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# Review of medicinal uses, phytochemistry and pharmacological properties of *Boscia senegalensis*

**Alfred Maroyi**

*Medicinal Plants and Economic Development (MPED) Research Centre, Department of Botany, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa*

**Abstract**

*Boscia senegalensis* is an evergreen shrub or small-sized tree widely used as herbal medicine in the Sahel region of northern Africa. The current study critically reviewed the botany, medicinal uses, phytochemistry and pharmacological activities of *B. senegalensis*. Literature on botany, medicinal uses, phytochemical and biological activities of *B. senegalensis* was collected from multiple internet sources including Elsevier, Google Scholar, SciFinder, Web of Science, Pubmed, BMC, Science Direct and Scopus. Complementary information was gathered from pre-electronic sources such as books, book chapters, theses, scientific reports and journal articles obtained from the University library. This study revealed that the species is used as herbal medicine in 47.4% of the countries in the Sahel region where the species is indigenous. The bark, fruits, leaves, roots and stem bark of *B. senegalensis* are mainly used as herbal medicines for cough, malaria, swellings, cancer, rheumatism, ulcers, jaundice, sexually transmitted infections, ethnoveterinary medicine, intestinal worms and bilharzia. Ethnopharmacological research showed that the crude extracts of the species and the compounds isolated from *B. senegalensis* exhibited antibacterial, antifungal, anti-hyperglycaemic, antioxidant, antiplasmodial, insecticidal, larvicidal and sEH inhibitory activities. *Boscia senegalensis* should be subjected to detailed phytochemical, pharmacological and toxicological evaluations aimed at correlating its medicinal uses with its phytochemistry and pharmacological activities.

**Keywords:** *Boscia senegalensis*, Capparaceae, herbal medicine, indigenous knowledge, Sahel region, northern Africa

## INTRODUCTION

*Boscia senegalensis* (Pers.) Lam. ex Poir. is an evergreen shrub or small-sized tree belonging to the Capparaceae or caper family. *Boscia senegalensis* is regarded as a multipurpose plant species in the Sahel region of northern Africa, serving as a buffer to famine and hunger due to a variety of products derived from the species. *Boscia senegalensis* is used as a coffee substitute, fodder, ethnoveterinary medicine, herbal medicine, repellent to protect stored grain and food from pests and planted in soil protection schemes, famine food, food additive, hedge, natural coagulant for water purification, source of construction materials and firewood.[1-11] The young roots of *B. senegalensis* are edible and sometimes pounded and cooked into porridge.[6] The berries of *B. senegalensis* are edible, often eaten fresh or boiled, and sometimes used to produce a sweet or alcoholic drink, and sometimes mixed with millet (*Eleusine coracana* Gaertn.) and curdled milk to make cakes.[6] In the Sahel region, the dried seeds of *B. senegalensis* are often used as a substitute for millet or lentils (Lens culinaris Medikus).[6] The leaves of *B. senegalensis* are harvested from the wild in many parts of the Sahel region and consumed as food condiments for soups, mixed with cereals and as important food resource in times of scarcity.[6,10] The fruits and leaves of *B. senegalensis* are commonly sold in local markets in the Sahel region as both food and herbal medicine.[4,8,10,11] *Boscia senegalensis* appears to be an important source of herbal medicines within its distributional range in the Sahel region, and therefore, there is need for formal documentation and systematic research which is beneficial to indigenous and traditional systems of herbal medicine. It is within this context that this review was undertaken aimed at reviewing the botany, medicinal uses and biological activities of *B. senegalensis* so as to provide baseline data required in evaluating the therapeutic potential of the species.

### Botanical profile of *Boscia senegalensis*

The genus name *Boscia* Lam. is in honour of a French naturalist, botanist, zoologist and horticulturist Louis Auguste Guillaume Bosc (1759-1828).[12] The species name "*senegalensis*" means "of Senegal". *Boscia senegalensis* is commonly referred to as "aizen", "bambara", "dilo", "hanza" and "mukheit". Synonyms of *B. senegalensis* include *B. octandra* Hochst. ex Radlk. and *Podoria senegalensis* Pers. *Boscia senegalensis* is an evergreen shrub or small-sized tree growing up to four metres in height.[13] The bark is smooth, grey to whitish grey in colour. The leaves are oblanceolate to elliptic in shape, grey-green to green in colour above and below. The flowers are small, sweetly scented and greenish-white in colour. The fruit is a berry, which is spherical in shape, slightly hairy and yellowish in colour when mature. This species has been recorded in Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Egypt, Ethiopia, Ghana, Guinea, Kenya, Mali, Mauritania, Niger, Nigeria, Senegal, Somalia, South Sudan, Sudan and Togo.[13] The species has been recorded in open scrub or savannah woodland, but often forming a thick understorey in woodland and dry forest in rocky, laterite, clay, sand-clay in zones characterized by 100 mm to 500 mm annual rainfall at an altitude ranging from 60 m to 1450 m above sea level.[13]

### Medicinal uses of *Boscia senegalensis*

Ethnomedicinal information on *B. senegalensis* has been found in Burkina Faso, Cameroon, Chad, Ethiopia, Mali, Nigeria, Senegal, South Sudan and Sudan, representing 47.4% of the countries where the species is indigenous. The country with the highest number of ethnomedicinal

uses is Nigeria with 11 literature records, followed by Sudan with ten literature records, Mali (six), Senegal (five), Chad and Ethiopia (three literature records each), Burkina Faso (two), Cameroon and Niger (one literature record each) (Table 1). The bark, fruits, leaves, roots and stem bark of *B. senegalensis* are mainly used as herbal medicines for cough, malaria, swellings, cancer, rheumatism, ulcers, jaundice, sexually transmitted infections, ethnoveterinary medicine, intestinal worms and bilharzia (Table 1, Figure 1). Other minor medicinal uses recorded in a single country but supported by at least two literature records include muscle pain, pain, tuberculosis and wounds (Table 1). In Nigeria, the roots of *B. senegalensis* are mixed with roots of *Oryza* spp. and root bark of *Prosopis africana* (Guill. & Perr.) Taub. as an arbotifacient.[14] In Niger, the leaves of *B. senegalensis* are mixed with those of *Nicotiana tabacuum* L. or *Cucumis prophetarum* L. as ethnoveterinary medicine for chronic helminth and ticks.[15]

**Table 1: Medicinal applications of *Boscia senegalensis***

| Medicinal use | Parts used | Country/region | References |
|---|---|---|---|
| Arbotifacient | Roots mixed with roots of *Oryza* spp. and root bark of *Prosopis africana* (Guill. & Perr.) Taub. | Nigeria | Adebisi and Alebiosa[14] |
| Arthritis | Leaves | Nigeria | Salihu et al.[16] |
| Bilharzia | Leaves and roots | Chad, Mali, Sahel and Sudan | Khalid et al.[4]; Pousset[17]; Maydell[18]; Ali et al.[19]; Inngjerdingen et al.[20]; Elkhalifa et al.[21]; Chahad et al.[22]; Suleiman[23] |
| Cancer | Roots | Ethiopia and Nigeria | Aliyu et al.[24]; Temitope[25]; Birhanu and Haji[26] |
| Colic | Leaves and roots | Chad | Chahad et al.[22] |
| Cough | Leaves | Mali and Sudan | Diallo et al.[27]; Doka and Yagi[28]; |
| Diabetes | Leaves and roots | Senegal | Dièye et al.[29] |
| Epilepsy | Roots | Burkina Faso | Kinda et al.[30] |
| Eye problems | Leaves | Sudan | Suleiman[23] |
| Fever | Stem bark | Nigeria | Ibrahim et al.[31] |
| Headache | Roots | Ethiopia | Birhanu and Haji[26] |
| Head pustules | Leaves | Sudan | Doka and Yagi[28] |
| Heart problems | Leaves | Mali | Diallo et al.[27] |
| Impotence | Roots | Nigeria | Nyam et al.[32] |
| Intestinal worms | Bark, leaves and roots | Mali, Sahel, Senegal and Sudan | Pousset[17]; Maydell[18]; Suleiman[23]; Diallo et al.[27]; Lucie et al.[33] |
| Jaundice | Leaves and roots | Nigeria, Sahel and Sudan | Pousset[17]; Maydell[18]; Ali et al.[19]; Diallo et al.[27]; Nyam et al.[32] |
| Malaria | Bark, fruits and leaves | Nigeria and Senegal | Lucie et al.[33]; El-Ghani[34] |
| Menstrual problems | Leaves | Senegal | Lucie et al.[33] |
| Muscle pain | Leaves | Sudan | Khalid et al.[4]; Elkhalifa et al.[21]; Suleiman[23] |
| Pain | Leaves and roots | Sahel | Pousset[17]; Maydell[18] |
| Rheumatism | Bark and leaves | Nigeria and Sudan | Elkhalifa et al.[21]; Nyam et al.[32]; Musa et al.[35] |
| Scabies | Leaves | Mali | Diallo et al.[27] |
| Sexually transmitted infections (syphilis and venereal diseases) | Bark, fruits, leaves and roots | Nigeria, Sahel and Senegal | Pousset[17]; Maydell[18]; Nyam et al.[32]; Lucie et al.[33]; El-Ghani[34] |
| Snake bites | Leaves and roots | Chad | Chahad et al.[22] |
| Swellings | Bark and roots | Nigeria and Sudan | Suleiman[23]; Aliyu et al.[24] |
| Tuberculosis | Fruits and leaves | Sudan | Khalid et al.[4]; Ali et al.[19]; Suleiman[23] |
| Ulcers | Leaves and roots | Nigeria and Sahel | Pousset[17]; Maydell[18]; Aliyu et al.[24]; Temitope[25] |
| Wounds | Leaves and roots | Mali | Inngjerdingen et al.[20]; Diallo et al.[36] |
| Ethnoveterinary medicine (abscesses, anthelmintic, anthrax, bleeding, foot and mouth disease, lymphadenitis, mange, trypanosomosis and wounds | Leaves | Burkina Faso, Cameroon, Ethiopia and Niger | Antoine-Moussieux et al.[15]; Hilou et al.[37]; Gebrehiwot and Shumbahri[38]; Vougat et al.[39] |
| Chronic helminth and ticks | Leaves mixed with those of *Nicotiana tabacuum* L. or *Cucumis prophetarum* L. | Niger | Antoine-Moussieux et al.[15] |

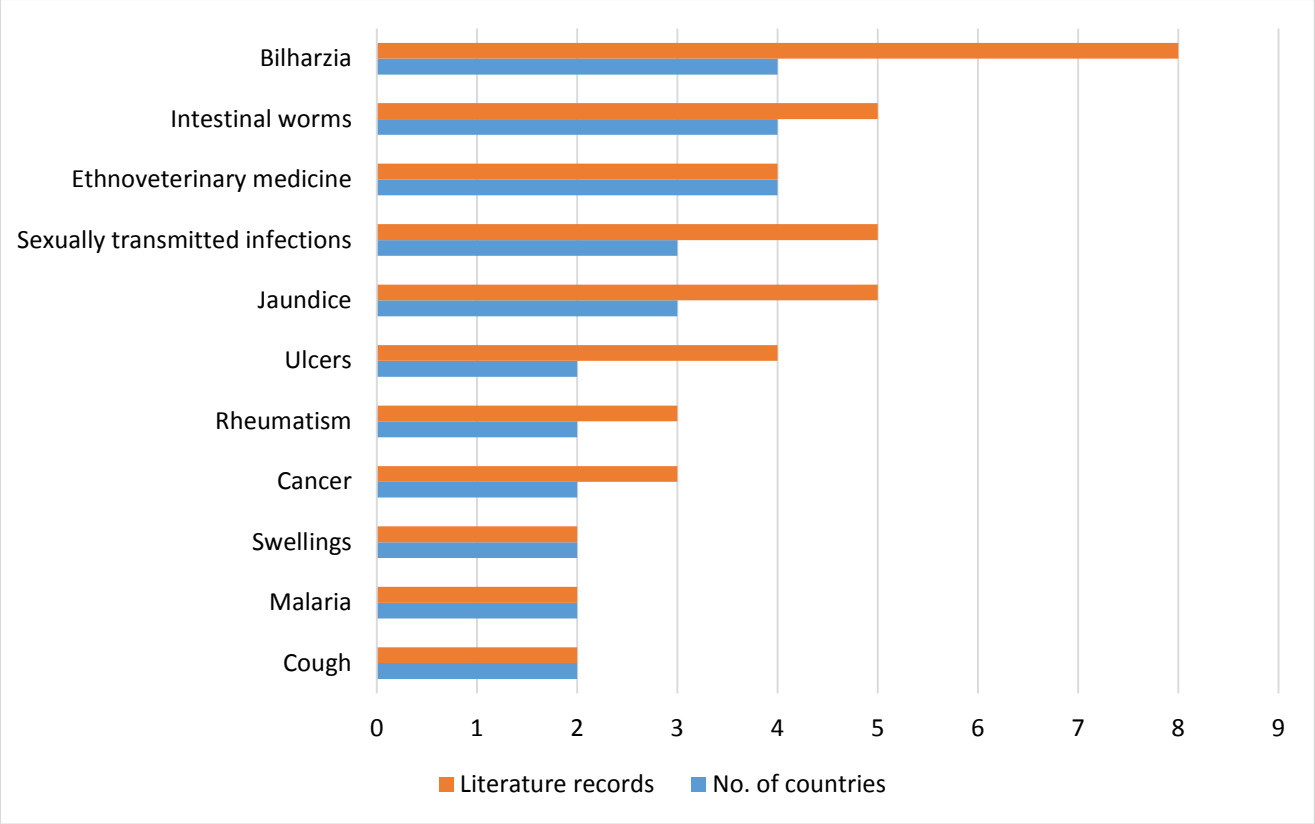


**Figure 1. Medicinal applications of *Boscia senegalensis* derived from literature records**

**Phytochemical and mineral composition of *Boscia senegalensis***

Table 2 provides values of macro- and micro-elements, rare earth and trace elements and nutritional composition of fruits, leaves, roots and seeds of *B. senegalensis*. Future research should focus on evaluating the biological activities of the isolated compounds.

**Table 2: Mineral and phytochemical composition of *Boscia senegalensis***

| Mineral and phytochemical composition | Values | Plant parts | References |
|---|---|---|---|
| 2-butyl-glucosinolate | - | Leaves | Kjaer et al.[40] |
| 3,4,5-trimethoxyphenol-β-D-glucopyrinoside | - | Leaves | Morgan et al.[41] |
| 3,7-dimethyl-1-octene-3,6,7-triol-6-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[41] |
| 4'-hydroxy-3,3',4,5,5'-pentamethoxy-7,9':7',9-diepoxylignane | - | Leaves | Morgan et al.[42] |
| (+)-lariciresinol-9-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[42] |
| (+)-lyoniresinol-3α-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[42] |
| (-)-lyoniresinol-3α-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[42] |
| Alangilignoside D | - | Leaves | Morgan et al.[42] |
| Alanine (g/16g nitrogen) | 3.5 – 4.2 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Alkaloids (%) | 4.25 | Roots | Temitope[25] |
| Arachidic acid (mg/g dry weight) | 0.1 | Seeds | Kim et al.[44] |
| Arginine (g/16g nitrogen) | 16.2 – 17.5 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Arsenic (µg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Ash (%) | 9.4 – 10.0 | Leaves and roots | Vougat et al.[39]; Temitope[25] |
| Ash (g/100g dry weight) | 2.2 – 4.3 | Fruits and seeds | Becker[1]; Deli et al.[45] |
| Aspartate (g/16g nitrogen) | 9.4 – 10.8 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Austroside B | - | Leaves | Morgan et al.[41] |
| Behenic acid (mg/g dry weight) | 0.1 | Seeds | Kim et al.[44] |
| Calcium (mg/100g dry weight) | 13.2 - 60.0 | Fruits, roots and seeds | Becker[1]; Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Carbohydrates (g/100 g dry weight) | 50.5 – 59.6 | Fruits and seeds | Becker[1]; Deli et al.[45] |
| Carotene (µg RE/100g fresh weight) | 1.8 | Fruits | Becker[1] |
| Chromium (µg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Condensed tannins (mg CE/g dry weight) | 1.8 – 3.2 | Seeds | Deli et al.[45] |
| Copper (mg/100g dry weight) | 1.2 – 10.0 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Crude protein (%) | 14.68 | Roots | Temitope[25] |

| Mineral and phytochemical composition | Values | Plant parts | References |
|---|---|---|---|
| Crude proteins (g/100 g dry weight) | 28.9 – 33.2 | Seeds | Deli et al.[45] |
| Crude fat (g/100 g dry weight) | 6.6 – 7.6 | Seeds | Deli et al.[45] |
| Cysteine (g/16g nitrogen) | 1.8 – 2.8 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Dehydrodiconiferyl alcohol-4-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[42] |
| Energy (kJ/100g fresh weight) | 80.0 | Fruits | Becker[1] |
| Fat (%) | 7.22 | Roots | Temitope[25] |
| Fibre (%) | 4.33 | Roots | Temitope[25] |
| Fibre (g/100g fresh weight) | 1.8 | Fruits | Becker[1] |
| Flavonoids (mg RE/g dry weight) | 0.2 – 0.3 | Seeds | Deli et al.[45] |
| Glucocapparin | - | Fruits and leaves | Gueye et al.[46] |
| Glutamate (g/16g nitrogen) | 10.2 – 11.7 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Glycine (g/16g nitrogen) | 3.9 – 4.1 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Histidine (g/16g nitrogen) | 1.6 – 2.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Iron (mg/100 g dry matter) | 0.5 – 22.1 | Fruits, leaves, roots and seeds | Becker[1]; Vougat et al.[39]; Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Isoleucine (g/16g nitrogen) | 3.7 – 4.4 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Isopropylisothiocyanate | - | Leaves | Auger et al.[47] |
| Lasianthionoside A | - | Leaves | Morgan et al.[41] |
| Lead (mg/100g) | 2.24 | Roots | Temitope[25] |
| Leucine (g/16g nitrogen) | 8.4 – 8.6 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Linoleic acid (mg/g dry weight) | 0.7 | Seeds | Kim et al.[44] |
| Lipids (g/100g fresh weight) | 1.6 | Fruits | Becker[1] |
| Liriodendrin | - | Leaves | Morgan et al.[42] |
| Lysine (g/16g nitrogen) | 1.8 – 3.1 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Magnesium (mg/100g dry weight) | 1.3 - 22.1 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Manganese (mg/100g dry weight) | 6.2 – 11.1 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Methionine (g/16g nitrogen) | 1.2 – 2.7 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Methyl, 2-propyl | - | Leaves | Kjaer et al.[40] |
| Methylisothiocyanate | - | Leaves | Auger et al.[47] |
| Moisture content (%) | 3.74 | Roots | Temitope[25] |
| Moisture (g/100 g dry weight) | 4.7 – 11.0 | Fruits and seeds | Becker[1]; Deli et al.[45] |
| Moisture (%) | 6.9 | Leaves | Vougat et al.[39] |
| Molybdenum (μg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Nickel (μg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Oleic acid (mg/g dry weight) | 0.9 | Seeds | Kim et al.[44] |
| Oxalate (%) | 6.57 | Roots | Temitope[25] |
| Palmitic acid (mg/g dry weight) | 6.9 | Seeds | Kim et al.[44] |
| Phenol (%) | 2.56 | Roots | Temitope[25] |
| Phenylalanine (g/16g nitrogen) | 5.1 – 5.9 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Phosphorus (mg/100g dry weight) | 17.9 - 332.0 | Fruits, roots and seeds | Becker[1]; Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Phylate (%) | 15.68 | Roots | Temitope[25] |
| Pinoresinol-4'-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[42] |
| Potassium (mg/100g dry weight) | 14.2 – 88.7 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Proline (g/16g nitrogen) | 6.9 – 7.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Protein (g/100g fresh weight) | 24.0 | Fruits | Becker[1] |
| Rhamnocitrin-3-O-β-D-glucopyranoside | - | Leaves | Morgan et al.[41] |
| Rhamnocitrin-3-O-β-D-(6"-O-E-p-coumaroyl)-glucopyranoside | - | Leaves | Morgan et al.[41] |
| Rhamnocitrin-3-O-β-D-(6"-O-E-feruloyl)-glucopyranoside | - | Leaves | Morgan et al.[41] |
| Saponin (%) | 9.78 | Roots | Temitope[25] |
| Selenium (μg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Serine (g/16g nitrogen) | 4.5 – 4.9 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Silicon (μg/g dry weight) | <5.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Sodium (mg/100g dry weight) | 14.6 – 10.0 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |
| Stearic acid (mg/g dry weight) | 1.3 | Seeds | Kim et al.[44] |
| Syringin | - | Leaves | Morgan et al.[41]; |
| Tannins (g EQ tannic acid/100 g dry matter) | 1.4 | Leaves | Vougat et al.[39] |
| Tannin (%) | 2.32 | Roots | Temitope[25] |
| Threonine (g/16g nitrogen) | 2.5 – 3.1 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Total phenols (mg GAE/g dry weight) | 1.6 – 2.1 | Seeds | Deli et al.[45] |
| Tryptophan (g/16g nitrogen) | 3.0 | Seeds | Kim et al.[44] |
| Tyrosine (g/16g nitrogen) | 3.0 – 3.1 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Vaccenic acid (mg/g dry weight) | 1.3 | Seeds | Kim et al.[44] |
| Valine (g/16g nitrogen) | 5.9 – 6.0 | Seeds | Salih et al.[43]; Kim et al.[44] |
| Vitamin C (mg/100g fresh weight) | 5.0 | Fruits | Becker[1] |
| Vitamin E (mg trolox/100 g) | 5.7 | Leaves | Vougat et al.[39] |
| Zinc (mg/100g dry weight) | 7.5 - 21.6 | Roots and seeds | Salih et al.[43]; Kim et al.[44]; Temitope[25] |

**Biological activities of *Boscia senegalensis***

The following biological activities have been reported from the leaves, roots, seeds and stem bark extracts and compounds isolated from *B. senegalensis*: antibacterial,[24,25] antifungal,[19,48,49] anti-hyperglycaemic,[8] antioxidant,[39,45,48,50] antiplasmodial,[19] insecticidal,[47,51-54] larvicidal[48] and sEH inhibitory[41] activities.

**Antibacterial activities**

Aliyu et al.[24] evaluated antibacterial activities of ethanol root extracts of *B. senegalensis* against methicillin resistant *Staphylococcus aureus* using disc diffusion and broth dilution assays. The extracts exhibited activities with 19 mm zone of inhibition, minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) values of 5.0 mg/mL and 6.0 mg/mL, respectively.[24] Temitope[25] evaluated antibacterial activities of aqueous, ethanol, hexane and ethyl acetate root extracts of *B. senegalensis* against *Salmonella typhi, Staphylococcus aureus, Klebsiella pneumoniae* and *Escherichia coli* using agar well diffusion method with streptomycin as a positive control. The extracts exhibited activities with zone of inhibition ranging from 1.0 mm to 13.0 mm which was comparable to 1.0 mm to 8.0 mm exhibited by the positive control.[25]

**Antifungal activities**

Diallo et al.[48] evaluated the antifungal activities of dichloromethane fruit extract of *B. senegalensis* against *Candida albicans* and *Cladosporium cucumerinum* using bioautography on thin-layer chromatograms. The extract exhibited activities against the tested pathogens. Ali et al.[19] evaluated antifungal activities of methanol leaf extract of *B. senegalensis* against *Microbotryum violaceum* using agar diffusion assay with miconazol as a positive control. The extract exhibited activities with 1 mm zone of inhibition, while the positive control exhibited 20 mm zone of inhibition.[19] Koïta et al.[49] evaluated antifungal activities of aqueous leaf extracts of *B. senegalensis* against two fungi species *Cercospora arachidicola* and *Phaeoisariopsis personata* that cause late leaf spots disease in groundnut, *Arachis hypogaea* L. The extract at 50 g dry weight per litre of distilled water was sprayed on infected plants and disease incidence, severity, defoliation rate, necrotic leaf area, pod yield, and seed weight were evaluated. The extract exhibited activities against pathogenic fungi.[49]

**Anti-hyperglycaemic activities**

Sakine et al.[8] evaluated anti-hyperglycaemic activities of the compound glucocapparin isolated from the seeds of *B. senegalensis* by assessing the level of hepatic liberation of glucose from the liver of rabbits. The compound glucocapparin induced reduction of glucose levels at different doses and best results were obtained at a dose of 30 mg/ml.[8]

**Antioxidant activities**

Cook et al.[50] evaluated the antioxidant activities of aqueous leaf extract of *B. senegalensis* using the trolox-based assay. The extract exhibited an antioxidant capacity of 22.0 µmol Trolox equivalent/ g dry weight.[50] Diallo et al.[48] evaluated the antioxidant activities of methanol fruit extract of *B. senegalensis* using the 2,2-diphenyl-picrylhydrazyl (DPPH) radical scavenging assay and β-carotene test with ascorbic acid as a positive control. The extracts were both active in DPPH assay and β-carotene test.[48] Vougat et al.[39] evaluated the antioxidant activities of water, 70% acetone, methanol, 80% methanol and dichloromethane leaf extracts of *B. senegalensis* using the DPPH radical scavenging and ferric iron reducing assays with ascorbique acid and butylated hydroxytoluene as positive controls. The methanol and water extracts were the most active with half maximal inhibitory concentration ($IC_{50}$) values of 1.4 µg/mL and 11.4 µg/mL, respectively which were better than 18.3 µg/mL and 22.4 µg/mL exhibited by ascorbique acid and butylated hydroxytoluene, respectively. The extracts were able to reduce the ferrous ion ($Fe^{3+}$) to ferric ion ($Fe^{2+}$).[39] Deli et al.[45] evaluated the antioxidant activities of methanol seed extract of B. senegalensis using the DPPH free radical scavenging and 2,2'-azinobis-3-ethylbenzothiazoline-6-sulphonate (ABTS) assays with ascorbic acid as a positive control. The extract exhibited activities with $IC_{50}$ values in ABTS and DPPH ranging from 21.5 µg/mL to 51.9 µg/mL and 49.5 µg/mL to 90.8 µg/mL, respectively.[45]

**Antiplasmodial activities**

Ali et al.[19] evaluated the antiplasmodial activities of methanol leaf extracts of *B. senegalensis* using the [$^3$H] hypoxanthine incorporation assay against multidrug resistant *Plasmodium falciparum* strain K1 and the chloroquine sensitive strain NF54. The extract exhibited activities against the NF54 and K1 strains with $IC_{50}$ values of 1.1 µg/ml and 4.1 µg/ml, respectively.[19]

**Insecticidal activities**

Seck et al.[51] evaluated insecticidal activities of fruit and leaf crude extracts as well as the compound methylisothiocyanate isolated from *B. senegalensis* fruits against stored grain insects which included *Callosobruchus maculatus, Prostephanus truncatus, Sitophilus zeamais, Sitotroga cerealella* and *Tribolium castaneum* on cowpeas, *Vigna unguiculata* (L.) Walp. When added to cowpeas at 2.0% to 4.0% (w/w), the extracts caused 80.0% to 100.0% mortality in *Callosobruchus maculatus* adults. The fruit extract exhibited fumigant effect on *Callosobruchus maculatus, Prostephanus truncates* and *Sitotroga cerealella* with $LT_{50}$ values of 2.3 hours, 3.8 hours and 1.5 hours, respectively. The $LC_{50}$ values for the extracts and methylisothiocyanate on *Tribolium castaneum, Sitophilus zeamais* and *Callosobruchus maculatus* showed differential response of the insects to the extracts and methylisothiocyanate.[51] Auger et al.[47] evaluated the insecticidal activities of the compounds methylisothiocyanate and isopropylisothiocyanate isolated from *B. senegalensis* against adults, eggs and larvae of pest species *Bruchidius atrolineatus, Bruchus pisorum, Ephestia kuehniella* and *Plodia interpunctella* with a common fumigant CCl4 as a

positive control. The compounds methylisothiocyanate and isopropylisothiocyanate exhibited toxic effects on adults, eggs and larvae of the pest species at a lower dose than that of common fumigant CCl4.[47] Doumma et al.[52] evaluated the insecticidal activities of leaf crude extracts of *B. senegalensis* on three developmental stages (egg, larvae and adult) of *Callosobruchus maculatus*, an insect pest of *Vigna unguiculata*. Mortality increased with increasing concentration of extract and at 4 g/l of the extract, 100% of adults were killed within 24 hour of exposure and the development of newly laid eggs and neonate larvae were also inhibited. The effect of the extract was influenced by the larval stage with the 2nd larval stage observed to be more susceptible than the 4th larval stage. The authors also found that efficacy of the extract decreased with the storage time and at a concentration of 20 g/l, the effect could persist for 7 days. Gueye et al.[53] evaluated the insecticidal activities of fruit and leaf crude extracts of *B. senegalensis* on groundnut (*Arachis hypogaea* L.) bruchid, *Caryedon serratus*. After 24 hours of exposure, fresh crushed leaves mixed with *Arachis hypogaea* seeds at 6% (w/w) induced 100% mortality of adults and similar results were obtained with fresh fruits at 3% (w/w). Only 6% (w/w) of the extracts ensured a complete protection of *Arachis hypogaea* pods and shelled nuts against the weevil *Caryedon serratus*.[53] Bambou et al.[54] evaluated the insecticidal activities of leaf extracts of *B. senegalensis* by fumigating *Sitophilus zeamais* with different doses of the extract. The extract exhibited 100% mortality within 24 hours at a dose ranging from 1 g/l to 9 g/l.[54]

**Larvicidal activities**

Diallo et al.[48] evaluated larvicidal activities of the dichloromethane and methanol leaf extracts of *B. senegalensis* against second-instar larvae of *Aedes aegypti*, *Anopheles gambiae* and *Culex quinquefasciatus*. Both extracts exhibited activities against *Anopheles gambiae* and *Culex quinquefasciatus* larvae.[48]

**sEH inhibitory activities**

Morgan et al.[41] evaluated the soluble epoxide hydrolase (sEH) inhibitory activities of the compounds rhamnocitrin-3-O-β-D-(6"-O-E-feruloyl)-glucopyranoside, rhamnocitrin-3-O-β-D-(6"-O-E-p-coumaroyl)-glucopyranoside, rhamnocitrin-3-O-β-D-glucopyranoside, 3,4,5-trimethoxyphenol-β-D-glucopyrinoside, lasianthionoside A, 3,7-dimethyl-1-octene-3,6,7-triol-6-O-β-D-glucopyranoside, syringin and austroside B isolated from the leaves of *B. senegalensis* using the sEH inhibitory activity and sEH kinetic assays with 12-(3-adamantan-1-yl-ureido) dodecanoic acid (AUDA) (IC50: 7.2 nM) as a positive control. The compounds rhamnocitrin-3-O-β-D-(6"-O-E-feruloyl)-glucopyranoside, rhamnocitrin-3-O-β-D-(6"-O-E-p-coumaroyl)-glucopyranoside and rhamnocitrin-3-O-β-D-glucopyranoside exhibited activities with $IC_{50}$ values of 12.8 μM, 18.4 μM and 11.3 μM, respectively. The study by Morgan et al.[41] showed that the compounds rhamnocitrin-3-O-β-D-(6"-O-E-feruloyl)-glucopyranoside and rhamnocitrin-3-O-β-D-(6"-O-E-p-coumaroyl)-glucopyranoside exhibited non-competitive inhibition characteristics, while compound rhamnocitrin-3-O-β-D-glucopyranoside exhibited competitive inhibition, with inhibition constants (Ki) of 7.6 μM, 23.7 μM and 7.4 μM, respectively.

**Toxicity activities**

Sakine et al.[8] evaluated toxicity activities of the compound glucocapparin isolated from the seeds of *B. senegalensis* using the Brine shrimp lethality assay. The extract exhibited activities with $LC_{50}$ value of 16.5 μg/ml.[8]

## CONCLUSION

The present review summarizes the ethnomedicinal uses, phytochemistry and biological activities of the bark, fruits, leaves, roots and stem bark extracts of *B. senegalensis*. The historical traditional usage of *B. senegalensis* as herbal medicine in the Sahel region calls for detailed phytochemical and pharmacological studies aimed at correlating its documented ethnomedicinal uses with the phytochemical and pharmacological properties of the species. There is need for clinical and toxicological evaluations of both crude extracts and phytochemical compounds associated with *B. senegalensis*.

**Conflict of interest**

The author declares that he has no conflict of interest.

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