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Review Article

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# Applications of Prickly Ash (*Zanthoxylum* spp.): Potential in Traditional Science, Modern Science, and Agriculture

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## Abstract

Plants have been recognized globally for their valuable contributions as sources of sustenance and medicinal remedies in the treatment of diverse medical conditions. Secondary metabolites derived from plants are known to have a substantial impact on both toxicity and health benefits. *Zanthoxylum* spp. is one such example of deciduous shrubs that exhibits these properties in Rutaceae family, with around 250 different species. *Zanthoxylum* spp. demonstrates a diverse range of biological activities due to its widespread distribution and plentiful bioactive substances, such as terpenoids, flavonoids, and alkaloids, hence augmenting their significance in therapeutics as well as insecticidal characteristics such as larvicidal, repellent, and anti-feedant effects. In addition to its medicinal properties, *Zanthoxylum* spp. is widely utilized as a spice in various worldwide culinary traditions. These plants possess substantial ethno-pharmacological importance and serve as crucial components in both traditional and modern healthcare systems, effectively managing several illnesses including heart disease, cancer, liver disorders, etc. The decrease in agricultural productivity resulting from the detrimental impacts of insects, weeds, and other similar factors has prompted the extensive adoption of chemicals to counteract these challenges. However, the use of these synthetic compounds has been linked to have negative consequences on both the environment and human health. An extensive literature survey was conducted to present a comprehensive examination on the feasibility of utilizing botanical products obtained from *Zanthoxylum* spp. as environmentally sustainable alternatives. The objective of this review paper is to promote further investigations into the utilization of *Zanthoxylum* spp. and their chemical constituents as reliable and effective pesticide solutions, with the aim of mitigating the detrimental effects of synthetic pesticides on human health and the environment.

## Keywords

*Zanthoxylum*, Essential oils, Secondary metabolites, Ethnobotany, Insecticidal, Sustainability, Zero Hunger, Good health

## Introduction

Plants hold a critical role in supporting life on our planet. Their significance spans across ecosystems, as they offer essential services such as producing oxygen, providing sustenance, yielding materials, and enhancing human welfare in various ways. Plant-derived goods encompass a wide spectrum of outcomes resulting from the exploitation of plants for multiple objectives, ranging from nourishment to industrial uses. Plants, being multicellular organisms capable of harnessing sunlight for energy through photosynthesis, not only produce oxygen but also form the foundational link in food chains. Their remarkable diversity in forms and sizes reflects their adaptability to diverse environments, spanning from lush rainforests to arid deserts. Beyond their ecological importance, plants hold cultural, inspirational, and scientific value. Throughout history, humans have relied on plants for nourishment and medicinal properties, showcasing an enduring interdependence. In response to harmful agents and environmental conditions, plants generate secondary metabolites. Consequently, efforts have been focused on isolating, identifying, and studying the beneficial effects of these secondary metabolites derived from these plants on human health. Importantly, specific active compounds obtained from plants have served as templates for the development of synthetic pharmaceuticals. Examples include artesunates derived from artemisinins and quinolone antimalarials originating from wild quinine [1]. Experts in the field of natural products chemistry often draw from traditional knowledge regarding medicinal plants to generate initial extracts with biological properties, which can be further applied in the modern science (Figure 1). This initial step is followed by subsequent processes aimed at isolating the bioactive compounds and elucidating their chemical structures. At times, modifications are introduced to these phytochemicals to create medicinal agents that are not only more potent but also safer.

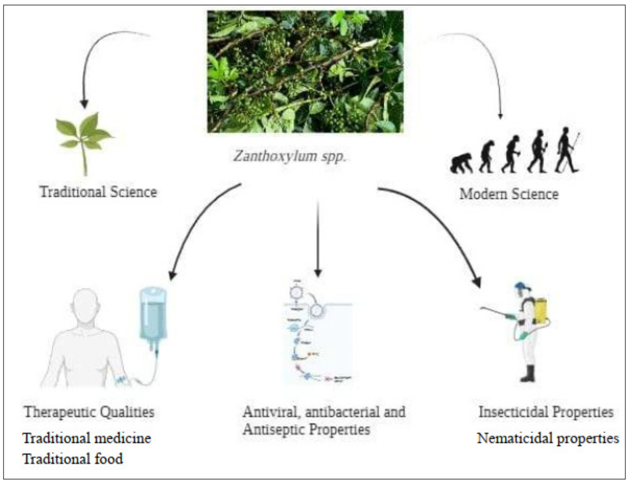


**Figure 1:** Application of *Zanthoxylum* spp. in traditional and modern science.

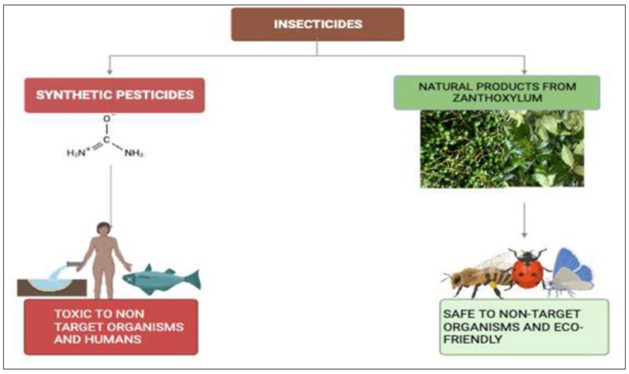


**Figure 2:** Synthetic vs. plant based insecticides.

*Zanthoxylum* spp. belongs to the Rutaceae family, a diverse group that encompasses more than 160 other genera and more than 2000 species. Within this genus, a wide array of plant species is distributed primarily across Asia, America, and Africa [2]. Historically, several *Zanthoxylum* spp. have been used as medical herbs to treat a variety of conditions. The secondary metabolites of these plants have showed a variety of pharmacological activities, including antioxidative, analgesic, anti-inflammatory, and regulatory effects on conditions such as diabetes, dementia, and obesity. Decoctions of *Zanthoxylum* leaves, stem bark, fruits, roots, or pericarp are frequently used to treat infections of all kinds, especially those brought on by parasites, sickle cell anemia, tumors, as well as bacterial, viral and fungal infections. They are helpful in preventing vector-borne infections since they are also used to ward off insects, particularly those that spread diseases via the bloodstream, like mosquitoes. The plant also has phyto-molecules with insecticidal, parasitic-repelling, nematicidal, and larvicidal properties. Some of the species' biological actions are caused by phytochemicals that have not yet been identified. Like this, certain isolated chemicals biological functions are yet unclear. *Zanthoxyllum* spp. extracts and compounds should be further researched as possible sources of novel medications and nutraceuticals because they collectively exhibit promising biological activity.

The pressure on current agricultural practices has increased dramatically because of the worldwide population growth. Most nations strive to boost food production to fulfil the demands of their expanding populations, which are expected to reach over 10 billion by 2050 [3]. A variety of agrochemicals, such as synthetic insecticides to fight illnesses and pests, have recently gained a lot of popularity. However, it is important to determine whether any agricultural practice will be sustainable and what impact it will have on the environment and human health. It is necessary to develop and employ natural products as long-term substitutes for synthetic insecticides, herbicides, and other pesticides (Figure 2). Recent research has revealed that plants like the *Zanthoxylum* spp. exude compounds that are poisonous to non-human beings but not to humans and are also safe for the environment [3]. This review article highlights the secondary metabolites of *Zanthoxylum* spp. as a suggested alternative to recommend substitute of natural insecticides and herbicides.

This study is divided into numerous sections. The first section, it provides an overview of the genus *Zanthoxylum*, its morphological characters, taxonomy, and botanical description of the genus. We also listed the vernacular names (with special reference to North-eastern states of India). In the second section, we provide an overview of the conventional applications of *Zanthoxylum* spp. as medicine and food across the globe. Here, we also gave an overview of various nations employing *Zanthoxylum* roots, bark, and stems for different purposes as a medicine or as an insecticide. In the third section, we discussed the common bioactive active compounds present in the genus *Zanthoxylum*. In the fourth section, we discussed the historical role of *Zanthoxylum* spp. in ancient pharmacology as an herbal remedy. In the fifth section, we discussed the various potentials or the functional effects of *Zanthoxylum* genus from its antimicrobial potential to its anti-inflammatory potential and more in depth in its insecticidal potential.

This study also provided an overview of various insecticidal research of *Zanthoxylum* spp. on various insect pests from 2019-2023. In the last section, we gave an overview of *Zanthoxylum* spp. As a commonly eaten edible spice in various regions of the world, particularly in the Asian countries. This study used a systematic review methodology to find pertinent studies. The literature examined in this area was sourced from ScienceDirect, Scopus, DOAJ, Google Scholar, PubMed, Research Gate, and other internet sources. Keywords like *Zanthoxylum*, insecticide, essential oils, secondary metabolites, ethnobotany were used in the title, abstract, and keywords of the systematic search carried out on these primary databases.

## Plant Literature

### The genus *Zanthoxylum*

*Zanthoxylum* spp. are a part of the Rutaceae family and fall within the subfamily Rutoideae, serving as the representative genus for the Zanthoxyleae tribe. There are approximately 549 known *Zanthoxylum* spp. with the majority inhabiting tropical and chilly climates. Plants within this genus commonly exhibit dioecy, meaning they have separate male and female individuals. The different plant parts including leaves, fruits, stems, bark, and seeds are versatile, tasty, and they are widely cultivated for these characteristics. The *Zanthoxylum* genus includes species of aromatic, medicinal deciduous shrubs, and trees. Most of the plants in this genus are known for having prickly spines and a pungent lemon-like odour. Several species, most notably Sichuan pepper, are grown for their use as spices. In the north-eastern regions of India, *Zanthoxylum* spp. is more commonly recognized by the common names such as bamboo-leaf prickly ash, or toothache tree or Nepal pepper [4]. However, different states have their vernacular names for this plant species (Table 1). *Zanthoxylum* spp. possesses a distinctive ability to enhance speech, alleviate conditions like asthma, rheumatism, arthritis, stomach discomfort, skin ailments, anorexia, and ataxia. Moreover, it exhibits anti-inflammatory, fertility-regulating, fat-storing, pain-relieving and liver-protective properties while also contributing to blood purification [1, 2]. The plant possesses phytomolecules with insecticidal, antiparasitic, nematicidal, larvicidal, and fungicidal properties. A comprehensive review examines the biological effects of extract (*Zanthoxylum*) and their metabolites, delving into their mode of action. Researchers have identified more than 500 distinct chemicals within *Zanthoxylum* spp. [3].

**Table 1:** Vernacular names of *Zanthoxylum* spp. in different states of India.

| State | Language | Vernacular name |
|---|---|---|
| Meghalaya | Khasis | *Jaiur* |
| Meghalaya | Pnar | *Yayur* |
| Manipur | Manipuri | *Mukthrubi* |
| Assam | Assamese | *Kulekhara* |
| Nagaland | Nagamese | *Mechinga* |
| Mizoram | Mizo | *Arhrikreh* |
| Tripura | Kokborok | *Bajna* |
| Sikkim | Sikkimese | *Bhalay timur* |
| Other states | Hindi | *Tejbal* |

### About the plant

The *Zanthoxylum* genus is bushy shrubs, trees, or woody climbers with trichome-armed leaves that make up the *Zanthoxylum* genus. According to the Royal Botanic Garden Sydney, the trees can grow up to 20 meters tall, have a leafy crown, and have few branches. The key characteristic setting apart species within this genus is the existence of curled spines on both the branches and trunk. There are two types of leaves: simple and compound and they are arranged oppositely or alternately, with an odd or even number of leaflets, sometimes reaching up to 15 pairs. Inflorescence often consists of clusters or panicles of tiny flowers, appearing at axillary or terminal locations. The flowers are typically actinomorphic, can be hermaphroditic or unisexual, and are usually white or green, rarely exhibiting bisexual traits. The fruits, which can be follicles or schizocarps, generally contain a single glossy seed in shades of red or black, emitting a pleasant scent, with each fruit housing one to five fragrant carpels [2].

### Taxonomy and botanical description of *Zanthoxylum* spp.

In the initial volume of work "Species Plantarum" released in 1753 by Carl Linnaeus he officially introduced the genus *Zanthoxylum* for the first time. The term *Zanthoxylum*, a broad designation,comes from Ancient Greek words "*xanthos*," denoting "yellow," and "*xylon*," signifying "wood." Linnaeus, in 1753, documented the first species, *Zanthoxylum trifoliatum*, in this genus. Since its inception, the genus *Zanthoxylum*, which Linné erected in 1757, has been mistaken for the genus *Fagara*. Engler distinguished between the two taxa in 1896 using the following traits: *Zanthoxylum* spp. exhibit a single perianth structure, whereas *Fagara* species possess a double perianth. In 1962, Brizicky identified a handful of species with perianths that displayed intermediate characteristics. This discovery highlighted how genus *Zanthoxylum* simple perianth developed from *Fagara*, primarily because several sepals failed to fully form. Consequently, it was inferred that these two genera were essentially identical [1]. Eventually, in 1966, Hartley merged *Zanthoxylum* and *Fagara* into a single genus, adopting the name *Zanthoxylum*. Nevertheless, it is worth noting that some authors continue to employ the term *Fagara* in some publications [1]. Kingdom: Plantae; Class: Magnoliopsida; Order: Rutales; Family: Rutaceae; Genus: *Zanthoxylum.*

### Traditional food and medicinal applications of *Zanthoxylum* spp.

*Zanthoxylum* spp. hold considerable economic importance due to their various contributions, including providing delectable fruits, valuable oils, and wood resources for industries, medicinal applications, ornamental value, and culinary uses. Additionally, their wood, often referred to as satinwood, is renowned for its frequent use in woodworking. For example, in Africa, species like Z. *tessmannii, Z. gillettii, Z. lemairei,* and Z. *leprieurii* play a pivotal role in constructing houses, buildings, ships, crafting drums, and various structures. They are also prized for their utility in decorative woodworking, carpentry, and supporting the paper industry. *Zanthoxylum* spp. in various countries across this continent have a history of employing their roots, bark, and stems for purposes such as expelling intestinal worms (vermifuges), reducing fevers (febrifuges), and acting as fish poisons (piscicides). Additionally, the *Zanthoxylum* inflorescences, fruits, and leaves' essential oils species find application in the culinary and perfume industries. Notably, some of the most sought-after essential oils are derived from *Z. simulans*, *Z. gillettii*, and *Z. xanthoxyloides* [4]. Another noteworthy trait common to nearly all *Zanthoxylum* spp. is their ability to produce resins suitable for tire manufacturing, serving various purposes as encapsulants, emulsifiers, or diluents in the pharmaceutical sector. In general, it is emphasized that infusion and decoction, which primarily use water as a solvent, are the most frequently used extraction procedures when discussing the ethnobotanical qualities of the *Zanthoxylum* genus [5].

Several species belonging to the *Zanthoxylum* genus have been harnessed across diverse global regions, particularly in Asia, Africa, and the Americas, for their efficacy in treating a wide array of human and animal ailments and many researchers and experts in the field have documented their therapeutic applications. Due to their significant ethnobotanical properties, several *Zanthoxylum* spp. have found a place in natural medicinal remedies [1, 5]. Furthermore, in Brazil, *Z. rhoifolium* are commercially incorporated into herbal tea blends available for purchase in supermarkets, pharmacies, and open-air markets [4]. Table 2 highlights a few of the conventional applications of *Zanthoxylum* spp. as medicine and other purposes.

# Bioactive Compounds

Numerous phytochemical substances have been found in the *Zanthoxylum* genus, including alkaloids, sterols, phenolic compounds, terpenoids, flavonoids glycosides, benzenoids, fatty acids, alkenic acids, amino acids, amides, lignans, neolignans, coumarins and peptides, are just a few of the 126 unique secondary metabolites that have been extracted from different *Zanthoxylum* spp. and identified [5] (Figure 3). Numerous investigations have demonstrated the pharmacological effects of substances from the genus *Zanthoxylum*, such as larvicidal, anti-inflammatory properties, antioxidant, antibacterial, anti-leukemic, and antimycobacterial effects. Bark of *Z. Armatum*, materials like armamide (amide), asarin, and fargesin (lignan) can be isolated. Other components of *Z. armatum* bark include lignans L-asarin, L-sesamin, and L-planinin, as well as alkaloids zanthonitrile and berberine. Seeds also contain the volatile compounds linalool, limonene, and methyl cinnamate. Tambulin, a flavonoid, was extracted from the seed.

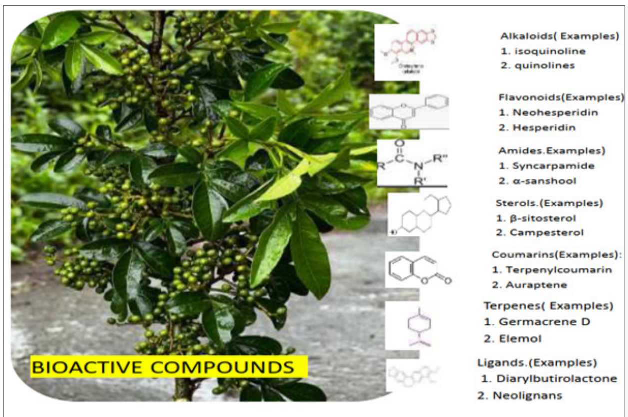


**Figure 3:** Bio-active compounds present in *Zanthoxylum* spp.

## Alkaloids

Alkaloids have been found in all plant organs and are particularly prevalent in the bark of the trunk and roots of most species of plants in the genus *Zanthoxylum*. Two classes of isoquinolines and quinolines make up most of the identified alkaloids. These include benzophenanthridine, aporphine, benzylisoquinoline protoberberine, berberine, and benzylisoquinoline. In several species of the genus, different kinds of alkaloids have also been discovered [1].

## Isoquinoline alkaloids

Benzophenanthridines, a class of alkaloids found in the *Zanthoxylum* genus, are renowned for their diverse biological activities, with a prominent focus on their anticancer potential. These alkaloids have been extensively studied and documented in various research papers [5]. They possess a variety of biological characteristics, including effectiveness against malaria, nematodes, leukemia, microbes, oxidative stress, HIV, bacteria, and fungi [3]. These alkaloids are found in limited distribution within plants and have been extracted primarily from genera within the Rutaceae, Papaveraceae, and Fumiraceae families. They are notably regarded as chemotaxonomic markers in these plant families. They are exclusive to the species of *Tetradium, Phellodendron*, *Fagaropsis*, *Toddalia*, and *Zanthoxylum* (including *Fagara*) within the Rutaceae family. Isoquinoline alkaloids are the most well-known alkaloids, along with fagaronine, nitidine, chelerythrine, and sanguinarine. Different authors have assigned benzophenanthridine alkaloids to substances with chemical structures comparable to iwamide and integriamide, which have been extracted from distinct members of the *Zanthoxylum* genus. Like benzophenanthridines, the common benzylisoquinoline alkaloids have a found in a restricted range in plants. The quaternary alkaloids xylopinidine and isotembetarine that have been discovered in the bark of *Zanthoxylum quinduense* do not exist in other species of the genus. *Zanthoxylum* spp. has been found to contain berberine and protoberberine alkaloids. The bark of *Z. quinduense* has yielded Tetrahydroberberines, such as N-methyltetrahydrocolumbamine and N-methyltetrahydropalmatine [1, 4]. The yellowing of the wood and bark is frequently caused by berberine in many species of this genus, such as *Z. monophyllum*, which is used as a dye. The significant leishmanicidal and bactericidal action of berberine makes it unique. Although they are not the most frequent compounds found in the *Zanthoxylum* genus, aporphine alkaloids have been discovered in several species and are particularly significant because several of them exhibit antitumoral effect [5].

## Quinoline alkaloids

Quinoline alkaloids, which mainly fall into two categories: furoquinolines and pyranoquinolines, are frequently found in the *Zanthoxylum* spp. Many of these quinoline alkaloids are known as 2-quinolones because at the 2$^{nd}$ position of the simple quinolinic they possess a carbonyl group. Two pyranoquinolines, N-methylflindersine and zanthobungeanine, as well as two furoquinolines, dictamine and skimmianin, have been isolated from *Z. budrunga* bark. Like this, pyranoquinoline alkaloids such as zhantosimulin and huajiaosimulim having apoptotic action have been discovered from *Z. simulans*. Quinazoline and Lunacridina alkaloid and other alkaloids have been extracted from *Z. budrunga*. *Z. rhoifolium* wood can be used to produce carbazole alkaloids, including 3-methoxy-9-methyl-9H-carbazol-2-ol. Notably, a proline-derived alkaloid called monophyllidin was recently discovered and was isolated from *Z. monophylum* bark and this substance showed antibacterial activity against *Enterococcus faecalis* (a Gram-positive bacterium) [1].

**Table 2:** Highlights few of the conventional applications of *Zanthoxylum* spp. as medicine and other purposes.

| S. No. | Country | Uses | Ref. |
|---|---|---|---|
| 1 | Kenya and South Africa | *Zanthoxylum* spp. - derived pastes are employed to alleviate pain linked to wounds and facilitate the process of wound healing. | [6] |
| 2 | Nigeria | *Z. zanthoxyloides* finds application in the treatment of various ailments, including toothache, infections of the urinary system, rheumatoid arthritis, sickle cell anaemia, and venereal diseases. | [5] |
| 3 | Uganda | Elephantiasis, toothaches, erectile dysfunction, gonorrhoea, malaria, dysmenorrhea, and intestinal discomfort are among the ailments that are treated using *Z. zanthoxyloides* root-bark. | [7] |
| 4 | Cote D'Ivoire (West Africa) | Decoction of the stem of *Z. zanthoxyloides* is utilized to alleviate toothache and address infections resulting from oral pathogens. *Z. gilletii* is extensively used as a therapy for hypertension, skin infections, and parasites (malaria). | [8] |
| 5 | Togo | *Z. zanthoxyloides* leaves and bark are used to treat wounds and toothaches, swellings, and worms and to induce milk after childbirth, respectively. | [1] |
| 6 | Ghana | Malaria is treated with decoction of *Z. zanthoxyloides* stem bark. | [9] |
| 7 | Central African Republic | Traditional remedies for malaria, diabetes, hypertension, and circulatory and respiratory disorders include the use of various portions of the species, *Z. clavaherculis* and *Z. zanthoxyloides.* | [1] |
| 8 | Other regions of Africa | *Z. gilletii* is utilized to cure erectile dysfunction, oral illnesses, and problems with female reproduction, either alone or in combination. | [10] |
| 9 | Kenya | *Z. chalybeum* is used to cure rheumatism by burning ashes from the bark and seeds, while the boiling and consumed components are used to treat malaria, amoebiasis, as well as post-operative pain and other sorts of discomfort. | [11] |
| 10 | Kenya | The stem, leaves, and bark of *Z. usambarense*, *Z. gilletii*, and *Z. chalybeum* Engl. are all used to cure malaria and associated symptoms including fever. | [1] |
| 11 | Cuba | Traditional uses of aerial and bark portions of *Z. elephantiasis, Z. martinicense* and *Z. fagara* include curing toothaches, fever, diarrhoea, and heart conditions. | [12] |
| 12 | China | In China, *Z. acanthopodium* DC. aerial parts have an extensive record of use as contraceptives, painkillers, and parasite control. | [13] |
| 13 | South Africa | For infections of the mouth and respiratory system roots of *Z. capense* are combined with *Callilepis laureola* roots are given orally. | [3] |
| 14 | Zulu (South Africa) | *Z. capense* bark and root decoction can be used to treat tuberculosis. | [1] |
| 15 | Thailand | Infections are treated with *Z. rhetsa*, which is also utilized in food as seasonings and condiments. | [5] |
| 16 | Cameroon and Madagascar | Traditional medicine uses the stem bark of *Z. gilletii* to treat hypertension and other related conditions. | [14] |
| 17 | Madagascar | Traditional treatments for inflammation, skin conditions, microbiological infections, and malaria in Madagascar include the stem bark of *Z. tsihanimposa.* | [15] |

| | | | |
|---|---|---|---|
| 18 | India | Decoction of *Z. armatum* fruits, and bark is used as a stimulant for the digestive system indigestion, treating fever, cholera. To treat cholera, fever, and stomach disorders, a conventional "Honyur" mixture was made using the fruit, seed, and bark of *Z. armatum* by the Indian Nyishi tribe. | [16] |
| 19 | Taiwan | Taiwan's indigenous Ya-Mei and Lanyu tribes employ the bark of *Z. integrifolium* as a traditional medicine for fever, indigestion, and snakebites. | [1] |
| 20 | Paraguay | Antiparasitic medications are made from *Z. chiloperene* var. *angustifolium* Engl. | [17] |
| 21 | Venezuela | Traditional medicine in Venezuela is reported to utilize *Z. monophyllum* as an anaesthetic, to cure jaundice, ophthalmia, runny nose, or inflammation of the nasal mucosa. | [1] |
| 22 | China | Many people use *Z. bungeanum* Maxim. (Syn. *Z. piperitum* Benn.) as a food seasoning and for maintaining skin quality as cosmetics. | [18] |
| 23 | Japan | In addition to being used as spices and food preservers, the leaves, fruits, and bark (*Zanthoxylum* spp.) are also used to cure bacterial and fungal infections. | [19] |
| 24 | Canada and United States | Traditional herbal healers employed *Z. americanum* (Mill.) herbal preparations made from various components to treat tumours, fungus-induced infections of the skin, breathing functions, urinary, vaginal, and gastrointestinal tract illness. | [1] |
| 25 | Pakistan | *Z. armatum* dried fruit is used as a spice. When suffering from cholera and indigestion, people consume a powdered combination of its dried berries, dried *Mentha longifolia* leaves, *Trachyspermum ammi* seeds, and black salt with water. Twigs are used as a toothbrush for toothaches and gum conditions. | [20] |
| 26 | Nepal | Abdominal pain is treated with fruit decoction. Berries are used for rheumatism, skin conditions, and as an antispasmodic and carminative. Asthma, diabetes, and cholera are all treated using bark. Fruit pickles can help with diarrhoea, dysentery, vertigo, headaches, tonsillitis, high altitude sickness, colds and coughs, and tonsillitis. When consumed with hot water, powdered dried fruits can treat stomachaches, dysentery, and diarrhea. | [21] |
| 27 | Indonesia | *Z. bungeanum* stem and root are ingested raw or after being boiled in water to cure respiratory conditions and prevent alcohol intoxication. | [1] |

## Additional alkaloids

Canthin-6-one, bishoderninyl terpene, indolopyridoquinazoline, carbazole, quinazoline, and some other alkaloids are uncommon in the family Rutaceae. However, distinct species within the genus *Zanthoxylum* have these alkaloid identified. For instance, leaves of *Z. integrifoliolum* were used to extract the bishoderninyl terpene alkaloids. Notably, certain species of *Z. integrifoliolum* yield indolopyridoquinazoline alkaloids, including 1-methoxyrutaecarpine, 1-hydroxyrutaecarpine and rutaecarpine, which exhibit significant anti-platelet activity. Only a few genera, including *Zanthoxylum*, contain canthin-6-one alkaloids, which are prized for their leishmanicidal effects which are not typically found in the Rutaceae family. Canthin-6-one alkaloids, such as canthin-6-one, have been isolated from *Z. rugosum*, *Z. chiloperone* and *Z. Budrunga* [2, 5] underscoring their rarity within this botanical family.

## Flavonoids

They are the type of phenolic compound widely distributed throughout various species within the *Zanthoxylum* genus. These compounds can be found in nearly all parts of the plant and play a significant contribution to boosting the antioxidant defense system. The biological activities of flavonoids, which include anti-inflammatory, antioxidant, antithrombotic, antiseptic, antihepatotoxic, cancer-preventing, anti-hypertensive, antiviral, antiallergic, and estrogenic actions, are well documented. Flavanoids in the genus *Zanthoxylum*, are primarily found in the form of glycosides of flavones, flavanols, and flavanones. *Zanthoxylum* flavonoids are characterised by their polymethoxylation, which is also a trait of other genera in the Rutaceae family. 3, 5-diacetyltambuline, a substance with high antiplatelet activity, was discovered on the fruits of *Z. integrifoliolum* [5].

## Amides

Amides play a significant role in the chemical composition of the *Zanthoxylum* genus and are particularly concentrated in the seed pericarp, roots of the plants, fruits, and the stems. Notably, *Zanthoxylum* spp. is distinguished by the abundance of olefinic alkamides, which are unsaturated aliphatic acid amide. These substances are created through a biogenetic process that involves the condensation of isobutyl amines and fatty acids like linolenic and linoleic acids. Isobutyl amides, in terms of their biological activity, exhibit strong insecticidal properties. Throughout history, these alkamides have found medicinal uses, including their recognition as sialogogues, antitussives, and analgesics. Their prevalence within the *Zanthoxylum* genus holds promise for medical applications [1, 4]. The amide produced from *Z. liebmannianum*, β -sanshool, is a prominent example of such a compound. This compound is renowned for having anthelmintic qualities. Additionally, aromatic amides, also known as alkaloids or trans-cinnamoylamides, are another class of amides that are found in the *Zanthoxylum* genus [1, 2].

### Sterols and terpenes

Many plants in the Rutaceae family possess glands that release volatile substances in various parts, including the roots, rhizomes, wood, berries, leaves, stem bark, and seeds. The resulting essential oils are often intricate blends of monoterpenes and sesquiterpenes. Recent studies examined the chemical make-up of essential oils using steam-distillation from *Z. monophyllum*, *Z. rhoifolium* and *Z. fagara* fruit and these oils were evaluated for their antifungal and insecticidal properties. A total of 57 substances were found using gas chromatography-mass spectrometry. Myrcene, phellandrene, and germacrene D were the three primary terpenes present in *Z. rhoifolium*oil. *Z. monophyllum* oil contained significant elements like sabinene (highest) followed by 1,8-cineole and then lastly cis-4-thujanol. In contrast, the main component of *Z. fagara* essential oil was germacrene D-4-ol, which was followed by elemol and β-cadinol. *Z. fagara* displayed the strongest effect against *Colletotrichum acutatum*, while *Z. monophyllum* exhibited remarkable activity against the pathogenic fungus, *Fusarium oxysporum* f.sp. *lycopersici* (a fungal plant pathogen). Isobauerenol terpenes extracted from the stem bark of *Z. heitzii* possess anti-obesity activity, γ-Terpinene isolated from the *Z. armatum* leaves essential oil possess antioxidant activity. The sterols are also found to be abundant in the genus *Zanthoxylum* spp. Stigmasterol isolated from *Z. paracanthum* stem bark possessed antioxidant activities. β-sitostenone extracted from different parts of *Z. bungeanum* has antioxidant and anti-thrombotic activities. Another example is β-sitosterol extacted from different parts of *Z. bungeanum*and leaves of *Z. budrunga* shows anti-thrombotic and antioxidant potential [1, 3].

### Coumarins

Biologically, coumarins have proven to be highly beneficial, with many demonstrating inhibition of bacteria, suppression of tumor growth, and dilation of blood vessels, on coronary vessels, and blood-thinning characteristics. Notably, coumarins generally lack toxic side effects and can be administered over extended periods without issue. Excessive intake, however, can lead to haemorrhages. Angiosperms frequently contain coumarins, although gymnosperms and lower plants do not. Particularly within plant groups like Apiaceae, Rutaceae, Poacea, Asteraceae, Poaceae, and Rubiaceae, they display extraordinary structural variety. All the families that make up the Rutaceae family, a suborder of the Rutales order, are characterized by coumarins. Despite being common in the family, coumarins are only found in the four subfamilies Flindersioideae, Aurantioideae, Toddalioideae, and Rutoideae. One of the most notable genera in the Rutoideae subfamily is *Zanthoxylum*, which is well-known for comprising several different coumarins, such as the simple coumarins e.g., linear coumarins, pyranocoumarins, dihydrofurocoumarins. The relative rarity of angular furanocoumarins among the Rutaceae might be attributed to the reduced frequency of prenyl substitution at C-8 compared to C-6. Larcinatin, a terpenylcoumarin that was isolated from the stems of *Z. shinifolium*, has been shown to have significant inhibitory effect against monoamine oxidase. Auraptene and collinine, two terpenylcoumarins with anti-platelet action and an inhibitory effect on the reproduction of the hepatitis B virus, were extracted from *Z. schinifolium* bark. *Z. americanum* berries contain psoralen and other furanocoumarins that are cytotoxic to human cancer cells [5].

### Ligands

Lignans are widespread in plants and offer diverse biological benefits including antimicrobial, antioxidant, antitumor, antiviral, and enzyme inhibition properties. They can interact with fungi, plants, and insects ecologically, sometimes acting as toxins. These compounds originate from two phenylpropanoid units and their arrangement determines lignan structure. Rutaceae plants exhibit various lignans, with *Zanthoxylum* genus mainly featuring diarylbutirolactones and 2, 6-diaryl-3,7-dioxabicyclooctanes. Furofuranic lignans like syringaresinol are found in *Z. quinduense* and *Z. monophylum.* (+)-Sesamin is isolated from *Z. integrifoliolum*, *Z. culantrillo*, and *Z. naranjillo*, while (-)-cubebin with trypanocidal effects is found in *Z. monophyllum* and *Z. naranjillo*. Ailanthoidol, a nor-neolignan, emerges from *Z. ailanthoides* wood, traditionally used for snake bite and cold treatments in Taiwan [3-5].

## The Biological Activities of *Zanthoxylum* spp. in Therapeutics

Since ancient times, several species within the genus *Zanthoxylum* have been used in many parts of the world, benefiting both people and their cattle. Bark from *Z. liebmannianum* has been used to treat parasites in Mexico. Preference has been given to *Z. rhoifolium* and *Z. acutifolium* from this species for treating malaria [1]. *Z. armatum* berries, seeds, and barks are all components of the conventional "Honyur" mixture used by the Indian Nyishi tribe to treat cholera, fever, and digestive problems, respectively [20]. *Z. chiloperene var. angustifolium* (Engl.) is recognized as a potent anti-parasitic in Paraguay [22]. The indigenous tribes in Taiwan (YaMei and Lanyu) use the bark of *Z. integrifolium* to treat dyspepsia and fever [1]. *Z. rhoifolium* has anticancer and colitis-relieving effects [21] and *Z. monophyllum* is used in Venezuelan medicine to treat ophthalmia and jaundice [1], whereas *Z. zanthoxyloides* roots are used to cure sickle cell anemia [1]. Additionally, *Z. alatum* has been used to treat diabetes, toothaches, and aberrant cell proliferation. Within the *Zanthoxylum* genus, their remarkable chemical diversity and ethnobotanical characteristics have ignited exploration into an array of biological activities. This pursuit has led to the discovery of fresh bioactive extracts and compounds, some with promising potential for novel drug development and diverse industrial applications. The biological landscape of *Zanthoxylum* spp. encompasses a broad spectrum of effects including insights into enzyme inhibition and effects on the central nervous system and blood components. It also includes antibacterial, insecticidal, anti-aging, anti-inflammatory, antiviral, anti-parasitic, antitumor, antihelmitic and antinociceptive activities (Figure 4). This following section categorizes these findings according to their specific biological actions, unveiling the most remarkable outcomes within the *Zanthoxylum* genus.

## Allelopathic activity of *Zanthoxylum* spp.

In a limited pool of research, a fascinating revelation emerges that indicates that *Zanthoxylum* spp. possess a rare allelopathic power. A captivating study focused on *Z. limonella* fruits delved into the ethyl acetate extract, uncovering a game-changing compound named xanthoxyline. Xanthoxyline exerted its power at a startling concentration of 2500 molar, precisely stopping the germination and development of Chinese amaranth seeds. A further twist came in its ability to restrict Barnyardgrass's seed germination by a remarkable 43.59%. This revelation, emerging from the work of [1, 2], highlights a realm of potential where *Zanthoxylum* spp. exert their influence in fascinating ways.

## Analgesic activity of *Zanthoxylum* spp.

In a journey to validate age-old practices, the genus *Zanthoxylum* has taken center stage in pain relief studies. For instance, the intriguing investigation involving *Z. xanthozyloides* that revealed potential for inducing analgesia using the aqueous extract of its root bark. The mechanism behind this phenomenon is believed to be an inhibition of prostaglandin production. Further study revealed that certain isolated and purified alkaloids from *Z. xanthoxyloides* root bark emerged as key players, flaunting their anti-prostaglandin synthetase activity [1].

## Anticonvulsant activity of *Zanthoxylum* spp.

In the realm of anticonvulsant exploration, *Zanthoxylum* spp. have been the subject of limited attention. A recent inquiry set its sights on *Z. capense* leaves, extracting their methanol and aqueous essence to unlock potential anticonvulsant properties. This property can induce seizures by diverse agents like bicuculline, strychnine, pentylenetetrazole, picrotoxin in mice. The study revealed intriguing results as both extracts resulted in significant influence across all five seizure-inducing agents, demonstrating its diverse effects. In certain cases, the extracts delicately delayed seizures, while in others; they assumed the role of agonists. This result offers a unique perspective into the potential role of *Zanthoxylum* spp. in treating convulsions [5].

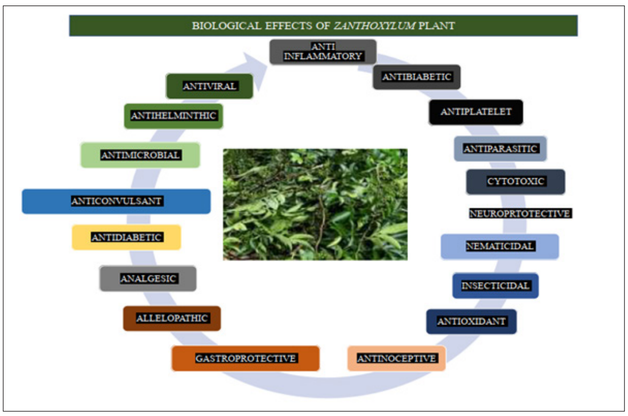


**Figure 4:** Potential applications of *Zanthoxylum* spp.

## Anti-inflammatory effects of *Zanthoxylum* spp.

It has been noted that *Z. armatum* stem and bark has anti-inflammatory properties against edema. Therefore, *Z. armatum* might be helpful in treating symptoms of inflammation and pain. High performance liquid chromatography analysis of the plant's stem and root extracts revealed the presence of eight lignans, including sesamin, kobusin, fargesineudesmin, horsfieldin, asarinin, planispine A, and pinoresinol-di-3,3-dimethylallyl. These lignans may be responsible for this curative property. In numerous studies, the acetate, hexane and ethanolic leaf extracts of *Z. chiloperone*, as well as the ethanolic bark extracts of *Z. elephantiasis, Z. fagara Z. martinicense* and *Z. coriaceum* have all shown good results of anti-inflammatory action in diverse studies [1, 2]. Additional research has uncovered secondary metabolites with potential anti-inflammatory properties. Extract of *Z. naranjillo* in hexane produced dibenzylbutirolactonic lignan, which has anti-inflammatory properties. Coumarins, lignans, benzophenanthridine alkaloids, and quinolone alkaloids are found in *Z. nitidum* stem wood after being extracted in methanol and showed promising anti-inflammatory effects. The methanolic extracts of stem wood from *Z. avicennae* and Z. *integrifoliolum* were found to contain quinolone alkaloids, phenylpropenoids, lignans, coumarins, and quinoline alkaloids with anti-inflammatory potential. A notable compound that has garnered significant interest from medical professionals, pharmaceutical experts, and researchers worldwide is lupeol, a dietary triterpene. This widely distributed compound, present in various *Zanthoxylum* spp., has been extensively studied for its ability to inhibit inflammation, which has been demonstrated in both laboratory-based and living organism-based models of inflammation [1].

## Antimicrobial effects of *Zanthoxylum* spp.

Analysing the *Zanthoxylum* spp. potential as an antibiotic is the focus of most investigations on its biological capabilities. Antifungal and antibacterial of Z. *tessmannii* was evaluated against different microbial strains including *Bacillus subtilis*, *Chlorella vulgaris*, *Escherichia coli*, *Staphylococcus aureus*, *Streptomyces viridochromogenes*, *Rhizomucor miehei*, *Candida albicans*, *Scenedesmus subspicatus* and *Chlorella sorokiniana* 2,6-dimethoxy-1,4-benzoquinone shows effectiveness against seven out of nine infections, whereas 3'-acetoxy-16'-hydroxybetulinic acid performed very poorly against hay *Bacillus* and *E. coli*. Similar results were seen when 3, 16-hydroxybetulinic acid was tested against *C. albicans* and *B. subtilis*. When examining *Z. armatum*, researchers investigated the extract from its fruits for its antibacterial potential against different microorganisms, such as *Pseudomonas aeruginosa*, *Shigella boydi*, *S. aureus*, and *E. coli*. The ethanolic extract of the berries did not show any activity against *P. aeruginosa*, however exhibited positive effects against the other three strains. These findings suggest that the *Z. armatum* fruit ethanolic extract may possess broad-spectrum antibacterial action as it exhibits activity against both Gram-positive and Gram-negative bacteria. In another study, *Z. chalybeum* and *Z. usambarense* leaves, roots, and stem bark extracts (water, hexane, and methanol) were tested for *in vi-*

*tro* antibacterial properties against Gram-positive bacteria *B. subtilis*, *Micrococcus luteus*, and *S. aureus*. The two *Zanthoxylum* species root and stem-bark extracts exhibited strong antibacterial activity. The antifungal potential of *Z. americanum* was probed through assessments involving extracts from its leaves, fruits, stems, bark, and roots against 11 strains of fungi. A comprehensive scrutiny encompassed 11 fungal strains. The fruit and leaf extracts were generally the most active among the extracts, which all showed a wide range of antifungal activity and inhibited at least eight different fungus species. These results provide a rationale for the widespread use of *Z. americanum* by the indigenous people in North America as ethnomedicine, particularly for conditions that could be related to fungi [9].

## Antihelminthic properties of *Zanthoxylum* spp.

Research focusing on antihelminthic properties has primarily concentrated on the *Z. xanthoxyloides* species. Recent investigations have illuminated this avenue, with two separate studies highlighting the potential of ethanol and acetone-water (70:30) extracts extracted from *Z. xanthoxyloides* leaves. These extracts displayed promising efficacy against three nematode pests *viz. Ascaris lumbricoides, Haemonchus contortus*, and *Trichostrongylus colubriformis*. These nematodes are notorious for inducing production losses, triggering clinical symptoms, and even precipitating fatal outcomes in sheep and goats globally. The species, *Z. xanthoxyloides* has the capacity to potentially combat these harmful nematodes, fostering a promising avenue of antihelminthic research [20].

## Antiviral properties of *Zanthoxylum* spp.

*Zanthoxylum* spp. took the center stage in experiments targeting the inhibition epidemic diarrhea virus (porcine) multiplication. Extracts from distinct *Zanthoxylum* sources, including *Z. planispinum* leaf and stem, *Z. coreanum* root and *Z. schinifolium* leaf, were brought under scrutiny. Impressively, these extracts displayed notable antiviral activity, against porcine epidemic virus. Regarding HIV viruses, three *Zanthoxylum* spp. assumed prominence in an anti-HIV screening initiative, this included the *Z. ailanthoides* root bark, *Z. integrifoliolum* root wood, and *Z. scandens* stem bark. Demonstrating anti-HIV activity, these species raised significant interest. Within the anti-HIV spectrum, *Z. ailanthoides* harboured key principles in the form of decarine and fagarine (an alkaloid) and an aromatic amide (+)-tembamide. Remarkably, this insight extended to *Z. integrifoliolum* as well, where the constituents decarine and fagarine were isolated. As a result, these elements become the key anti-HIV agents in *Z. integrifoliolum* root wood, illuminating a fascinating story of therapeutic promise [1, 5].

## Antiplatelet properties of *Zanthoxylum* spp.

Utilizing the turbidimetric technique, potent antiplatelet potential was unveiled in the *Z. beecheyanum* stem methanolic extract. Employing washed rabbit platelets *in vitro*, notable antiplatelet activity was reported. In response to various stimuli including arachidonic acid (100 M), thrombin (0.1 U/ml), collagen (100 g/ml), and PAF (2 ng/ml), aggregation rates ranged around 90-95% [5].

## Antiparasitic properties of *Zanthoxylum* spp.

In the pursuit of novel actions against parasitic diseases, there is a significant focus on assessing the potential antimalarial, trypanocidal, and antileishmanial effects of frequently employed traditional remedies. Exploring the antimalarial potential of widely utilized plant species offers valuable insights for identifying candidates suitable for comprehensive pharmacological, toxicological, and phytochemical investigations. Notably, compounds such as sesquiterpene lactones, alkaloids, coumarins, triterpenoids, and limonoids have exhibited significant antimalarial activity. Among the intriguing species within the *Zanthoxylum* genus that have shown promise in this regard are *Z. chalybeum, Z. limonella, Z.rhoifolium Z. zanthoxyloides, Z. gilletii*, *Z. syncarpum* and *Z. usambarense*. Strong anti-plasmodial action was shown by root bark extracts of *Z. chalybeum* and certain quinoline alkaloids derived *Z. chalybeum* displayed substantial antiplasmodial action against the protozoan parasite, *Plasmodium falciparum* [1]. Syncarpamide and decarine, two chemicals extracted from *Z. syncarpum*, have significant *in vitro* anti-plasmodial activity against *P. falciparum* strains. *In vitro P. falciparum* growth was inhibited by fagaronine, a benzophenanthridine alkaloid synthesized from *Z. zanthoxyloides* root extract. The ethanolic extract made from *Z. guilletti* stem bark and the chloroform extract made from *Z. limonella* fruits have also been shown to have positive results in terms of antimalarial potential [1].

## Cytotoxic potential of *Zanthoxylum* spp.

The search for a cure is the most important human effort since cancer continues to be the leading cause of death worldwide. Natural substances have long been investigated as potential treatments and preventatives for cancers [1]. Due to the existence of numerous compounds from *Zanthoxylum* spp. that have showed powerful cytotoxic effects against several types of cancer cells, these species are thought to be prospective repositories for the discovery of new anti-tumor medicines. In laboratory tests and an animal model employing Ehrlich ascites tumors, the study examined the possible anti-tumor effects of the essential oil generated from *Z. rhoifolium* leaves and specific terpenes. While α humulene, β pinene, and α pinene did not demonstrate any direct action against Ehrlich tumor cells *in vitro*, the volatile oil and β caryophyllene did. The presence of caryophyllene and the potential synergy with other natural chemicals found in the essential oil from *Z. rhoifolium* leaves may also be responsible for the volatile oil's *in vivo* anti-tumor effects and significant immunomodulatory effects [6]. Cytotoxic properties of the essential oil isolated/extracted from the leaves of *Z. rhoifolium* were the subject of another investigation. According to the study, the essential oil had cytotoxic effects on malignant cells, with CD50 values of 82.3 g/ml for the human lung carcinoma A-549, 90.7 g/ml for the human cervical carcinoma HeLa, and 113.6 g/ml for the human colon cancer HT-29 cell lines. It is significant that it exhibited no cytotoxicity towards non-cancerous cells, such as Vero cells and mouse macrophages. The essential oil isolated from *Z. rhoifolium* leaves thus appears to hold promise as a potential therapeutic agent due to its specific cytotoxicity against malignant cell lines [6].

In the *Zanthoxylum* genus, a series of secondary metabolites called benzophenanthridine alkaloids are well known for their powerful anti-tumor activities. Fagaronine and nitidine stand out as highly efficient among these alkaloids. The cytotoxic effect of hexahydrobenzophenanthridine alkaloids makes them interesting as well. Chelidonine, one of these alkaloids, is now the main ingredient of Ukrain®, an investigational anti-cancer drug used in oncology research [1]. *Z. monophyllum* bark contains the alkaloid berberine, which has been shown to be effective against several cancer cell lines, including the HT29 cell line (colorectal cancer), MCF-7 cell line (breast cancer), HEp-2 cell line (larynx cancer), and MKN-45 cell line (gastric cancer) cell lines. In addition, two benzophenanthridine alkaloids, 6-methoxy-5, 6-dihydronitidine and nitidine chloride, were found to have anti-tumor potential when tested against different human cell lines. Berberine, an alkaloid obtained from the bark of *Z. monophyllum*, has demonstrated effectiveness against various cancer cell lines, including HT29 (colorectal cancer), MKN-45 (gastric cancer), MCF-7 (breast cancer) and HEp-2 (larynx cancer) [5].

## Antinociceptive potential of *Zanthoxylum* spp.

Researchers have dug into studies on antinociceptive activity to help further our knowledge of the pharmacological characteristics of the *Zanthoxylum* genus and support the traditional use of some species as painkillers. Using animal models pain for acute discomfort caused by chemicals, extracts from the leaves of *Z. chilipirone*, including ethyl acetate, hexane, and ethanol extracts from the stem bark of *Z. rhoifolium*, as well as its partitioned fractions, and the compound lupeol, were examined. At dosages of 100 mg/kg and 200 mg/kg for every extraction, results of the *Z. chilipirone* analysis showed significant decreases in paw licking, indicating an existence of possibly antinociceptive elements in the *Z. chilipirone* extracts [1].

## Antioxidant properties of *Zanthoxylum* spp.

More than ten methods have been employed to assess the antioxidant potential of compounds derived from *Zanthoxylum* genus species, the majority of which revolve around quantifying their capacity for scavenging free radicals. Among these methodologies, several are notably prevalent, including: 1) Total phenolic content determination; 2) Evaluation of radical DPPH scavenging performance; 3) Evaluation of the radical scavenging power of ABTS; 4) evaluation of scavenging effectiveness for superoxide anion. Most of the research on the antioxidant properties of *Zanthoxylum* spp. has focused on extractions from fruits and seeds. Investigations, for instance, have examined the volatile oils obtained from *Z. bungeanum* seeds, the ethanol extract made from *Z. alatum* berries, as well as extraction made from *Z. piperitum* fruits utilizing solvents such methanol, hexane, ethyl acetate, and ethyl ether. Additionally, the effectiveness of antioxidants has been demonstrated in *Z. achanthopodium* fruit extracts employing solvents such as acetone, hexane, and ethanol demonstrating very attractive antioxidant capability.

## Gastroprotective potential of *Zanthoxylum* spp.

Essential oils of *Z. rhoifolium* Lam. stem bark inhibits the development of stomach ulcer by boosting the activity of enzymes such as catalase, which lowers oxidative stress, as well increase the mucous secretion and nitric oxide, which heals damage of the gastrointestinal tract *Z. rhoifolium* extracts also aids in activating the KATP channel to regulate the $H^+$ pump and acid secretion [5].

## Neuroprotective potential of *Zanthoxylum* spp.

Three alkaloids columbamine, berberine and chelerythrine, were produced by *Z. schreberi* chloroform extraction acts as cholinesterase and butyrylcholinesterase suppression, an enzymes responsible for Ach (acetyl choline) breakdown. Blocking of these enzymes helps in spike of nerve transmitters which is helpful for the people suffering from Alzheimer's disease. *Z. bungeanum* extraction can act as a antidepressant and helps people dealing with Alzheimer's disease [2].

## Cardiovascular potential of *Zanthoxylum* spp.

The *Z. bungeanum* essential oil assisted in the relaxing of constricted aortic muscles by lowering the inflow of calcium through calcium channels**.** *Z. bungeanum* essential oil also had substantial impact on the reduction of triglycerides, glycerol. *Z. armatum* fruits also shows efficacy for heart diseases protection [3].

## Antidiabetic potential of *Zanthoxylum* spp.

The *Zanthoxylum* spp. has been used since ancient times to combat diabetes. In a rat oral glucose tolerance test, an aqueous extract of *Z. chalybeum* stem bark normalised the rats blood sugar levels. The experimental results of *Z. chalybeum* and *Z. armatum* bark aqueous-alcohol extract have also demonstrated a promising anti-diabetic efficacy [3].

## Nematicidal potential of *Zanthoxylum* spp.

Few studies have been conducted in order to check the efficacy of *Zanthoxylum* spp. extracts for controlling nematode pests. A study revealed that more than 90% of the nematode, *Bursaphelenchus xylophilus* was killed by the essential oils of *Z. armatum* fruit at a 5 mg/ml dosage and its constituents such as ethyl trans cinnamate, methyl trans cinnamate also demonstrated 100% effectiveness. *Z. armatum* leaves decreased the hatching ability of *Meloidogyne incognita*. When applied directly to the soil, the leaves of *Z. armatum* also function as a nematicide against *M. incognita* [1, 2].

## Insecticidal potential of *Zanthoxylum* spp.

The *Zanthoxylum* spp. extracts may act as a larvicidal, adulticidal, ovicidal, repellent or food deterrent or even as fumigant toxicity (Figure 5). The bark of *Z. usambarense* when extracted with di-chloromethane exhibited insecticidal effects against *Musca domestica* at a concentration of 5000 g/ha. However, the individual components of this extract did not demonstrate any insecticidal activity. The *Z. armatum* bark essential oil (EO) consists of β-mycrene, sabinene, D-germacrene, γ-elemene. The larvicidal potential of EO and its components from *Z. armatum* seeds were tested against three mosquito species, including *Aedes aegypti, Anopheles stephensi*, and *Culex quinquefasciatus*, *C. quinquefasciatus*, outperformed the other two species in terms of sensitivity, with $LC_{50}$ and $LC_{95}$ values of just 49 and 146 ppm. Linalool, the main component that makes up 57% of the essential oil, did not exhibit significant larvicidal properties when evaluated on its own. Combinations of *Calophyllum inophyllum* nut oil with *Z. armatum* seed oil along with its constituents, either as a single compound or as a binary mixture, showed potential as insect repellents against *Stomoxys calcitrans* (stable fly) [23].

In another study, three bioactive chemicals from *Z. armatum* seed oil - piperitone, myrtanol, and citronellal were tested for their fumigant toxicity against stable flies, while also being compared to the organophosphorus insecticides dichlorvos and chlorpyrifos. According to the results of the vapor phase experiment (fumigant test), the vapor toxicity capability of *Z. armatum* seeds extract or oil and its three constituents showed a high $LC_{50}$ value ranging from 0.242 to 0.456 g/cm$^3$. However, compared to organophosphorus pesticides, their degree of toxicity was substantially lower by a factor of five. This suggests that *Z. armatum* has the potential to be a bio-insecticide. Furthermore, it has been reported that the stable fly canbe significantly repelled by a number of the EO constituents, including linalool, linalool oxide, cuminaldehyde, citronellal, neral, terpinen-4-ol, 1,8-cineole, and piperitone . The ethanol extract of *Z. armatum* bark proved effective against *Lipaphis erysimi* (mustard aphid) *in vitro* at different doses. Notably, 100% aphid death was attained after one day of spraying at a concentration of 2.0 mg/L, demonstrating the efficacy of *Z. armatum* as an insecticide.

At the amount of 1-5%, *Z. rhoifolium* essential oil nanoencapsulated from leaves showed effective reduction in the amount of *Bemisia tabaci* (white fly) nymphs and eggs. Limonene 1,8-cineole and piperitone, were three of the 32 components found in the ethanol extract of *Z. armatum* twigs that had substantial insecticidal action on cigarette bettle, *Lasioderma serricorne* and red flour beetle, *Tribolium castaneum* [24]. Another study examined the antifeedant potential/efficacy of *Z. armatum* methanolic leaves extraction on the adult stage of *T. castaneum* [1]. The impacts of ethanol extract, n-hexane and methanol extract derived from *Z. armatum* leaves on diamondback moth scientifically known as the *Plutella xylostella* were examined in a different study [25]. The investigation found that the n-hexane fraction had the strongest larvicidal effect.

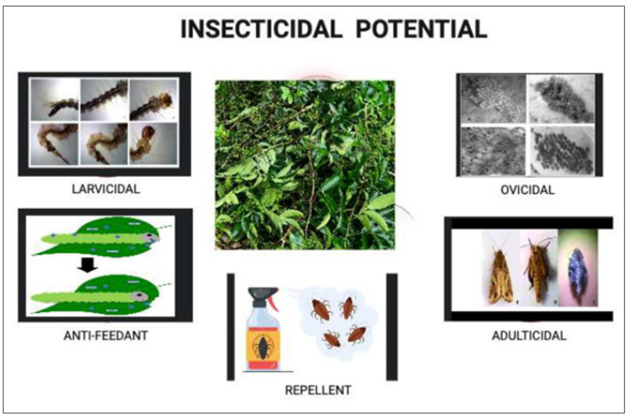


**Figure 5:** Insecticidal potential of *Zanthoxylum* spp.

The n-hexane portion of the *Z. armatum* leaf extract also contained two distinct chemicals, 2-undecanone and 2-tridecanone, which were discovered using gas chromatography-mass spectrometry analysis and may have contributed to the larvicidal activity seen [1]. Additionally, using the oil extracts from *Z. rhoifolium* and *Z. riedelianum* at dosages ranging from 1.0-2.0% greatly decreased (85-98%) the egg-laying ability of *B. tabaci*, a serious pest for tomatoes and other vegetables [5]. Several researchers have conducted studies on *Z. armatum* since it has been found to have insecticidal effects on agricultural pests. Many extracts from the fruit pericarp and leaves of *Z. armatum*, including n-hexane, methanol, ethyl acetate, and aqueous extracts, were found to be toxic to the oriental leaf worms (*Spodoptera litura*) both orally and through contact [4]. Results demonstrated that these extracts promoted pest mortality, with an $LC_{50}$ range of 0.179% to 5.97%. Table 3 enlisted the literature on the insecticidal potential of *Zanthoxylum* spp. between 2019 and 2023.

## *Zanthoxylum* spp. utilized as a seasoning agent in food

The *Zanthoxylum* genus includes the Sichuan pepper (*Z. piperatum*), which is well-known for its acrid scent and numbing flavor which is used a spice throughout the world [39]. Five *Zanthoxylum* species, *Z. armatum, Z. bungeanum, Z. simulans*, *Z. shinifolium,* and *Z. piperitum* are classified as "spice". In addition to the seeds, the plant fruits, leaves, and the bark, as well as the root are all used as spices in China, Japan, and Korea. It is famously used in China to produce the peculiar "Mala" flavor, which is characterised by numbness and spice. This genus is well known for having more than 100 volatile chemicals that give it its distinct spicy flavor and scent Non-volatile substances like alkylamides (like sanshools and capsaicin) and polyphenolic substances have also been discovered in addition to these. *Zanthoxylum* spp. has established a place in cosmetics, medicines, and culinary applications, such as the production of "five spice powder". The enormous array of scents that the *Zanthoxylum* genus offers, such as sweet, minty, herbal, floral, fruity, rosy, and citrus scents, is important to the cosmetics sector and has significant implications in the cosmetics industry. Spices from this species are known for their strong flavor, which is due to the presence of chemicals including β sanshool, β-, γ-δ and hydroxyl α [39].

From a pharmacological standpoint, Sichuan pepper has antioxidant and anti-inflammatory activities due to its content of polyphenolic components including flavonoids and glycosides. The essential oil from the *Z. bungeanum* fruit has antibacterial properties that are effective against bacteria of all kinds [40]. The synthesis of heterocyclic amines, which are recognized human carcinogens, during the grilling of beef, has been particularly inhibited by Sichuan pepper and its ingredient sanshool amide. The existing literature on the knowledge of spices from the genus lacks the utilization of analytical techniques for comparative component analysis. Furthermore, providing detailed insights into the impact of heat during the cooking process on both the spice as a whole and its individual compounds would greatly benefit the world of herbs and spices [40].

# Conclusion

Based on references from the previous ten years, the *Zanthoxylum* genus represents a treasure trove of medicinal flora overflowing with the potential in therapeutics, modern science, and agriculture. This compendium of knowledge, encompassing both traditional wisdom and contemporary insights, offers readers a wealth of information concerning the herbal attributes of numerous *Zanthoxylum* spp., including but not limited to *Z. liebmannianum, Z. armatum, Z. acanthopodium, Z. acutifolium, Z. ailanthoides, Z. bungeanum, Z. chalybeum, Z.chiloperone, Z. coreanum, Z. elephantiasis, Z. fagara, Z. flavum, Z. heitzii, Z. integrifoliolum, Z. zanthoxyloides, Z. leprieurii, Z. limonella, Z. martinicense, Z. monophyllum, Z. piperitum, Z. planispinum, Z. rhoifolium, Z. riedelianum, Z. scandens, Z. schinifolium, Z. schreberi, Z. tingoassuiba, and Z. usambarense*. This extensive reservoir of knowledge has the potential to ser-

**Table 3:** Literature on the insecticidal potential of *Zanthoxylum* spp. between 2019-2023.

| Year | Species | Pests | Results | Ref. |
|---|---|---|---|---|
| 2023 (January) | *Z. myriacanthum* Wall. ex Hook (Fruits) | *T. castaneum* (red flour beetle) *Lasioderma serricorne* (Cigarette beetle) and *Liposcelis bostrychophila* (book lice) | The purpose of this study was to assess the effectiveness of *Z. myriacanthum* Wall. ex Hook fruit extracts against three types of insect pests (*T. castaneum*, *L. serricorne*, and *L. bostrychophila*). The bioassays revealed that the EOs and significant chemicals were toxic to all the three insects. | [26] |
| 2023 (March) | Citrus oil, *Z. piasezkii* Maxi, *Z. bungeanum* Maxim., *Citrus maxima* and orange leaf oil (Fruits) | *Thrips flavus* (Thrips) | The outcomes demonstrated that under controlled circumstances, orange leaf oil, *Zanthoxylum* oil, and pomelo peel oil all exhibited insecticidal effects. They can be used against *T. flavus* as efficient, low-toxicity botanical insecticides and synergistic agents. | [27] |
| 2023 (June) | *Z. armatum* DC (Fruit) | *L. erysimi* (mustard aphid) and *M. incognita* (root knot nematode) | The study's goal was to evaluate the insecticidal as well as the nematicidal properties of the EO made from *Z. armatum* fruits that were gathered in the Pithoragarh villages of Chandak and Gumma. It was discovered that *Z. armatum* from Dharchula exhibited increased *M. incognita* mortality and inhibited the egg-hatching. As seen by their respective $LC_{50}$ values of 0.006 and 0.165 L/ml after 36 hours, the sample from Dharchula had stronger activity when evaluated for insecticidal activity against *L. erysimi.* | [28] |
| 2022 (July) | *Z. armatum* (Fruit) | *Spodoptera frugiperda* (Fall army worm) and *Tuta absoluta* (pin worm) | The *Z. armatum* fruit extract showed 100% ovicidal activity against the test insects sat a dosage of 22.0 ml/L. | [29] |
| 2023 (April) | *Z. myriacanthum* (Fruit) | *Tetranychus urticae and Tetranychus truncates* (spider mite) | Dried fruit extracts from *Z. myriacanthum* may be used as acaricides for pest management programmes and may be able to control *T. urticae* and *T. truncatus.* | [30] |
| 2022 (March) | *Z. rhoifolium* (Fruit) | *B. tabaci* (white fly) | The outcomes show that the insecticidal potential of EO made from *Z. rhoifolium* fruits with extra formulation as nanospheres provides greater photostability and enhanced effectiveness as an insecticide against *B. tabaci* under difficult environmental circumstances. | [31] |
| 2022 (October) | *Z. riedelianu* (Leaves) | *B. tabaci* (white fly) | In bioassays employing crude and nanoencapsulated essential oils, the number of *B. tabaci* nymphs and eggs was significantly reduced, with the highest results showing at concentrations of 5 and 2%. | [32] |
| 2021 (June) | *Z. zanthoxyloides* (Rootbark) | *Callosobruchus maculatus* (Fab.) (pulse beetle) | According to the results of the toxicity test, n-hexane at concentrations of 1%, 2%, and 3%, acetone extract at concentrations of 3%, and crude powder at 1.5 g all had the same impact on the pest as the positive control, succeeding 100% mortality at 24 hours following treatment. The findings demonstrate that the most effective components as an insecticide against *C. maculatus* are found in n-hexane extract. | [33] |
| 2021 (March) | *Artemisia maritima* L. and *Z. armatum* (Leaves) | *Plodia interpunctella* (codling moth) | Both plant species EO possess insecticidal properties at different concentrations. | [34] |

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| 2020 (December) | *Z. limonella* (Seeds) | *T. castaneum* (red flour beetle) | Insecticidal activity showed that 10% of EO at 14 days obtained 100% mortality against *T. castaneum* eggs, whereas 5% of EO at 120 hours had the maximum effect against *T. castaneum* adults and 48 hours for larvae. The EO of *Z. limonella* from dried seeds appeared to have insecticidal potential in the management of *T. castaneum*. | [33] |
| 2020 (August) | *Z. caribaeum* (EO) | *Dysdercus peruvianus* (cotton stainer bug) | The antennae, wings, and legs of nymphs were discovered to be distorted. | [35] |
| 2020 (January) | *Z. dimorphophyllum spinifolium* (Stem bark) | *T. castaneum* (red flour beetle) | In comparison to the positive control, compounds toosendanin, pellopterin demonstrated increased feeding deterrent activity ($EC_{50}$=64.00 ppm). | [36, 37] |
| 2019 (June) | *Z. planispinum var. Dintanensis* (Leaves and fruit pericarp) | *T. castaneum*, *L. serricorne* and *L. bostrychophila* adults | According to test results, the three chosen target insects were effectively repelled and killed by terpinen-4-ol, linalool, EFP, and 2-dodecanone. | [38] |
| 2019 (April) | *Z. armatum* DC (Fruits and leaves) | *Pieris brassicae* (cabbage butterfly) | The $LC_{50}$ values for the pericarp and leaf extracts were recorded at 0.15% and 0.22%, respectively, after a period of 72 hours. The extracts obtained from both the pericarp and leaves displayed contact toxicity when applied to caterpillars. The pericarp extracts proved to be 1.50 times more toxic than azadirachtin 0.15 EC when utilized as a reference substance in terms of relative toxicity. The caterpillar developmental time was lengthened when exposed to sub-lethal quantities of these extracts, and the percentage of the pupation and emergence of adults in the treated caterpillars was significantly affected. | [4] |
| 2019 (May) | *Rabdosia rugosa*, *Artemisia maritima (L.)*, and *Colebrookea oppositifolia*, *Z. armatum* (DC) (Leaves) | *T. castaneum* (red flour beetle) *Sitophilus oryzae (L.)* (rice weevil), *Stegobium paniceum (L.)* (drug store beetle) and *Plodia interpunctella* (codling moth) | The results of the current study indicate that, among the plants examined as the future insecticide, *R. rugosa* and *Z. armatum*, followed by *A. maritima* and *C. oppositifolia*, demonstrated the highest level of effectiveness in their ability to repel all the tested insect pests. | [39] |

ve as a foundational resource for future research endeavours, including the development of novel drug formulations, the conservation of medicinal plant species, the exploration of pharmacokinetics, and the discovery of innovative plant-based pharmaceuticals for applications in different fields of studies.

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## Conflict of Interest

The authors have declared no conflict of interest regarding this manuscript.

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