73  | Isoaromadendrene epoxide         | Aerial parts                            | Petroleum ether, EOs            | [23, 40]            |
| 74  | Isoborneol                       | Aerial parts                            | EOs                             | [40]                |
| 75  | Isobornyl acetate                | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 76  | Isobornyl formate                | Aerial parts                            | EOs, petroleum ether, ethyl acetate | [23, 44] |
| 77  | Isoledene                        | Leaves                                  | EOs                             | [42]                |
| 78  | Isothymol methyl ether           | Leaves                                  | EOs                             | [42]                |
| 79  | Ledene                           | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 80  | Ledol 6-epi-cubenol              | Flowering top                           | EOs                             | [41]                |
| 81  | Limonene                         | Aerial parts, flowering top             | EOs                             | [15, 41]            |
| 82  | Linalool                         | Aerial parts, flowering top             | EOs                             | [41, 45]            |
| 83  | Linalyl propionate               | Aerial parts                            | Ethyl acetate, petroleum ether  | [23]                |
| 84  | Thymol methyl ether              | Aerial parts, flowering top             | EOs                             | [40, 41]            |
| 85  | Myrcene                          | Aerial parts, flowering top             | EOs                             | [15, 41]            |
| 86  | Octan-3-one                      | Aerial parts                            | EOs                             | [45]                |
| 87  | Octen-3-ol                       | Aerial parts                            | EOs                             | [40]                |
| 88  | p-Cymen-8-ol (2-(4-methylphenyl) propan-2-ol) | Flowering top | EOs                             | [41]                |
| 89  | p-Cymene                         | Aerial parts, flowering top             | EOs, petroleum ether, ethyl acetate | [23, 41, 45] |
| 90  | Pentasilaoxane                   | Aerial parts                            | Petroleum ether                 | [23]                |
| 91  | Pinocarveol                      | Aerial parts                            | EOs                             | [40]                |
| 92  | p-Menth-2-en-1-ol                | Aerial parts                            | EOs                             | [40]                |
| 93  | p-Menta-1.8-diene                | Aerial parts                            | Petroleum ether, ethyl acetate  | [23]                |
| 94  | Sabinene                         | Aerial parts                            | EOs                             | [49]                |
| 95  | Santolina triene                 | Aerial parts                            | EO, petroleum ether             | [23, 43]            |
| 96  | Spathulenol                      | Aerial parts                            | EOs                             | [40]                |
| 97  | ta-Cadinol                      | Aerial parts, whole plant               | EOs                             | [19, 44]            |
| 98  | Terpinene-4-ol                   | Aerial parts, whole plant               | EOs                             | [19, 44]            |
| 99  | Terpinolene                      | Aerial parts                            | EOs                             | [40]                |
| 100 | Thuja-2,4(10)-diene              | Aerial parts                            | EOs                             | [40]                |
| 101 | Thujone                          | Aerial parts, whole plant               | EOs                             | [19, 44]            |
| 102 | Trans-1,2-diphenylclobutane      | Aerial parts                            | Petroleum ether                 | [23]                |
| 103 | trans-Pinocarveol                | Flowering top                           | EOs                             | [41]                |
| 104 | trans-Sabinene hydrate           | Flowering top                           | EOs                             | [41]                |
| 105 | Tricyclene                       | Aerial parts, whole plant, flowering top | EOs                             | [19, 41, 46]        |
| 106 | Valencene                        | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 107 | α-Amorphene                      | Leaves                                  | EOs                             | [42]                |
| 108 | α-Cadinol                        | Aerial parts                            | EOs                             | [21]                |
| 109 | α-Campholenal                    | Aerial parts                            | EOs                             | [44]                |
| 110 | α-Campholene aldehyde            | Aerial parts                            | EOs, petroleum ether            | [23, 43]            |
| 111 | α-Cubebele                       | Aerial parts                            | EOs                             | [40]                |
| 112 | α-Curcumene                      | Aerial parts                            | EOs                             | [44]                |
butanol extracts) enabled to detect the presence of flavonoids, catechols, gallic tannins, and anthraquinones [60]. Moreover, the quantitative HPLC analysis of crude and organic extracts of *T. satureioides* aerial parts showed the presence of phenolic acids (caffeic acid and rosmarinic acid) and the flavonoids quercetin and hesperetin in crude and methanolic extracts, whereas rosmarinic acid, hyperoside, quercetin, and hesperetin in crude and methanolic extracts, whereas rosmarinic acid, hyperoside, quercetin, and hesperetin were detected in ethyl acetate extracts [39].

Interestingly, Kouar et al. [38] have determined the phytochemical profile of alcoholic extract of *T. satureioides* leaves, using the electrocoagulation and solvent extraction assays, and detected the presence of saponins, sterols, triterpene, tannins, and flavone aglycones. The quantitative analysis showed that *T. satureioides* alcoholic extract contains high levels of total polyphenols (70.2 ± 0.4 mg of gallic acid equivalents/g extract) and total flavonoids (52.7 ± 0.01 mg of quercetin equivalents/g extract). The high performance liquid chromatography (HPLC) analysis allowed to identify six compounds in this alcoholic extract, including four phenolic acids ([12–16], [18]) and two flavonoid compounds ([1–2], [19]) [39].

The phenolic compound content and nature vary depending on the extraction solvent, plant’s part used, plant’s origin, storage conditions, and analytical method used. Indeed, flavonoids are the main phenolic group detected in *T. satureioides* extracts with 11 compounds ([1–11]) (Figure 2). Moreover, five phenolic acids were identified ([12–16]) (Figure 3).

### 3.3.2. Volatile Compounds

Numerous studies have investigated and characterized the chemical composition of *T. satureioides* EOs, particularly from the aerial parts.

The chemical analysis showed that *T. satureioides* EOs are mainly composed of borneol, thymol, carvacrol, camphene, α-pinene, α-terpineol, p-cymene, and linalool (Figure 4).

The percentages and the nature of these volatile compounds vary noticeably depending on several intrinsic and extrinsic factors of the plant, including geographical origin, phenological stage, genotype, plant’s part used, and storage and extraction conditions [61, 62].

Sbayou et al. [43] indicated that borneol and thymol are the chief components of *T. satureioides* EOs with 26.45% and 11.24%, respectively, followed by α-terpinyl acetate (10.99%), β-caryophyllene (8.24%), and camphene (7.16%). The studies carried out on *T. satureioides* from the High Atlas of Morocco indicated that carvacrol (26.5%) and borneol (20.1%) are the main compounds of its EOs, while thymol was not identified [15, 49].

It is well seen that borneol, carvacrol, and thymol constitute the major proportion of the volatile compounds of *T. satureioides*. Indeed, in an earlier study, Jaafari et al. [23] described the EOs of *T. satureioides* harvested in Tiznit region as a “borneol chemotype (59.57%),” those of Marrakech region (Asni-My Brahim) as “carvacrol (35.90%) and borneol (30%) chemotypes,” and the one of Beni Mellal region (Bin El

| No. | Compounds     | Parts used           | Extracts                  | References |
|-----|---------------|----------------------|---------------------------|------------|
| 113 | α-Ferulene    | Aerial parts         | EOs, petroleum ether      | [23, 43]   |
| 114 | α-Guajene     | Aerial parts         | EOs, petroleum ether      | [23, 43]   |
| 115 | α-Gurjunene   | Aerial parts         | EOs                      | [44]       |
| 116 | α-Humulene    | Aerial parts, flowering top | EOs                  | [15, 41]   |
| 117 | α-Muuroleone  | Aerial parts         | Petroleum ether          | [23]       |
| 118 | α-Panasisien  | Aerial parts         | EOs                      | [40]       |
| 119 | α-Pentasiloxane | Aerial parts       | EOs                      | [43]       |
| 120 | α-Phellandrene | Aerial parts     | EOs, petroleum ether      | [23, 43]   |
| 121 | α-Pine 2      | Aerial parts, whole plant | EOs                  | [19, 46]   |
| 122 | α-Thujene     | Aerial parts, whole plant, flowering top | EOs                  | [19, 41, 46] |
| 123 | β-Bourbonene  | Flowering top        | EOs                      | [41]       |
| 124 | β-Caryophyllene | Aerial parts     | EOs                      | [47]       |
| 125 | β-Cubebe 1    | Aerial parts         | EOs                      | [40]       |
| 126 | β-Gurjunene   | Aerial parts         | EOs                      | [40]       |
| 127 | β-Ionone      | Aerial parts         | EOs                      | [40]       |
| 128 | β-Linalool    | Aerial parts         | Ethyl acetate            | [23]       |
| 129 | β-Opopenone   | Aerial parts, whole plant | EOs                  | [19, 44]   |
| 130 | β-Patchoulene | Aerial parts         | EOs                      | [40]       |
| 131 | β-Phellandrene | Flowering top, aerial parts | EOs                  | [41, 48]   |
| 132 | β-Pinene      | Aerial parts, flowering top | EOs, petroleum ether, ethyl acetate | [16, 23, 41] |
| 133 | γ-Cadinene    | Aerial parts, flowering top | EOs                  | [41, 47]   |
| 134 | γ-Costol      | Aerial parts         | EOs                      | [48]       |
| 135 | γ-Methylionone | Aerial parts       | EOs                      | [48]       |
| 136 | γ-Muuroleone  | Aerial parts         | EOs                      | [41, 42]   |
| 137 | r-Muurol 1    | Aerial parts         | Petroleum ether          | [23]       |
| 138 | γ-terpine 1   | Aerial parts         | EOs, petroleum ether, ethyl acetate | [15, 23, 50] |
| 139 | δ-Cadinene    | Aerial parts, flowering top | EOs                  | [41, 50]   |
Widane) as “borneol (51.98%) and thymol (26.81%) chemotypes,” thus showing a variation in chemotypes of the *T. satureioides* EOs according to harvest zones.

A comparative study of *T. satureioides* leaf and flower EOs, using simultaneous GC-FID and GC-MS tools, showed major differences regarding the main compounds of these two plants’ part EOs. Thereby, borneol (a monoterpenic alcohol) was the main compound of the flowers EOs with 19.3%, followed by carvacrol (10.0%) and thymol (3.8%), while carvacrol (37%), thymol (13.7%), γ-terpinene (8.4%), and (E)-β-caryophyllene (6.6%) were the main components of the leaves EOs [41].

**Figure 2:** Flavonoid compounds isolated from *T. satureioides* extracts.
Another study revealed the presence of 68 volatile compounds representing 93.3% of *T. satureioides* aerial parts’ total EOs using capillary gas chromatography and gas chromatography coupled to mass spectrometry (GC-MS) [40]. These volatile compounds mainly belong to the monoterpenoid class (monoterpene hydrocarbons, oxygenated monoterpenes, and phenolic monoterpenes) such as borneol, carvacrol, thymol, camphene, linalool, and camphor.

3.4. Pharmacological Properties. Numerous pharmacological investigations have shown that *T. satureioides* essential oils and extracts obtained from different plant parts possess various biological activities, including antibacterial, antioxidant, antifungal, antiparasitic, anticancer, antidiabetic, and anti-inflammatory effects (Figure 5).

3.4.1. Antibacterial Activity. The antibacterial activity of *T. satureioides* EOs and extracts, against a panel of bacterial strains, including Gram-positive and Gram-negative bacteria, was reported in the literature [16, 63, 64]. Indeed, the EOs obtained from different parts of *T. satureioides* were evaluated against several pathogenic bacteria known by their drug multiresistance, including *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Escherichia coli*, *Acinetobacter baumannii*, *B. cereus*, and *Enterobacter cloacae* revealed a significant antibacterial activity (inhibition zone diameters (Φ): 16 mm < Φ < 30.7 mm for leaves EOs; 22 mm < Φ < 45 mm for flowering top EOs) and a bacteriostatic effect against all tested strains except *B. cereus* [71].

In another study, testing of the bacteriostatic and bactericidal effects of EOs of *T. satureioides* leaves and flowering top on *E. coli*, *S. aureus*, *A. baumannii*, *B. cereus*, and *Mycobacterium smegmatis* revealed that EOs obtained after the flowering stage were more active against the studied strains than those obtained in the flowering stage. In fact, the highest activity was shown against *M. smegmatis* followed by *B. subtilis*, while the weakest activity was noticed against *E. coli* [70].

![Figure 3: Phenolic acids identified in *T. satureioides.*](image)

Mekkaoui et al. [70] tested in vitro the antimicrobial effect of EOs of *T. satureioides* harvested at two different phenoological stages (flowering and postflowering) against three pathogenic bacteria responsible for foodborne disease in Morocco (*E. coli*, *B. subtilis*, and *M. smegmatis*). They showed that EOs obtained after the flowering stage were more active against the studied strains than those obtained in the flowering stage. In fact, the highest activity was shown against *M. smegmatis* followed by *B. subtilis*, while the weakest activity was noticed against *E. coli* [70]. In the same context, Oussalah et al. [72] evaluated the antibacterial potential of the *T. satureioides* flower EOs against...
four pathogenic bacteria including two Gram-positive bacteria: *S. aureus* and *Listeria monocytogenes* (2812 1/2a), and two Gram-negative bacteria: *E. coli* O157:H7 and *S. typhimurium* (SL 1344), using the broth microdilution method. The results indicated that *S. aureus* was the most sensitive bacterium with MIC $\leq 0.05\%$ (v/v) followed by *E. coli* O157:H7 and *S. typhimurium* (MIC $\leq 0.2\%$ (v/v)), while *L. monocytogenes* was the least sensitive bacteria to the tested EOs with MIC $\leq 0.4\%$ (v/v).

More interestingly, Amrouch et al. [18] investigated both *in vitro* and in a food system the antibacterial activity of *T. satureioides* EOs, extracted from the whole plant, against foodborne bacteria (*E. coli, S. aureus,* and *B. cereus*). The paper disc diffusion and broth microdilution methods were used for the *in vitro* test and the beef minced meat was used as food model. Thereby, the addition of *T. satureioides* EOs to inoculated beef minced meat decreased the tested strain population after 4 days of storage. Moreover, *in vitro* investigations indicated that *B. cereus* was the most sensitive bacteria ($\Phi = 19$ mm and MIC $= 1.1\%$), followed by *S. aureus* ($\Phi = 16$ mm, MIC $= 1.1\%$) and then *E. coli* ($\Phi = 14.25$ mm, MIC $= 1.25\%$) [18].

El Abdouni Khayari et al. [65] reported a good antibacterial activity of the *T. satureioides* aerial part EOs against *B. cereus* ($\Phi = 30.00 \pm 0.50$ mm, MIC $= 2.25$ mg/mL), followed by *M. luteus* ($\Phi = 26.70 \pm 0.20$ mm, MIC $= 4.5$ mg/
Figure 5: Pharmacological properties of *T. satureioides*.

Table 3: Antibacterial activity of *T. satureioides*.

| Parts used | Extracts               | Methods used                    | Bacteria tested                        | Key results           | References |
|------------|------------------------|---------------------------------|----------------------------------------|-----------------------|------------|
| Aerial parts | Essential oil (0.93%) | Broth microdilution method      | *Staphylococcus aureus* CCMM B3        | MIC = 4.50 mg/mL      | [65]       |
|            |                        |                                 | *Micrococcus luteus* ATCC 10240         | MIC = 4.50 mg/mL      |            |
|            |                        |                                 | *Bacillus cereus* ATCC 14579           | MIC = 2.50 mg/mL      |            |
|            |                        |                                 | *Listeria monocytogenes* ATCC 19115    | MIC = 4.50 mg/mL      |            |
|            |                        |                                 | *Escherichia coli* ATCC 25922          | MIC = 18.00 mg/mL     |            |
|            |                        |                                 | *Pseudomonas aeruginosa* ATCC 27853    | MIC > 18.4 mg/mL      |            |
|            |                        |                                 | *Klebsiella pneumoniae*                | MIC = 9 mg/mL         |            |
| Stem       | Aqueous extract        | Paper disc diffusion assay      | *Clavibacter michiganensis* subsp. michiganensis H195 isolate | Φ = 23.3 ± 2.4 mm    | [66]       |
| Leaves     | Aqueous extract        | Paper disc diffusion assay      | *Clavibacter michiganensis* subsp. michiganensis H195 isolate | Φ = 16.4 ± 0.5 mm    | [66]       |
| Aerial part | Essential oil          | Agar disc diffusion method      | *Staphylococcus aureus* ATCC 29213     | Φ = 34.67 ± 0.33 mm  | [20]       |
|            |                        |                                 | *Escherichia coli* ATCC 25922          | Φ = 20.67 ± 0.27 mm  |            |
|            |                        |                                 | *Pseudomonas aeruginosa* ATCC 27853    | Φ = 7.00 ± 0.00 mm   |            |
| Aerial part | Essential oil          | Microdilution assay            | *Escherichia coli* ATCC 25922          | MIC = 0.125%         | [67]       |
|            |                        |                                 | *Pseudomonas aeruginosa* ATCC 27853    | MIC = 1%             |            |
|            |                        |                                 | *Micrococcus luteus* ATCC 14452        | MIC = 0.03%          |            |
|            |                        |                                 | *Staphylococcus aureus* ATCC 29213     | MIC = 0.03%          |            |
|            |                        |                                 | *Bacillus subtilis* ATCC 6633          | MIC = 0.03%          |            |
|            |                        |                                 | *Salmonella typhimurium*               | MIC = 0.25%          |            |
|            |                        |                                 | *Bacillus cereus*                      | MIC = 0.015%         |            |
| Parts used    | Extracts         | Methods used       | Bacteria tested                                   | Key results                      | References |
|--------------|------------------|--------------------|---------------------------------------------------|----------------------------------|------------|
| Whole plant  | Essential oil    | Microdilution assay| *Staphylococcus aureus* ATCC 25923                 | MIC = 2.5 μl/mL                  | [17]       |
|              |                  |                    | *Streptococcus fasciens* ATCC 29212               | MIC = 2.5 μl/mL                  |            |
|              |                  |                    | *Escherichia coli* ATCC 4157                      |                                  |            |
|              |                  |                    | *Pseudomonas aeruginosa* ATCC 27853               |                                  |            |
|              |                  |                    |                                                    | *Staphylococcus aureus* ATCC 29213 | PHI = 15 ± 0 mm |
|              |                  |                    |                                                    | MIC = 0.625 μg/mL                | [43]       |
|              |                  |                    |                                                    | MBC = 0.625 μg/mL                |            |
|              |                  |                    |                                                    | **Escherichia coli**             |            |
|              |                  |                    |                                                    | **Pseudomonas aeruginosa** ATCC 27853 | PHI = 0 ± 0 mm |
|              |                  |                    |                                                    | MIC > 20 μl/mL                   |            |
|              |                  |                    |                                                    | MBC > 20 μl/mL                   |            |
|              |                  |                    |                                                    | **Enterobacter cloacae**         |            |
|              |                  |                    |                                                    | **Staphylococcus aureus** ATCC 29213 | PHI = 15 ± 0 mm |
|              |                  |                    |                                                    | MIC = 0.312 μg/mL                | [68]       |
|              |                  |                    |                                                    | MBC = 0.312 μg/mL                |            |
|              |                  |                    |                                                    | **Staphylococcus aureus**        |            |
|              |                  |                    |                                                    | **Enterococcus faecium**         |            |
|              |                  |                    |                                                    | **Enterobacter cloacae**         |            |
|              |                  |                    |                                                    | **Staphylococcus aureus** ATCC 29213 | PHI = 16 ± 0 mm |
|              |                  |                    |                                                    | MIC = 125 μl/mL                  |            |
|              |                  |                    |                                                    | MBC = 125 μl/mL                  |            |
| Aerial part  | Essential oil    | Agar-diffusion      | *Enterobacter cloacae* (clinical strain, nosoco.tech Abdel1) | MIC = 2.9 μg/mL                  | [68]       |
|              |                  | method             | *Escherichia coli* CIP 54127                       | MIC = 2.9 μg/mL                  |            |
|              |                  |                    | *Klebsiella pneumoniae* CIP 104216                 | MIC = 2.9 μg/mL                  |            |
|              |                  |                    | *P. aeruginosa* ATCC 15442                        | MIC = 11.7 μg/mL                 |            |
|              |                  |                    | *Salmonella typhimurium* ATCC 133115               | MIC = 2.9 μg/mL                  |            |
|              |                  |                    | *Listeria monocytogenes* ATCC 35152                |                                  |            |
|              |                  |                    | Methicillin-resistant *Staphylococcus aureus* (MRSA) |                                  |            |
|              |                  |                    | *Enterococcus faecalis* CIP A185                   |                                  |            |
|              |                  |                    | *Streptococcus equinus* CIP 56.23                  |                                  |            |
|              |                  |                    | *Streptococcus pyogenes* CIP 70.3                  |                                  |            |
| Parts used | Extracts | Methods used | Bacteria tested | Key results | References |
|------------|----------|--------------|-----------------|-------------|------------|
| Aerial parts | Essential oil | Agar diffusion method | *Escherichia coli* ATCC25922 | \( \Phi = 12.3 \pm 0.6 \text{ mm} \) |
| | | Broth microdilution method | \( \text{MIC} = 1.5\% \) |
| | | | Non-O1 *Vibrio cholera* | \( \Phi = 33.3 \pm 2.9 \text{ mm} \) |
| | | | \( \text{MIC} = 0.5\% \) |
| | | | *Pseudomonas aeruginosa* CCMMB11 | \( \Phi = 11.7 \pm 1.5 \text{ mm} \) |
| | | | \( \text{MIC} = 1.5\% \) |
| | | | *Enterobacter cloacae* | \( \Phi = 11.7 \pm 0.6 \text{ mm} \) |
| | | | \( \text{MIC} = 1.5\% \) |
| | | | *Klebsiella pneumoniae* | \( \Phi = 13.3 \pm 0.6 \text{ mm} \) |
| | | | \( \text{MIC} = 1.5\% \) |
| | | | *Staphylococcus aureus* CCMMB3 | \( \Phi = 29.3 \pm 2.1 \text{ mm} \) |
| | | | \( \text{MIC} = 0.125\% \) |
| | | | *Bacillus subtilis* ATCC9524 | \( \Phi = 34.3 \pm 1.1 \text{ mm} \) |
| | | | \( \text{MIC} = 0.003\% \) |
| | | | *Bacillus cereus* ATCC14579 | \( \Phi = 30 \pm 0 \text{ mm} \) |
| | | | \( \text{MIC} = 0.003\% \) |
| Aerial parts | Essential oil (1.86%) | Agar disc diffusion Agar dilution technique | *Staphylococcus aureus* CCMM B1 | \( \Phi = 29.67 \pm 1.15 \text{ mm} \) |
| | | | \( \text{MIC} = 1.78 \text{ mg/mL} \) |
| | | | *Bacillus subtilis* ATCC 9524 | \( \Phi = 43.67 \pm 1.53 \text{ mm} \) |
| | | | \( \text{MIC} = 0.89 \text{ mg/mL} \) |
| | | | *Bacillus cereus* ATCC 14579 | \( \Phi = 43.67 \pm 1.53 \text{ mm} \) |
| | | | \( \text{MIC} = 0.89 \text{ mg/mL} \) |
| | | | *Micrococcus luteus* ATCC 10240 | \( \Phi = 42.00 \pm 1.73 \text{ mm} \) |
| | | | \( \text{MIC} = 0.45 \text{ mg/mL} \) |
| | | | *Escherichia coli* ATCC 25922 | \( \Phi = 22.5 \pm 1.32 \text{ mm} \) |
| | | | \( \text{MIC} = 1.78 \text{ mg/mL} \) |
| | | | *Escherichia coli* CCMM B4 | \( \Phi = 23.00 \pm 1.00 \text{ mm} \) |
| | | | \( \text{MIC} = 1.78 \text{ mg/mL} \) |
| | | | *Salmonella sp.* CCMM B17 | \( \Phi = 22.33 \pm 0.58 \text{ mm} \) |
| | | | \( \text{MIC} = 1.78 \text{ mg/mL} \) |
| | | | *Enterobacter cloacae* | \( \Phi = 21.00 \pm 1.00 \text{ mm} \) |
| | | | \( \text{MIC} = 1.78 \text{ mg/mL} \) |
| Leaves | Essential oil (2.95%(v/w)) | Agar diffusion assay | *Bacillus cereus* | \( \Phi = 12.5 \text{ mm} \) |
| | | | *Staphylococcus aureus* ATCC 5638 | \( \Phi = 8.0 \text{ mm} \) |
| | | | \( \text{MIC} = 640 \mu\text{g/mL} \) |
| | | | *Listeria monocytogenes* | \( \Phi = 14.5 \text{ mm} \) |
| | | | \( \text{MIC} = 40 \mu\text{g/mL} \) |
| | | | *Aeromonas hydrophila* | \( \Phi = 11.8 \text{ mm} \) |
| | | | \( \text{MIC} = 160 \mu\text{g/mL} \) |
| | | | *Escherichia coli* | \( \Phi = 9.0 \text{ mm} \) |
| | | | \( \text{MIC} = 320 \mu\text{g/mL} \) |
| | | | *Proteus vulgaris* | \( \Phi = 7.4 \text{ mm} \) |
| | | | \( \text{MIC} = 640 \mu\text{g/mL} \) |
| | | | *Pseudomonas aeruginosa* | \( \Phi = 7.2 \text{ mm} \) |
| | | | \( \text{MIC} = 1280 \mu\text{g/mL} \) |
| | | | *Pseudomonas fluorescens* | \( \Phi = 7.8 \text{ mm} \) |
| | | | \( \text{MIC} = 640 \mu\text{g/mL} \) |
| | | | *Salmonella abony* | \( \Phi = 7.8 \text{ mm} \) |
| | | | \( \text{MIC} = 640 \mu\text{g/mL} \) |
| Parts used | Extracts | Methods used | Bacteria tested | Key results | References |
|------------|----------|--------------|-----------------|-------------|------------|
| Inflorescences (flowers) | Essential oil (2.95% (v/v)) | | Bacillus cereus | $\Phi = 13.8$ mm; $\text{MIC} = 80 \mu\text{g/mL}$ | [41] |
| | | | Staphylococcus aureus ATCC5638 | $\Phi = 8.4$ mm; $\text{MIC} = 320 \mu\text{g/mL}$ | |
| | | | Listeria monocytogenes | $\Phi = 15.2$ mm; $\text{MIC} = 40 \mu\text{g/mL}$ | |
| | | | Aeromonas hydrophila | $\Phi = 14.2$ mm; $\text{MIC} = 80 \mu\text{g/mL}$ | |
| | | | Escherichia coli | $\Phi = 10.4$ mm; $\text{MIC} = 160 \mu\text{g/mL}$ | |
| | | | Proteus vulgaris | $\Phi = 8.2$ mm; $\text{MIC} = 320 \mu\text{g/mL}$ | |
| | | | Pseudomonas aeruginosa | $\Phi = 6.8$ mm; $\text{MIC} = 640 \mu\text{g/mL}$ | |
| | | | Pseudomonas fluorescens | $\Phi = 8.0$ mm; $\text{MIC} = 320 \mu\text{g/mL}$ | |
| | | | Salmonella abony | $\Phi = 8.6$ mm; $\text{MIC} = 320 \mu\text{g/mL}$ | |
| Aerial part | Ethanolic extract | Agar-well diffusion method | Staphylococcus aureus 25923 | $\Phi = 6$ mm; $\text{MIC} = 6.25 \text{mg/mL}$; $\text{MBC} = 12.5 \text{mg/mL}$ | [69] |
| | | | Listeria monocytogenes 4032 | $\Phi = 8.1 \pm 0.31$ mm; $\text{MIC} = 6.25 \text{mg/mL}$; $\text{MBC} = 12.5 \text{mg/mL}$ | |
| | | | Bacillus cereus ATCC 14579 | $\Phi = 13.2 \pm 0.23$ mm; $\text{MIC} = <0.5 \text{mg/mL}$; $\text{MBC} = 1 \text{mg/mL}$ | |
| | | | Escherichia coli ATCC 25929 | $\Phi = 6$ mm; $\text{MIC} = 25 \text{mg/mL}$; $\text{MBC} = 50 \text{mg/mL}$ | |
| | | | Pseudomonas aeruginosa 195 | $\Phi = 10 \pm 0.043$ mm; $\text{MIC} = 25 \text{mg/mL}$; $\text{MBC} = 50 \text{mg/mL}$ | |
| | | | Salmonella enterica | $\Phi = 6$ mm; $\text{MIC} = 12 \text{mg/mL}$; $\text{MBC} = 25 \text{mg/mL}$ | |
| Aerial part | Essential oil | Disc diffusion assay | Escherichia coli | $\Phi = 13.66 \pm 0.43$ mm | [70] |
| | | | Bacillus subtilis | $\Phi = 26.21 \pm 2.08$ mm | |
| | | | Mycobacterium smegmatis | $\Phi = 28.34 \pm 1.05$ mm | |
| Leaves | Essential oil (2.7%) | Disc diffusion assay | Escherichia coli | $\Phi = 15.5$ mm | [71] |
| | | | Staphylococcus aureus | $\Phi = 30.7$ mm | |
| | | | Acinetobacter baumannii | $\Phi = 19$ mm | |
| | | | Bacillus cereus | $\Phi = 16$ mm | |
| | | | Enterobacter cloacae | $\Phi = 20$ mm | |
| Flower | Essential oil (4.1%) | Disc diffusion assay | Escherichia coli | $\Phi = 20$ mm | [71] |
| | | | Staphylococcus aureus | $\Phi = 45$ mm | |
| | | | Acinetobacter baumannii | $\Phi = 35$ mm | |
| | | | Bacillus cereus | $\Phi = 38$ mm | |
| | | | Enterobacter cloacae | $\Phi = 22$ mm | |
| Whole plant | Essential oil | Agar diffusion method | Staphylococcus aureus | $\Phi = 16$ mm; $\text{MIC} = 1.1\% (v/v)$ | [18] |
| | | | Bacillus cereus | $\Phi = 19$ mm; $\text{MIC} = 1.1\% (v/v)$ | |
| | | | Escherichia coli | $\Phi = 14.25$ mm; $\text{MIC} = 1.25\% (v/v)$ | |
| Parts used         | Extracts      | Methods used          | Bacteria tested                                         | Key results                                                                 | References |
|--------------------|---------------|-----------------------|---------------------------------------------------------|-----------------------------------------------------------------------------|------------|
| Flowering plant    | Essential oil | Agar dilution method  | *Escherichia coli* O157:H7                              | High antibacterial effect against the four pathogenic bacteria (MIC 0.05–0.4% (v/v)) | [72]       |
|                    |               |                       | *Listeria monocytogenes* 2812                           |                                                                             |            |
|                    |               |                       | *Salmonella typhimurium* SL 1344                        |                                                                             |            |
|                    |               |                       | *Staphylococcus aureus* ATCC 29213                      |                                                                             |            |
|                    |               |                       | *Pseudomonas aeruginosa* IH                             |                                                                             |            |
|                    |               |                       | *Pseudomonas aeruginosa* CECT 110T                       |                                                                             |            |
|                    |               |                       | *Pseudomonas aeruginosa* CECT 118                       |                                                                             |            |
|                    |               |                       | *Pseudomonas Fluorescens* CECT 378                      |                                                                             |            |
|                    |               |                       | *Escherichia coli* k12                                   |                                                                             |            |
|                    |               |                       | *Staphylococcus aureus* MBLA                             |                                                                             |            |
|                    |               |                       | *Staphylococcus aureus* CECT 976                        |                                                                             |            |
|                    |               |                       | *Staphylococcus aureus* CECT 794                        |                                                                             |            |
|                    |               |                       | *Bacillus subtilis* DCM 6633                            |                                                                             |            |
|                    |               |                       | *Bacillus capsulat*                                      |                                                                             |            |
|                    |               |                       | *Enterococcus faecium* CECT 410                         |                                                                             |            |
|                    |               |                       | *Listeria innocua* CECT 4030                            |                                                                             |            |
|                    |               |                       | *Listeria monocytogenes* CECT 4032                      |                                                                             |            |
| Flowering top      | Essential oil | Agar diffusion method | *Escherichia coli* 1 from patient                       |                                                                             | [73]       |
|                    |               |                       | *Escherichia coli* ATCCS                                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 2 from patient                       |                                                                             |            |
|                    |               |                       | *Escherichia coli* 1 from raw sheep milk                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 2 from Raw Sheep Milk                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 3 from raw sheep milk                 |                                                                             |            |
|                    |               |                       | *Enterohemorrhagic* *Escherichia coli* (EHEC) O157      |                                                                             |            |
|                    |               |                       | *Enteropathogenic* *Escherichia coli* (EPEC)             |                                                                             |            |
|                    |               |                       | *Enterotoxigenic* *Escherichia coli* (ETEC)              |                                                                             |            |
|                    |               |                       | *Enteroaggregative* *Escherichia coli* (EAaggEC)        |                                                                             |            |
|                    |               |                       | *Enteroinvasive* *Escherichia coli*                     |                                                                             |            |
| Aerial part        | Essential oil | Microdilution assay   | *Escherichia coli* 1 from patient                       |                                                                             | [64]       |
|                    | (3.2%)        |                       | *Escherichia coli* ATCCS                                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 2 from patient                       |                                                                             |            |
|                    |               |                       | *Escherichia coli* 1 from raw sheep milk                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 2 from Raw Sheep Milk                 |                                                                             |            |
|                    |               |                       | *Escherichia coli* 3 from raw sheep milk                 |                                                                             |            |
|                    |               |                       | *Enterohemorrhagic* *Escherichia coli* (EHEC) O157      |                                                                             |            |
|                    |               |                       | *Enteropathogenic* *Escherichia coli* (EPEC)             |                                                                             |            |
|                    |               |                       | *Enterotoxigenic* *Escherichia coli* (ETEC)              |                                                                             |            |
|                    |               |                       | *Enteroaggregative* *Escherichia coli* (EAaggEC)        |                                                                             |            |
|                    |               |                       | *Enteroinvasive* *Escherichia coli*                     |                                                                             |            |
| Leaves             | Essential oil | Disc diffusion method | *Microbacterium testaceum*                               | High antibacterial effect (Φ > 20 mm)                                        | [63]       |
|                    | 1.35% (v/w)   |                       | *Serratia marcescens*                                    |                                                                             |            |
|                    |               |                       | *Enteropathogenic* *Escherichia coli* (EPEC)             |                                                                             |            |
|                    |               |                       | *Enterotoxigenic* *Escherichia coli* (ETEC)              |                                                                             |            |
|                    |               |                       | *Enteroaggregative* *Escherichia coli* (EAaggEC)        |                                                                             |            |
|                    |               |                       | *Enteroinvasive* *Escherichia coli*                     |                                                                             |            |
Table 3: Continued.

| Parts used     | Extracts                    | Methods used     | Bacteria tested                               | Key results                                      | References |
|----------------|-----------------------------|------------------|-----------------------------------------------|--------------------------------------------------|------------|
| Leaves         | Aqueous extract             | Disc diffusion method | Microbacterium testaceum                     | Slight antibacterial activity (Φ < 8 mm)          | [63]       |
|                | 100 mg/mL (w/v)             |                  | Serratia marcescens                           |                                                  |            |
| Aerial parts   | Essential oil               | Microdilution method | Mycobacterium aurum A+                        | MIC = 0.015% (v/v)                               | [16]       |
|                |                             |                  | Mycobacterium smegmatis mc2-155               | MBC = 0.015% (v/v)                               |            |

the antioxidant potential of this plant species. In fact, several works reported the antioxidant activity of *T. satureioides* EOs as well as their extracts obtained from different plant parts (aerial parts, flowering top, and leaves) using different methods such as 2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging, ferric reducing power, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, thiobarbituric acid reactive substances (TBARS), 2,2-azobis 2-aminopropane dihydrochloride (APPH), and β-carotene/linoleic acid bleaching assays [13, 21, 39, 75]. All published works that studied the antioxidant activity of *T. satureioides* EOs and extracts have been listed and summarized in Table 4.

**3.4.2. Antioxidant Activity.** The use of *T. satureioides* as a food preservative and against several pathologic disorders in Moroccan folk medicine encouraged the research teams to study the antioxidant potential of this plant species. In fact, several works reported the antioxidant activity of *T. satureioides* EOs as well as their extracts obtained from different plant parts (aerial parts, flowering top, and leaves) using different methods such as 2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) radical scavenging, ferric reducing power, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging, thiobarbituric acid reactive substances (TBARS), 2,2-azobis 2-aminopropane dihydrochloride (APPH), and β-carotene/linoleic acid bleaching assays [13, 21, 39, 75]. All published works that studied the antioxidant activity of *T. satureioides* EOs and extracts have been listed and summarized in Table 4.

**3.4.2. Antioxidant Activity.** The use of *T. satureioides* as a food preservative and against several pathologic disorders in Moroccan folk medicine encouraged the research teams to study
Table 4: Antioxidant effects of *T. satureioides*.

| Parts used         | Extracts                             | Methods used                           | Findings                                      | Reference |
|--------------------|--------------------------------------|----------------------------------------|-----------------------------------------------|-----------|
| Aerial parts       | Crude extract                        | DPPH free radical scavenging activity | IC<sub>50</sub> = 0.44 ± 0.06 mg/mL           | [39]      |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 41.41 ± 4.55 mmol/L         |           |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 0.33 ± 0.02 mg/mL           |           |
| Aerial parts       | Ethyl acetate extract                | DPPH assay                             | IC<sub>50</sub> = 0.71 ± 0.09 mg/mL           |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 82.69 ± 2.29 mmol/L         |           |
|                    | Methanolic extract                   | DPPH assay                             | IC<sub>50</sub> = 0.33 ± 0.02 mg/mL           | [108]     |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 82.69 ± 2.29 mmol/L         |           |
|                    | Aqueous extract                      | DPPH assay                             | IC<sub>50</sub> = 0.71 ± 0.09 mg/mL           |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 82.69 ± 2.29 mmol/L         |           |
|                    | Dichloromethane extract              | DPPH assay                             | IC<sub>50</sub> = 0.33 ± 0.02 mg/mL           |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 82.69 ± 2.29 mmol/L         |           |
| Aerial parts       | Aqueous extract                      | TBARS method                           | Significant inhibition of lipid peroxidation product (MDA) | [24]      |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 0.44 ± 0.01 mg/mL           |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 40.14 ± 4.55 mmol/g         |           |
| Aerial parts       | Aqueous extract                      | ABTS assay                             | IC<sub>50</sub> = 14.65 ± 0.36 μg/mL         | [76]      |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 167.00 ± 2.47 μg/mL         |           |
| Aerial part        | Essential oil (1.86%)                | Reducing power technique               | IC<sub>50</sub> = 0.21 ± 0.17 mg/mL           | [15]      |
|                    |                                      | Reducing power assay                   | IC<sub>50</sub> = 0.23 ± 0.67 mg/mL           |           |
| Aerial parts       | Essential oil (2%)                   | β-Carotene/linoleic acid bleaching     | IC<sub>50</sub> = 0.21 ± 0.74 mg/mL           | [49]      |
|                    |                                      | assay                                  | IC<sub>50</sub> = 0.15 ± 0.36 mg/mL           |           |
|                    |                                      | ABTS assay                             | Absorbance = 0.507 ± 0.019                   |           |
|                    |                                      | Reducing power assay                   | Percent inhibition = 42.99%                   |           |
|                    | Flowering top                        |                                        | Percent inhibition = 74.50%                   |           |
|                    | Essential oil                        |                                        | Percent inhibition = 24.64 ± 0.03%           |           |
| Aerial part        | Ethyl acetate extract                | DPPH assay                             | IC<sub>50</sub> = 109.98 ± 3 μg/mL           | [60]      |
|                    |                                      | β-Carotene test                        | IC<sub>50</sub> = 122.53 ± 2.38 μg/mL        |           |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 177.13 ± 2.1 mg/mL         | [46]      |
|                    |                                      | β-Carotene bleaching assay             | IC<sub>50</sub> = 122.53 ± 2.38 μg/mL        |           |
| Leaves             | Methanolic extract                   | Free radical scavenging activity       | SC<sub>50</sub> = 14.6 μg                   | [14]      |
|                    |                                      | (DPPH° test)                           | IC<sub>50</sub> = 0.25 ± 0.03 mg/mL          |           |
| Aerial parts       | Essential oil                        | β-Carotene/linoleic acid assay         | Percent inhibition = 81.78 ± 0.37%           | [43]      |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 300.32 ± 1.50 mg/mL        |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 50.79 ± 2.02 mmol Trolox/g |           |
| Aerial part        | Essential oil                        | Malondialdehyde (MDA) assay           | IC<sub>50</sub> = 0.480 ± 0.010 mg/mL        | [13]      |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 86.38 ± 0.85 μg/mL         |           |
|                    | Aqueous extract                      | DPPH assay                             | IC<sub>50</sub> = 0.48 ± 0.05 mg/mL          |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 33.48 ± 0.08 mmol/L        |           |
| Aerial part        | Hot water extract                    | DPPH assay                             | IC<sub>50</sub> = 0.81 ± 0.81 mg/mL          | [44]      |
|                    |                                      | β-Carotene bleaching assay             | IC<sub>50</sub> = 15.99 ± 0.47 μg/mL         |           |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 20.33 ± 0.19 μg/mL         |           |
| Aerial part        | Cold water extract                   | DPPH assay                             | IC<sub>50</sub> = 14.69 ± 0.69 μg/mL         |           |
|                    |                                      | β-Carotene bleaching assay             | IC<sub>50</sub> = 53.42 ± 1.17 μg/mL         |           |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 64.32 ± 0.52 μg/mL         | [77]      |
|                    |                                      | β-Carotene bleaching test              | IC<sub>50</sub> = 50.20 ± 0.33 μg/mL         |           |
|                    |                                      | DPPH assay                             | IC<sub>50</sub> = 30.24 ± 0.19 μg/mL         |           |
|                    |                                      | FRAP assay                             | IC<sub>50</sub> = 30.48 ± 0.52 μg/mL         |           |
|                    |                                      | β-Carotene bleaching test              | IC<sub>50</sub> = 86.38 ± 0.85 μg/mL         |           |
In addition, the antioxidant capacity of *T. satureioides* extracts was also studied by many researchers. Khouya and his coworkers [39] tested the antioxidant effect of ethyl acetate, methanolic, aqueous, dichloromethane, and crude extracts of *T. satureioides* aerial parts using DPPH radical scavenging, FRAP, and APPH assays and showed a higher reductive potential of these extracts than the reference compounds (Trolox). In fact, the highest reducing power of ferric metal was shown by the ethyl acetate fraction (IC₅₀ = 82.69 ± 2.29 mmol Trolox/g of dry extract), and the lowest was observed for the aqueous fraction (IC₅₀ = 25.46 ± 2.71 mmol Trolox/g of dry extract). The radical scavenging activity indicated that ethyl acetate fraction exerted the highest antioxidant activity with an IC₅₀ value of 0.33 ± 0.02 mg/mL, followed by crude extract (IC₅₀ = 0.44 ± 0.06 mg/mL), dichloromethane fraction (IC₅₀ = 0.48 ± 0.05 mg/mL), and then methanolic fraction (IC₅₀ = 0.71 ± 0.09 mg/mL). However, the aqueous fraction showed the weakest antioxidant capacity (IC₅₀ = 0.85 ± 0.06 mg/mL) [39]. Furthermore, the APPH test indicated that the addition of the tested extracts to suspensions containing erythrocyte and 2,2′-azobis 2-aminodipropylhydrazine (APPN) induced an increase in the hemolysis half time [39].

The antioxidant activities of *T. satureioides* extracts obtained from the aerial part were also examined by Labiad et al. [22] who reported remarkable antioxidant activities for hexane, dichloromethane, ethyl acetate, and hydro-ethanolic extracts, using ABTS radical scavenging, DPPH, and ferric reducing antioxidant power (FRAP) methods, with ascorbic acid as positive control. The hydro-ethanolic extracts exhibited the highest antiradical effect against DPPH and ABTS radicals with IC₅₀ values of 3.86 ± 0.07 µg/mL and 51.27 ± 0.82 µg/mL, respectively, followed by dichloromethane (IC₅₀DPPH = 23.75 ± 0.67 µg/mL, IC₅₀ABTS = 80.09 ± 0.65 µg/mL), ethyl acetate (IC₅₀DPPH = 23.75 ± 0.67 µg/mL, IC₅₀ABTS = 85.16 ± 3.22 µg/mL), and then hexane extracts (IC₅₀DPPH = 275.71 ± 11.26 µg/mL, IC₅₀ABTS = 127.38 ± 3.83 µg/mL). Moreover, the hydro-ethanolic extract also exerted a great FRAP activity (233.292 ± 0.377 mg equivalent ascorbic acid/g of extract). However, the hexane extract showed the lowest FRAP capacity (97.819 ± 0.377 mg equivalent ascorbic acid/g of extract) [22].

In a recent study, Hmidani et al. [76] measured the capacity of aqueous extracts of *T. satureioides* to scavenge the generated radical ABTS+, using ABTS assay, and showed significant scavenging activity of this extract (IC₅₀ABTS = 14.65 ± 0.36 µg/mL) compared to ascorbic acid as standard (IC₅₀ = 1.96 ± 0.1 µg/mL). These findings support those obtained by Khouya et al. [24], which showed a considerable antioxidant activity of the *T. satureioides* aerial part aqueous extract. Indeed, the tested aqueous extracts displayed potent scavenging activity against DPPH radical with an IC₅₀ value equal to 0.44 ± 0.01 mg/mL TAE and a higher reducing power of ferric complex (40.14 ± 4.55 mmol Trolox/gTAE) than the Trolox used as positive control (44.33 ± 7.55 mmol Trolox/gTAE). Moreover, the aqueous extracts of *T. satureioides* exerted a potent protective potential against hemolysis of erythrocytes according to APPH.
test results [24]. These considerable antioxidant effects of the aqueous extracts were attributed to their high phenolic content [24].

3.4.3. Antifungal Activity. The antifungal activity of T. satureioides, especially its essential oils against several pathogenic fungal, has been reported in the literature [19, 50, 78, 79].

Boukhira et al. [20] evaluated the antifungal activity of T. satureioides EOs obtained from aerial parts against a yeast, Candida albicans (ATCC-10231), and a mould Aspergillus brasilensis (ATCC-16404), using radial growth inhibition and broth microdilution assays. This study showed that the studied EOs exert effective effect against C. albicans (Φ = 24.67 ± 0.67 mm, MIC = 0.6 μL/mL) and A. brasilensis (MIC = 1.3 μL/mL).

Asadi et al. [19] studied the antifungal activity of T. satureioides EOs (10 μL) against nosocomial fluconazole-resistant strains (Candida dubliniensis, C. albicans, C. glabrata, and C. krusei) using disc diffusion and microdilution methods, with fluconazole (10 μL) and amphotericin B (10 μL) as positive controls. According to this study, C. dubliniensis was the most sensitive strain to the tested EOs (Φ = 85 mm), followed by C. krusei (Φ = 67 mm), while C. albicans and C. glabrata were the least sensitive fungal strains with Φ of 53 mm and 49 mm, respectively. The microdilution assays showed an interesting antifungal effect with minimal fungicidal concentration (MFC) values ranging between 0.3300 mg/mL and 0.9062 mg/mL [19].

In addition, El Bouzidi et al. [15] assessed the antifungal activity of T. satureioides EOs obtained from aerial parts against four candida species, including C. albicans, C. glabrata, C. parapsilosis, and C. krusei using disc diffusion and microdilution assays, and fluconozol (40 μL) as reference. The findings of this study showed that all tested strains were more sensitive to the tested EOs (37.67 ± 1.53 mm < Φ < 42.00 ± 1.00 mm) than to the synthetic fungicide (fluconozol) used as a positive control (26.50 ± 0.50 mm < Φ < 29.83 ± 1.15 mm).

More interestingly, Salhi et al. [50] reported the antifungal activity of four chemotypes of T. satureioides EOs from aerial parts, namely, borneol/α-terpineol, borneol/carvacrol/α-terpineol, borneol/carvacrol/thymol, and borneol/camphene/α-terpineol against fungal strains responsible of wood damages (Coniophora puteana BAM Ebw. 15, Gloeophyllum trabeum BAM Ebw.109, Oligoporus placenta FPRL. 280, and Trametes versicolor CTB 863). The studied samples were harvested from four different locations in Southwest Morocco (Oulad Berhil, Amskroud-East, Aoulouz, and Timoulay Aksri), and qualitative and quantitative assays were used for antifungal screening [50]. The results showed that, at a concentration of 1/500 (v/v), all tested chemotypes inhibit the growth of the tested wood-decaying fungi. However, the investigated chemotypes exhibited a variable degree of the antifungal effect. Therefore, the chemotype borneol/carvacrol/thymol was the most active against the tested strains, followed by borneol/camphene/α-terpineol, borneol/α-terpineol, and borneol/carvacrol/α-terpineol. Moreover, the highest antifungal activity was noticed against G. trabeum with MIC ranging between 1/1500 v/v and 1/500 (v/v), followed by C. puteana (1/1250 v/v) <MIC< 1/500 (v/v)), T. versicolor (MIC = 1/500 (v/v)), and O. placenta (MIC = 1/500 (v/v)) [50].

In the same context, Rahmouni et al. [42] reported fungicide effect of T. satureioides EOs and their major components (thymol, α-terpineol, carvacrol, and borneol) against a phytopathogenic fungus responsible for fusarium wilt on date palm in Morocco, named Fusarium oxysporum f. sp. Albedinis. The results of this study showed that these EOs as well as their major compounds inhibited noticeably the mycelia growth of Fusarium oxysporum f. sp. Albedinis in a concentration-dependent manner. The maximal fungicidal effect of the studied compounds was noticed by thymol with a minimum fungicidal concentration (MFC) value of 0.08 μL/mL, followed by α-terpineol (MFC = 12.20 μL/mL), carvacrol (MFC = 16.96 μL/mL), and borneol (MFC = 22.73 μL/mL) [42]. Furthermore, T. satureioides EO was found to inhibit spore germination of phytopathogenic fungi of citrus, namely, Penicillium digitatum, P. italicum, and Galactomyces citriaurantii at concentrations greater than 500 μL/mL [79].

Recently, El-Bakkal et al. [21] tested the antifungal effect of the EOs of T. satureioides aerial parts against Botrytis cinerea, P. digitatum, and Verticillium dahliae using disc diffusion method and fluconozol (40 μg/disc) as standard antifungal drug. Their results showed a promising antifungal effect, of the studied EOs, against the three tested strains, with inhibition zone diameters ranging from 31.50 ± 1.32 mm to 36.27 ± 1.15 mm compared to fluconozol (25.50 ± 0.50 < Φ < 28.00 ± 0.50).

3.4.4. Anti-Inflammatory Activity. Inflammation is a complex biological process that maintains homeostasis of the organism in response to multiple injuries such as infection, trauma, or immune reaction. It is characterized by pain, heat, redness, and swelling [80].

Inflammation is related to the occurrence of several human pathologies, including heart diseases, Alzheimer’s disease, and cancer [81–83]. The mechanisms of the anti-inflammatory response involve various mediators such as phospholipase A2 activation, cytokines, chemokines, reactive oxygen species (ROS) generation, macrophages and mast cells, platelet-activating factor, and nitric oxide (NO) [83].

Khoyha et al. [39] have evaluated in vivo the anti-inflammatory activity of T. satureioides crude extracts and fractions (dichloromethane, ethyl acetate, methanol, and aqueous) using croton-oil-induced ear oedema and carrageenan-induced paw oedema in mice and rats. The results of this study showed that topical applications of the dichloromethane and ethyl acetate fractions (1 mg/ear) reduced significantly ear oedema volume of 31.60% and 27.16%, respectively, after 4 h of treatment. The crude extracts exhibited the greatest activity, and its tropical application decreased significantly ear oedema (29.67%) 8 h after
treatment. However, the methanol and aqueous fractions did not decrease ear oedema. Moreover, the results of carrageenan oedema assay showed that the ethyl acetate and methanol fractions (60 mg/kg) reduced significantly oedema induced by carrageenan during the first phase (16.40 ± 0.33% and 14.51 ± 1.40%, respectively) [39]. This study confirmed results obtained by the same authors, indicating that aqueous extracts of *T. satureioides* exhibited a remarkable anti-inflammatory effect in carrageenan-induced rats paw edema and in croton oil-induced mice ear edema [24]. In another previous study, Ismaili et al. [14] investigated the in vivo topical anti-inflammatory effect of methanol and chloroform extracts of *T. satureioides* leaves, using the croton oil ear test in mice, and showed that chloroform extract induced significant edema inhibition (at a inhibition concentration of 2.4 μg/ml and 14.51 μg/ml). However, the methanol and chloroform extracts did not show any topical anti-inflammatory activity.

### 3.4.5. Antiparasitic Effect. *T. satureioides* EOs from different plant parts were studied against a number of human, virus, and plant parasites. Indeed, Pavela [84] assessed the toxicity of *T. satureioides* EOs against the larvae of *Culex quinquefasciatus* Say (Diptera: Culicidae) and showed its effective larvicidal property with respective lethal concentrations (LC50 and IC50) of 44 μg/ml and 81.5 μg/ml.

Kasrati et al. [49] reported a considerable insecticidal activity of *T. satureioides* EOs against adults of pest Tribolium castaneum responsible for stored-product deterioration (lethal dose values of LD50 = 0.315 μl/cm2 and LD90 = 0.71 μl/cm2). Moreover, Santana et al. [25] examined the toxicity of *T. satureioides* EOs against insect pest’s larvae of Spodoptera littoralis, insect adults of Myzus persicae and Rhopalosiphum padi, as well as against adults and eggs of root-knot nematodes Meloidogyne javanica. A strong antifeedant effect of *T. satureioides* EOs was observed against S. littoralis larvae (EC50 = 36.9 ± 22.7 μg/cm2), M. persicae adults (EC50 = 53.3 ± 6.5 μg/cm2), and R. padi (EC50 = 49.0 ± 6.6 μg/cm2). Additionally, an important nematicidal effect was noticed against the tested M. javanica at two different development stages: second-stage juveniles (J2) (LC50 = 0.1 mg/mL and LC90 = 0.2 mg/mL) and eggs (mortality rate of 38.9% after 7 days) [25].

Another study conducted by Avato et al. [26] showed that *T. satureioides* EOs exhibit a promising nematicidal activity against *Meloidogyne incognita* juveniles (mortality rate of 10.6 ± 0.7%) and adults of Pratylenchus vulnus (100 ± 0.0%) and Xiphinema index (14.9 ± 0.7%) and that, after 48 h, this effect was dose-dependent.

The acaricidal activity of *T. satureioides* EOs was also reported in the literature. Ramzi et al. [85] studied the effect of the EOs of *T. satureioides* aerial parts against adults of Varroa destructor (Acari: Varroidae) and indicated an interesting mortality rate of 50% after 24 h and 80% after 48 h. Additionally, *T. satureioides* EO was shown to destroy completely the wheat pest Sitophilus oryzae (coleoptera) at a concentration of 2.4 × 10−7 μl/cm2 after 24 h [86].

### 3.4.6. Other Pharmacological Properties. *T. satureioides* was also reported to exhibit other pharmacological properties such as antitumor, antidiabetic, and hypolipidemic effects.

Jaafari et al. [23] evaluated the in vitro antitumor activity of *T. satureioides* EOs collected in different regions (High Atlas of Morocco, Bin Elwidane-Beni Mellal, and Tiznit) on P815 mastocytoma cell line using the 3-(4,5-di-methylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) assay. The results showed that all tested EOs exhibit an important cytotoxic effect against P815 cell line with IC50 values from 0.225% (v/v) to 0.24% (v/v). The antiproliferative effect of *T. satureioides* crude extracts was studied against MCF-7 breast cancer cell line using MTT assay and showed their strong inhibition with a half-inhibitory concentration (IC50) value of 37.5 ± 402 μg/ml [24].

Kabbaoui et al. [2] investigated the antidiabetic effect of *T. satureioides* aqueous extracts obtained from the aerial parts on streptozotocin- (STZ-) induced diabetic rats via the administration of an oral concentration of 500 mg/kg. As a result, *T. satureioides* aqueous extracts decreased significantly blood glucose levels and improved body weight and glucose tolerance in STZ-diabetic rats.

### 4. Conclusion and Perspectives

This scientific review reports the ethnomedicinal uses, chemical profile, and pharmacological properties of an endemic Moroccan medicinal plant: *T. satureioides*. This plant is widely used in Moroccan traditional medicine to treat several diseases such as hypertension, diabetes, skin ailments, and bronchitis.

Indeed, several investigations have demonstrated that *T. satureioides* exhibits numerous biological activities, including antibacterial, antifungal, antioxidant, anti-inflammatory, anticancer, antidiabetic, and antiparasitic activities. These pharmacological effects have proven the traditional uses of *T. satureioides*. However, the evidence supporting the traditional practices such as skin disorders, hypertension, influenza, and visual ailments of modern pharmacology is still limited. In this regard, we invite research groups to conduct further studies on the antiviral, antileishmanial, and hypotensive effects of *T. satureioides*. Furthermore, the pharmacological mechanisms of action, of this plant, on molecular targets need to be explored using current experimental assessments such as network pharmacology, proteomic, and pharmacokinetic. Additionally, an appropriate pharmacological approach should be considered for providing comprehensive pharmacological information for *T. satureioides*. Moreover, *T. satureioides* have shown interesting biological effects against some related oxidative stress such as inflammation and cancer. Accordingly, extensive clinical studies should be carried out to determine pharmacodynamic and pharmacokinetic parameters in order to develop drug from *T. satureioides*.

The phytochemical analysis using different chromatographic tools such as GC-MS and HPLC revealed the presence of a plethora of bioactive compounds mainly belonging to the terpenoids class in the essential oils of *T. satureioides*. This chemical diversity varied depending on plant’s part used, season’s harvest, plant’s origin, as well as
Many bioactive compounds have been isolated and identified from *T. satureioides* essential oils, few pure components have been assessed for their pharmacological effects. Furthermore, few studies have investigated the phenolic content of *T. satureioides* extracts. Therefore, further efforts should be focused on such area in order to determine in detail the phenolic profile of this species using different extraction solvents and the current spectroscopic tools such as HPLC-DAD, infrared (IR), and $^1$H NMR technique.

Finally, the acute, subacute, and subchronic toxicity tests are strongly required to verify the innocuity and the safety of this plant.

**Abbreviations**

EOs: Essential oils  
HPLC: High-performance liquid chromatography  
$^1$H: Proton nuclear magnetic resonance  
NMR: Nuclear magnetic resonance  
GC: Gas chromatography  
GC-MS: Gas chromatograph-flame ionization detection mass spectrometry  
FID: Flame ionization detection  
MIC: Minimal inhibitory concentration  
MBC: Minimum bactericidal concentration  
Φ: Inhibition zone diameter  
ABTS: 2,2-Diphenyl-1-picrylhydrazyl  
DPPH: 2,2-Diphenyl-1-picrylhydrazyl  
TBARS: Thiobarbituric acid reactive substances  
APPH: 2,2-Azobis 2-amidinopropane dihydrochloride  
BHT: Butylated hydroxytoluene  
MFC: Minimal fungicidal concentration  
MTT: 3-(4,5-Di-methylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide  
TAE: Tannic acid equivalent

**Data Availability**

All data analyzed during this investigation are available from the corresponding author.

**Conflicts of Interest**

The authors declare that they do not have any conflicts of interest.

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