Phytochemical Wealth of *Vachellia nilotica* : An Updated Review of It's Bioactive Compounds and Health Benefits

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Abstract:

The adaptable medicinal plant *Vachellia nilotica* contains a wealth of bioactive chemicals that have significant therapeutic promise. Examining the many phytochemicals found in Vachellia nilotica, such as flavonoids, tannins, saponins, phenolic compounds, and essential oils, is the focus of this review. With notable antioxidant, antibacterial, and anti-diabetic effects, each of these substances adds to the plant's remarkable pharmacological profile. Quercetin and kaempferol are two flavonoids that increase insulin sensitivity, which makes the plant a powerful tool for managing diabetes. Gallic and ellagic acid are two examples of tannins that fight oxidative stress and shield cells from harm. Furthermore, the plant's broad-spectrum antibacterial activity targets a variety of infections, enhancing its reputation as a safe, natural substitute for pharmaceutical medications. The numerous health advantages and safe profile of *Vachelia nilotica* underscore its potential as a long-term herbal remedy for contemporary therapies.

Keywords: Phytochemicals, Antioxidant, Quercetin, Medicinal plant, Vachellia nilotica, Tannins.

1 Introduction

The flowering tree *Vachellia nilotica*, also called Acacia nilotica or by other colloquial names such gum arabic tree, babul, thorn mimosa, Egyptian acacia, or thorny acacia, is a member of the Fabaceae family (1).This adaptable leguminous plant is well-known for both its ecological value and its many uses(2). *Vachellia nilotica* is a plant that is native to Africa, the Middle East, and the Indian subcontinent. It has a wide natural range and thrives in tropical and subtropical climates from Egypt and Mauritania to southern Africa and the Indian subcontinent (3). The tree, which is locally known as kikar or babul, is well acknowledged as a plant with multiple uses(1, 4). It is essential to traditional medicine, agroforestry, and environmental sustainability(5-7). *Vachellia nilotica* is a member of the tribe Acacieae, sub-family Mimosoideae, and family Fabaceae. It is distinguished by its resilience and adaptation to a wide range of climatic conditions. Its ability to fix nitrogen and increase soil fertility emphasises its significance for sustainable farming techniques (8-10).

One of the many advantages that plants provide to humans is their potential for medical use. The study of medicinal plants is important because it creates new opportunities for the development of innovative therapeutic agents, alternative forms of therapy, and an improved understanding of natural substances that may eventually result in safer and more effective medications. In addition to confirming historical applications, research on Vachellia nilotica's medicinal potential opens the door for its integration into contemporary medical procedures and may even result in the creation of novel medications that take advantage of the plant's inherent qualities (11).

Extracts from the several sections of the plant *Vachellia nilotica*, such as the pods (12), leaves (13), and bark (14),have been shown to provide a wide range of therapeutic advantages. The leaves are useful in treating infections and lowering inflammation because of their strong antibacterial and anti-inflammatory qualities. The bark, which is high in tannins and flavonoids, has been used in traditional medicine to treat cancer and improve general health because of its strong antioxidant (15) and anti cancer potentials (16). The gum pods of Vachellia nilotica are highly valued because to their high gum arabic content (17).Gum arabic is a calming and demulcent substance that is used to treat respiratory and digestive problems. These diverse advantages derived from various plant sections demonstrate Vachellia nilotica's extensive therapeutic potential, making it an essential tool for creating novel therapeutic uses. Examining the function of insilico and invivo investigations on extracts of various Vachellia nilotica parts, such as pods, leaves, and bark, is one of

the study's objectives. The knowledge of *Vachellia nilotica's* medicinal qualities and therapeutic potential has greatly expanded thanks to computational research and in vivo experiments.

Key bioactive chemicals in *Vachellia nilotica* and their interactions with biological targets have been found by computational investigations, such as molecular docking and bio informatics analysis (18). The processes behind the plant's anti-inflammatory, antibacterial, and anticancer properties have been better understood thanks to these investigations. In vivo investigations (19), which support these computational methods, have confirmed the effectiveness of Vachellia nilotica extracts in animal models, indicating their potential for treating a range of illnesses. Promising outcomes from these trials include the induction of cancer cell death, inhibition of microbial development, and reduction of inflammation (20). In addition to supporting the traditional applications of *Vachellia nilotica*, computational and in vivo investigations help increase the validity of the species in the scientific and medical sectors. These discoveries highlight the significance of the plant in contemporary medicine and its potential for further pharmacological uses, aiding in the creation of novel medicinal medicines.

The purpose of this review is to investigate Vachellia nilotica's ethnobotany, taxonomy, historical background, medicinal significance, phytochemistry, and prospective applications in pharmaceuticals. This essay aims to demonstrate the noteworthy contributions made by this extraordinary species to science and society by combining the best available research with conventional wisdom.

Table.1. describes medicinal uses of different parts of the plant ***Vachellia nilotica:***

Common medicinal uses of different parts of A. nilotica:

Part of Plant	**Uses**	**References**
Root	The roots are used to treat spleen and liver indurations, TB, and malignancies as well as tumours of the ear, eye, or testicles.	(21) , (22)
Leaf	Astringent, antimicrobial, antimutagenic, antibacterial, anticancer, and chemopreventive properties Tender leaves are used as a remedy for ulcers, diarrhoea, aphrodisiacs, anti-inflammatory, and Alzheimer's illness.	(23) , (24)
Gum	Liver tonic, astringent, emollient, antipyretic, and antiasthmatic	(25)
Stem Bark	The bark is used to treat a range of medical conditions, such as bleeding, wound ulcers, leprosy, leucoderma,	(26) , (27) , (28)

	smallpox, skin diseases, biliousness, burning sensation, toothache, leucoderma, dysentery, and seminal weakness. It also possesses antibacterial, antioxidant, anti-mutagenic, and cytotoxic properties. In addition, it has aphrodisiac, styptic, emollient, anthelmintic, diuretic, expectorant, emetic, and nutritional qualities. Colds, bronchitis, diarrhoea, dysentery, biliousness, and leucoderma can all be treated with trunk bark.	
Seeds	Antiplasmodial and spasmogenic properties.	(29)
Pods	Anti-diarrhearial, astringent, anti-hypertensive, anti-spasmodic, anti-fertility, and anti-HIV-1 PR, prevented the cythopathogenicity, antiplatelet aggregatory activity, and antioxidant effects of HIV-1.	(30) , (31)

2 Bioactice Compounds and their Chemical composition(Extracted from *Vachellia nilotica*):

Phytochemicals and bioactive compounds are primarily responsible for *Vachellia nilotica's* medicinal and therapeutic properties. These compounds are widely known to possess antibacterial, anti-inflammatory, antioxidant, and anticancer effects.(32). They strengthen the immune system, support general health, and aid in the prevention and treatment of a number of ailments. These bioactive compounds have the ability to modify biological processes, which improves the effectiveness of conventional therapy and may lead to the creation of novel pharmacological agents(33). Some of the key phytochemicals present in this plant are Flavonoids,Tannins (condensed tannins, hydrolysable tannins, phlobatannins) ,Saponins, Glycosides, Alkaloids, Terpenoids ,Steroids, Phenolic compounds, Gallic acid, ellagic acid, (+)-catechin, Volatile oils, and carbohydrates (34). A brief description of every phytochemical present in Vachellia nilotica and its major role in therapeutics is described below:

2.a.Tannins:

Vachellia nilotica is an important plant in both conventional and contemporary medicine because of its tannin content, which greatly adds to the plant's therapeutic usefulness(35).

Condensed Tannins:

Condensed tannins are oligomeric or polymeric flavan-3-ol molecules connected by carbon-carbon bonds. They are also referred to as proanthocyanidins. In V. nilotica, these are the tannins that are most prevalent. Research has demonstrated the antibacterial, anti-inflammatory, and antioxidant properties of condensed tannins (36).

Hydrolyzable Tannins:

Esters of gallic acid (or its dimer, ellagic acid) with a polyol, typically glucose, are known as hydrolyzable tannins. Hydrolyzable tannins like gallic and ellagic acids are present in V. nilotica. Antiviral, antibacterial, and antioxidant characteristics are displayed by hydrolyzable tannins (37).

Phlobatannins:

A class of tannins with a phloroglucinol nucleus is known as phenolatannins. Phlobatannins have reportedly been found in V. nilotica. Phlobatannins have been linked to antibacterial and antioxidant properties(38) .

2.b. Flavonoids:

Flavonoids are a class of polyphenolic compounds found abundantly in V. nilotica . Some of the key flavonoids and their pharmaceutical potentials are mentioned Tabl**e 2:**

Flavonoids	**Medicinal Role**	**Reference**
Quercetin ($C_{15}H_{10}O_7$)	Neutralizes free radicals and reduces oxidative stress. Inhibits the production of pro-inflammatory cytokines. Induces apoptosis in cancer cells and inhibits tumor growth. Effective against a broad spectrum of bacteria and fungi.	(39)
Kaempferol ($C_{15}H_{10}O_6$)	Protects cells from oxidative damage. Reduces inflammation by inhibiting inflammatory pathways. Inhibits the proliferation of cancer cells and induces cell death. Supports heart health by reducing blood pressure and improving lipid profiles.	(40)
Catechin ($C_{15}H_{14}O_6$)	Reduces oxidative damage and scavenges free radicals. regulates immunological responses to reduce inflammation. Demonstrates activity against a range of pathogens, such as viruses and bacteria. Cardioprotective because it enhances blood vessel activity, hence improving cardiovascular health.	(41)
Luteolin ($C_{15}H_{10}O_6$)	Lowering oxidative stress and shielding cells from harm. This can offer defence against long-term conditions linked to oxidative stress, like	(42)

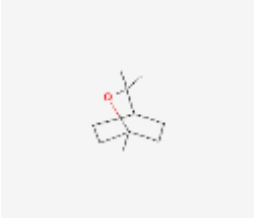
	neurological and cardiovascular illnesses. Reduces oxidative stress and neuroinflammation, preventing neurodegenerative illnesses. Effective against bacteria, fungi, and viruses, aiding in infection prevention and treatment.	
Rutin ($C_{27}H_{30}O_{16}$)	Strengthens blood vessels, reduces capillary fragility, and prevents hemorrhages. Inhibits cancer cell proliferation and induces apoptosis.	(43)

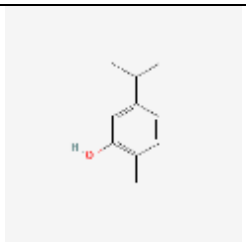
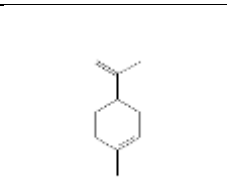
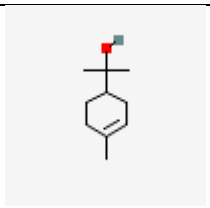
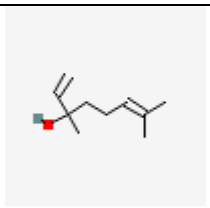
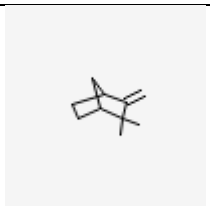
2.c. Alkaloids:

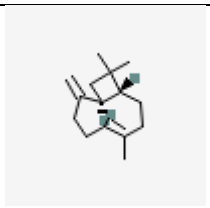
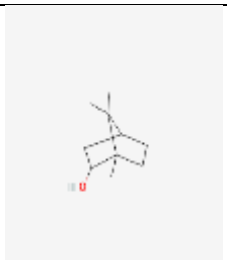
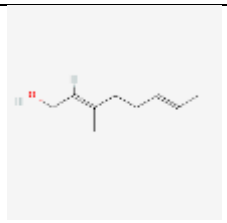
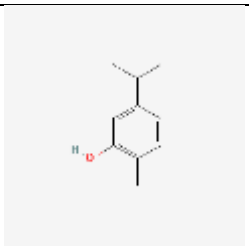
V. nilotica contains several important alkaloids, such as 5-MeO-DMT (5-Methoxy-N,N-dimethyltryptamine) - C13H18N2O, DMT (N,N Dimethyltryptamine) - C12H16N2, Harmane (Norharmane) - C12H10N2, and Tryptamine - C10H12N2 (44). The pharmacological activities of these alkaloids are worth mentioning. Hallucinogenic and psychotropic effects are associated with DMT and 5-MeO-DMT.
It has been demonstrated that tryptamine and harmane have neuroprotective, antioxidant, and anti-inflammatory qualities(45). Alkaloids act as reservoirs for nitrogen storage and plants have evolved their metabolic diversity to cope with environmental stress conditions. Many alkaloids show potent antimicrobial activities against various pathogenic microorganisms(46). Alkaloids with anticancerous activities, such as vincristine, vinblastine, and taxol, are being effectively used as chemotherapeutic drugs(47).

2.d. Essential Oils:

Volatile compounds and oils, often referred to as essential oils, are aromatic, volatile substances extracted from plants. These compounds evaporate easily at room temperature, contributing to the fragrance and flavor of the plant (48). Table 3 describes essential oils present in *Vachellia nilotica* , their formulae , structure and medicinal potential :

Essential Oil Components of *V.nilotica*	Molecular Formula	Structure	Pharmaceutical Activity	References
1,8-Cineole (Eucalyptol)	C10H18O		Antimicrobial Anti-inflammatory Expectorant	(49)

Alpha Pinene	C10H16		Bronchodilator Anti-inflammatory	(50)
P-Cymene	C10H14		Antioxidant: Antimicrobial:	(51)
Limonene	C10H16		Antioxidant Anticancer	(52)
Terpineol	C10H18O		Anti inflammatory Sedative	(53)
Linalool	C10H18O		Antimicrobial: Sedative	(54)
Camphene	C10H16		Antimicrobial Antioxidant	(55)

Myrcene	C10H16		Analgesic Antioxidant	(56)
β-Caryophyllene	C15H24		Reduces inflammation by interacting with CB2 receptors. Provides pain relief.	(57)
Borneol	C10H18O		Possesses antibacterial and antifungal properties. Offers calming and relaxing effects.	(58)
Geraniol	C10H18O		Reduces inflammation and pain. Helps relieve digestive issues	(59)
Carvacrol	C10H14O		hows potential in inhibiting the growth of cancer cells. Neutralizes free radicals, protecting cells from damage	(60)

2.e. Other Bioactive Compounds Present in Vachellia nilotica:

Saponins, Glycosides, Terpenoids, Steroids, Phenolic compounds , Gallic acid, ellagic acid are also present in high percentages in *Vachellia nilotica*. Saponins exhibit anti-inflammatory, antimicrobial, and antioxidant activities. They can also induce apoptosis in cancer cells, making them a potential therapeutic agent against tumors (61). Glycosides are compounds consisting of a sugar group bonded to a non-sugar group (aglycone). *V. nilotica* contains various types of

glycosides, including cyanogenic glycosides and anthraquinone glycosides. These compounds have been associated with laxative, anti-inflammatory, and antimicrobial properties(62). A class of lipids known as steroids is distinguished by a carbon skeleton that has four fused rings. Phytosterols are among the several kinds of steroids found in *V. nilotica*. It has been demonstrated that phytosterols reduce cholesterol and may be a factor in the plant's anti-atherosclerotic qualities.

(63).Certain phenolic chemicals present in *V. nilotica* include gallic acid, ellagic acid, and (+)-catechin. Two hydrolyzable tannins having antiviral, antibacterial, and antioxidant qualities are gallic and ellagic acids. One flavanol that adds to the plant's anti-inflammatory and antioxidant properties is (+)-catechin. (64).

3. Therapeutic Capabilities of *Vacellia nilotica*:

The qualitative phytochemical study of the plant extract's various components indicates that tannins are present in the leaves and fruits (65), Stearic acid, kaempferol-3-glucoside, isoquercetin, and leucocyanidin are found in flowers (66). The gum contains Arabic acid along with calcium, magnesium, and potassium, while the pods are high in tannins (67). Moreover, polyphenolic substances have been found in the bark and pods.(26). Traditionally, this plant was also used for treatment of leucorrhoea, prolapse, and bleeding disorders.

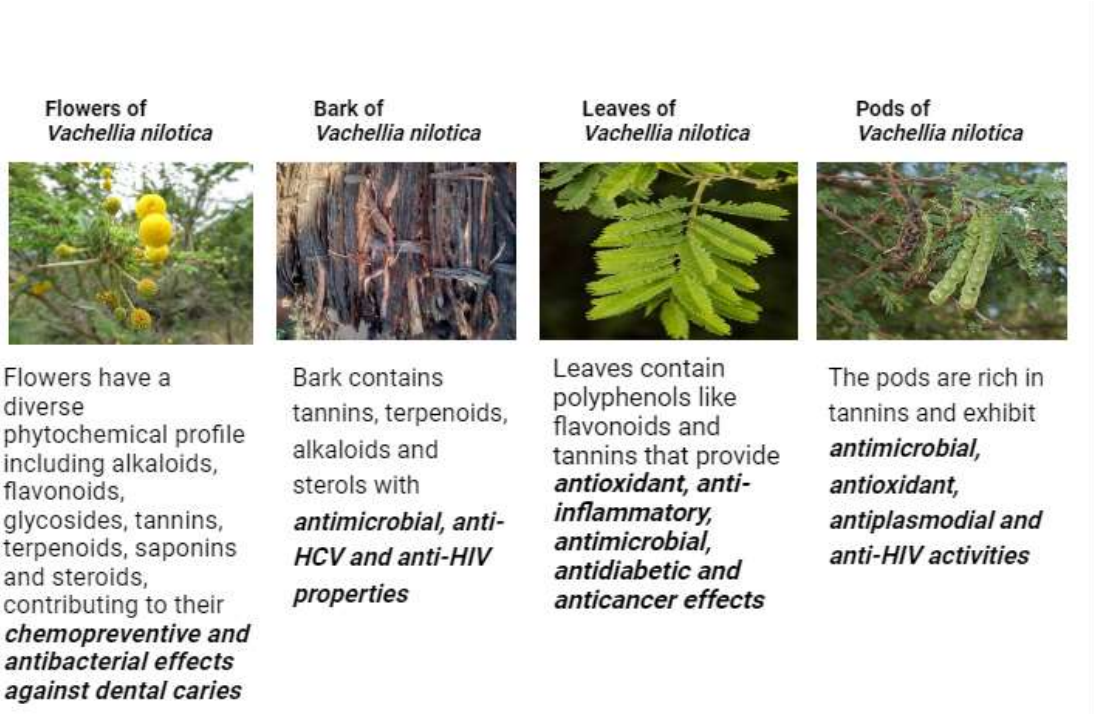


Fig.1. Particular Phytochemicals and their relevant pharmaceutical potential of Flowers, Bark, Leaves and Pods of Vachellia nilotica , respectively.

V. nilotica has been shown through experimental research to have antihypertensive, antispasmodic, antibacterial, antifungal, and antioxidant properties (25).

3.a. Anti-cancer Activity:

Because it contains a high concentration of bioactive components, such as gallic acid, ellagic acid, kaempferol, catechin, and tannins, *Vachellia nilotica* has considerable anticancer potential. These substances have potent anti-inflammatory and antioxidant properties as well as the ability to cause cancer cells to undergo apoptosis. More specifically, kaempferol and catechin cause cell cycle arrest and diminish angiogenesis, starving tumours of oxygen and nutrients, while gallic acid and ellagic acid cause programmed cell death and inhibit cancer cell proliferation (68). Furthermore, these chemicals'

antioxidant action aids in shielding healthy cells from DNA damage and oxidative stress. Experiments have demonstrated that extracts from Vachellia nilotica can successfully target a range of malignancies, including leukaemia, breast, prostate, lung, and colon cancers. These findings suggest that Vachellia nilotica may have a role in integrative cancer therapy.

Leaves , gum and flowers extracts of V. nilotica have demonstrated chemopreventive properties against mice's DMBA-induced cutaneous papillomas (69). Cervical cancer (CaSki) cells have been shown to be susceptible to growth inhibition and apoptosis induction by ellagic acid derived from V. nilotica (14). The leaf extracts of V. nilotica shown anticancer efficacy when tested against MDA-MB-231 breast cancer cells (70). Strong inhibitory effect was demonstrated by the V. nilotica floral extract against HepG-2 liver cancer cells. It has been found that ellagic acid from V. nilotica inhibits chemically-induced tumours in mice' oesophagus and lung (18).

3.b. Anti-microbial activity:

The ethanol and chloroform extracts of *V. nilotica* fruits have shown effective antimicrobial activity against *Pseudomonas aeruginosa* .The methanolic fruit extract of V. nilotica exhibited significant inhibition against both Gram-positive and Gram-negative bacterial species, including *Staphylococcus aureus* and *Escherichia coli (26)*. The aqueous extract of V. nilotica leaves also demonstrated good antibacterial activity against isolated pathogens, with minimum inhibitory concentration (MIC) values as low as 3.13 µg/ml against *Staphylococcus aureus* and *Streptococcus agalactiae(71)* .Comparative studies have shown that the methanol extracts of *V. nilotica* leaves had statistically higher antibacterial activity against *E. coli* compared to Lawsonia inermis and Ziziphus jujuba Linn (72). On the other hand, the L. inermis extract showed significantly higher activity against Streptococcus species. The minimum bactericidal concentration (MBC) of the *V. nilotica* leaf extract was found to be 10 mg/ml, which was lower than the standard antibiotic streptomycin sulfate against *S. aureus* and *E. coli(73)* .

3.c. Mechanism of Antimicrobial Action

It is thought that bioactive substances such tannins, flavonoids, and saponins are what give V. nilotica preparations their antibacterial properties. These phytochemicals have the ability to cause bacterial cell death by rupturing bacterial cell membranes, suppressing enzyme function, and interfering with the synthesis of bacterial DNA and proteins (74). According to studies, V. nilotica's tannin-rich fractions had the strongest antibacterial activity.

3.d. Antifungal Potential:

Significant antifungal activity against *Candida albicans*, *Aspergillus niger*, *Trichophyton rubrum*, and *Trichophyton mentagrophytes* has been demonstrated by the ethanolic leaf extract of *V. nilotica*. Using the ethanolic leaf extract, the highest zone of inhibition against *Candida albicans* (18.50 mm) was seen. (75). The antifungal properties of V. nilotica leaves have been found to include gallic acid and its methyl ester, which have been shown to be effective against *Pythium aphanidermatum*. (76).The ethanolic leaf extract of *V. nilotica* exhibited increased antifungal activity when mixed with honey (77). When 50% v/v honey was used against *Trichophyton rubrum*, the highest zone of inhibition (20.00 mm) was seen(78).

3.e. Anti-diabetic Activity:

Pods of Vachellia nilotica are said to have high levels of polyphenols and tannins. Tannins, like tannic acid, promote glucose transport while preventing the development of adipocytes. Blood glucose levels are lowered by polyphenol (79). Conventional anti-diabetic plants may be a valuable source of novel oral hypoglycemic chemicals for application in pharmaceutical development or as easy-to-eat dietary supplements to current treatments. Research on *Vachellia nilotica's* anti-diabetic properties has been conducted in Pakistan, revealing favourable hypoglycemic and hypolipidemic effects(27). Compounds like catechin, epicatechin, quercetin, kaempferol, and luteolin present in V. nilotica have been shown to exhibit insulin-sensitizing effects. These flavonoids can improve glucose uptake in peripheral tissues, thereby

enhancing insulin sensitivity. Tannins have been reported to inhibit carbohydrate-digesting enzymes like α-amylase and α-glucosidase, which can help reduce postprandial hyperglycemia. Saponins present in V. nilotica have been associated with enhanced insulin secretion from pancreatic β-cells. Improved insulin secretion can contribute to better glucose homeostasis and insulin sensitivity. Compounds like oleanolic acid and ursolic acid, which are terpenoids isolated from V. nilotica, have been shown to inhibit gluconeogenesis and enhance glucose uptake in peripheral tissues.

3.f. Antioxidant Activity:

Oxidative damages creates by free radicals, play a substantial role in the evolution of human diseases. Toxicity of free radicals contributes to proteins and DNA damage, inflammation and tissue injury (80). Oxidative stress is created in the body due to a disruption in the equilibrium between the production of reactive oxygen/nitrogen species (ROS/RNS) and the removal via the antioxidant defence system (15). Antioxidants can interfere with the oxidative processes by reacting with free radicals, chelating catalytic metals and also by acting as oxygen scavengers thus helping the human body to reduce oxidative damage (81). From various epidemiological studies, it is proved that polyphenolic compounds possess an excellent antioxidant properties specially polyphenols from methanolic bark extracts of *Acacia* or *Vachellia nilotica* (82)**.** Natural antioxidants like flavonoids, phenolics, tannins, curcumin and terpenoids present in Vachellia nilotica can reduce the access of oxidants and other deleterious molecules due to their ability to scavenge oxygen-nitrogen-derived free radicals by donating hydrogen atom or an electron, chelating metal catalysts, activating antioxidant enzymes, and inhibiting oxidases (83).

4. Conclusion:

This review underscores the significant potential of *Vachellia nilotica* in traditional medicine, supported by its rich array of bioactive compounds such as flavonoids, tannins, saponins, phenolic compounds, and essential oils. These compounds contribute to the plant's strong anti-diabetic, antioxidant, and antimicrobial properties, reinforcing its value in modern therapeutic applications. Although Vachellia nilotica has a lot of potential, it is important to pay close attention to dosage, usage, and any side effects because using medicinal herbs improperly might have negative repercussions. To protect this natural resource, a steady and sustainable supply of its activr ingredients is essential.

5. Future Directions:

Subsequent investigations ought to focus on elucidating the specific pathways through which the bioactive constituents of Vachellia nilotica achieve their remedial impacts. It is essential to carry out clinical experiments to verify the plant's safety and effectiveness in people. Examining the mutually beneficial relationships between its constituents may result in the creation of all-encompassing, multi-targeted therapies. Its use may also be expanded by extending research into its potential in other therapeutic domains, such as anti-inflammatory and anticancer properties. In order to ensure a consistent supply of bioactive chemicals, sustainable growing methods has to be given top priority. Further research into innovative biosynthesis techniques or the production of these organic substances is also required. Further research into innovative biosynthesis techniques or the production of these organic substances is also required. A crucial first step in confirming and developing novel drugs derived from Vachellia nilotica and guaranteeing their efficacy and safety for human use is transitioning from preclinical research to clinical trials.

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