JOURNAL OF NATURAL REMEDIES
DOI: 10.18311/jnr/2025/47861
REVIEW ARTICLE

An Updated Review on Traditional and Modern Application of Himalayan *Zanthoxylum armatum* with its Pharmacological Significance

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Abstract

The Himalayan region is a hotspot for a variety of herbal or medicinal plants that meet the dietary and medicinal needs of the indigenous tribes of the Himalayas. The Himalayan region is also home to *Zanthoxylum armatum*, also referred to as the Himalayan pepper, a plant with important medicinal and economic value. It has historically been widely used in traditional medical systems to treat a wide range of illnesses, such as fever, toothaches, digestive issues, and as a general tonic. The bioactive components of the plant such as alkaloids, flavonoids, phenols, terpenes, saponins, lignins, phytosterols, and tannins especially the essential oils like linalool, limonene lignan and alkaloids, have been recognized for their analgesic, antibacterial, anti-inflammator, Antioxidant, anthelmintic, and spasmolytic qualities. Because of its bioactive nature, *Z. armatum* has drawn interest in modern applications due to its potential in the pharmaceutical, nutraceutical, and cosmetic industries. Recent studies have concentrated on the plants potential as an antioxidant, antibacterial, and anti-cancer agent, providing fresh perspectives on its wider range of therapeutic applications. This review seeks to integrate scientific research from the present with traditional applications, highlighting the plants growing role in. The diverse range of bioactive compounds in *Z. armatum* makes it a potential candidate for drug discovery. *Zanthoxylum armatum* exhibits significant therapeutic potential due to its rich profile of bioactive compounds with antioxidant, antibacterial, and anti-inflammatory properties. Its traditional uses, combined with emerging scientific evidence, position it as a promising candidate for pharmaceutical, nutraceutical, and cosmetic applications. However, realizing this potential will require significant investment in research and development, including clinical trials and sustainable cultivation methods.

Keywords: Antioxidant, Antibacterial, Himalayan pepper, Nutraceutical, Toothaches

1. Introduction

The Northern Indian Himalayan region is abundant in medicinal plants, despite its harsh climate and brief growing season. The Indian Trans-Himalayan mountain range supports a sparse plant cover. This area hosts over 8,000 species of flowering plants (*angiosperms*), 44 species of cone-bearing plants (*gymnosperms*), and 600 species of ferns and their relatives (*pteridophytes*). Notably, 1,748 of these plant species are valued for their medicinal propertiesdevelopment of modern healthcare systems and our everyday lives are deeply reliant on plants[1]. For thousands of years, plants have been the foundation of traditional medicine. Even today, they continue to offer new treatments for humanity. Phytochemicals are bioactive compounds produced by plants that offer health benefits. They help protect plants from diseases and environmental damage. These compounds contribute to the development of color, flavor, and aroma in plants. In general, phytochemicals safeguard plants from various physical challenges such as UV radiation, insect infestations, pollution, and both biotic and abiotic stresses, including drought, among them *Z. armatum*, belonging to the *Rutaceae* family, is considered a highly valuable medicinal plant due to its significant therapeutic properties[2,3]. *Z. armatum*,

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Article Received on: 19.12.2024 Revised on: 09.06.2025 Accepted on: 24.06.2025

also known as Indian Prickly ash, Nepal Pepper, or the Toothache tree, is widely distributed across India, from Kashmir to Bhutan, at elevations of up to 2,500 meters. It is also found in the Himalayan regions of Northeastern India and extends to regions in China, Taiwan, Nepal, Philippines, Malaysia, Pakistan, and Japan at altitudes ranging from 1,300 to 1,500 meters. The species typically grows in valleys, mountain thickets, wastelands, and the understory of mixed forests[4,5].

This plant is either a small tree or a large, spiny shrub. Its leaves are notably trifoliate, with a winged petiole. The leaflets are sessile, measuring between 2.0-7.5 cm in length and 1.0-1.7 cm in width, and are elliptic to ovate in shape, with edges that are either smooth or slightly toothed, and a pointed tip. The base may sometimes be oblique. Tiny yellow flowers emerge from the leaf axils. These flowers feature 6-8 sharp sepals, but lack petals. Male flowers contain 68 stamens and prominent anthers, giving them a yellow appearance. Female flowers possess a 1-3 celled ovary that is pale red, splitting in two when mature. The seeds are round, about 3 mm in diameter, and have a glossy black surface. This plant thrives in the subtropical climate of the lower warm valleys of the Himalayas, provided there is sufficient rainfall. The plant flowers between March and April[6]. A detailed taxonomical profile is provided below in Table 1.

Zanthoxylum armatum may grow in both shaded and sunny areas and does best in moist, well-drained soil. Usually, older branches are where its flowers are found[7]. Unripe seeds can be stored, but if they are ripe, they should be kept in a cool environment for 3 months[8]. The growth period lasts around 6 months, and the seeds can take another 12 months to develop. When the seeds are large enough to handle readily, they can be carefully taken from the soil. When the wood is half-ripe, it is ready for cutting. The roots should grow to around 3 cm before being clipped to help the plant produce properly. Any excess grass or wood should be removed before planting the plant in its permanent location to grow appropriately[9].

Table1. Taxonomy of *Z. armatum*

Kingdom	*Plante*
Class	*Angiosperms*
Order	*Sapindales*
Family	*Rutaceae*
Genus	*Zanthoxylum*
Species	*Z. armatum*



Figure1. *Z. armatum* plant with fruits.

Zanthoxylum armatum is a member of the family *Rutaceae*. It's a little spiky tree or shrub with a strong scent. At elevations of 1000 to 1200 meters, it grows in Jammu and Kashmir and Himalayan region at 1200 meters, it flourishes in Orissa and Andhra Pradesh. Many regions of the world, including Eastern and Southeast Asia, including India, Bangladesh, Bhutan, Vietnam, Cambodia, Thailand, and Malaysia, are home to this plant. In addition, it is found in regions of Africa such as Ethiopia and Zimbabwe, as well as Brazil, Argentina, and Puerto Rico. These are thorny plant of this kind all over the world that are either dioecious (male and female) or monoecious (having both male and female parts on the same plant). *Z. armatum* is found in roughly 13 species in India, and it thrives best in tropical and warm climates. This plant is primarily found in areas of Assam, Manipur, Meghalaya and Nagaland. It typically grows in areas with mountains, valleys, and forests[10].

2. Traditional Uses

The bark, fruits, and seeds of *Z. armatum* are widely utilized in traditional medicine for their carminative, stomachic, and anthelmintic properties. The fruit

Table 2. The traditional uses of *Z. armatum* in different countries

S. No.	Country	Plant Part	Traditional Use	Reference
1	India	Seeds, bark and aerial parts	Fever, dyspepsia cholera and insecticidal	12
2	Japan	Seeds	GIT problems and depression.	13
3	Nepal	Fruit, berries, bark, and fruits	Decoction is used for abdominal pain (Fruit), carminative, antispasmodic, anti-rheumatic and skin diseases (Berries), Cholera, diabetes and asthma (Bark), pickles are useful for cold and cough, tonsillitis, high, limbs numbness, vertigo or dizziness. Dried powdered decoction against diarrhoea, dysentery and stomachache (Fruit).	15
4	Pakistan	Fruit	Spice and condiment. Powder of its dried fruit along with *Mentha longifolia* dried leaves, *Trachyspermum ammi* seeds and black salt is taken with water during cholera and indigestion. Twigs are used as toothbrushes during gum problems and toothache.	13,16
5	China	Aerial plant	Infusions in vinegar are used to expel bugs or worms infecting the ear. Scabies are treated by the plant, using a lotion applied to the skin.	17
6	Malaysia, Thailand	Branches and stems	Stomach tonic, to treat snake bites	18

and seeds are also used as an aromatic tonic to treat fever and indigestion[11]. The plant is also used as an insect repellent. In North America, people crush the bark and apply it to their gums for pain relief, which is why it is called the "toothache tree". In China and India, it is also used as a remedy for snake bites. In China, the dried fruits are sold in the market. These small red fruits contain black, shiny seeds that are spicy and slightly bitter, and they are about 3.1 mm in size[12,13]. The young shoots of the Timur plant are used as natural toothbrushes. Recently, people have also started using a powder made from dried Timur fruit to clean their teeth. For common stomach problems, Timur soup is used as a remedy. The plant holds significant medicinal and culinary value. The dried fruits and seeds of *Z. armatum* are commonly used as a spice due to their strong aroma and flavor, often added to curries, pickles, and condiments The Bhotiya community also makes liquor from Timur, but it is only enjoyed by those who are very used to drinking it. Most people in the community believe the Timur tree has religious importance and magical powers its leaves and fruits are used in various religious rituals[14].

2.1 Role in *Ayurveda*

In *Ayurveda*, *Z. armatum* holds a significant role due to its diverse therapeutic properties. It is primarily considered to have a heating (*Ushna*) nature, making it effective for balancing the *Vata* and *Kapha* doshas, which are typically aggravated by cold or damp conditions. Its dominant taste is pungent (*Katu*), and it acts as a digestive stimulant, promoting the secretion of digestive enzymes, thereby enhancing digestion and alleviating issues such as indigestion, flatulence, and loss of appetite. This carminative action helps in breaking down accumulated gas in the intestines, making it valuable for gastrointestinal discomfort. Additionally, *Z. armatum* is recognized for its anti-inflammatory and analgesic properties, traditionally used to relieve toothaches, sore muscles, and joint pain. In cases of respiratory ailments, it serves as an expectorant, aiding in the removal of mucus and clearing congestion, which is particularly helpful in managing coughs and colds. Its antimicrobial and antifungal actions make it useful in treating infections, wounds, and skin disorders. In summary, *Ayurveda* uses *Z. armatum* as a versatile medicinal plant, beneficial for its digestive, anti-inflammatory, antimicrobial, and respiratory supporting properties[50].

2.2 Phytochemistry

Various phytochemical compounds have been identified in *Z. armatum*, including lignins, coumarins, alkaloids, phenolics, flavonoids, terpenoids, and

Table 3. Traditional applications of *Z. armatum*

S. No.	Conventional Applications	Flora Parts Applied	References
1	Abdominal discomfort	Boiled fruits preparation	19
2	Helminthicide	Fruits, seeds	20
3	Alcoholic extract	Fruits	21
4	Antipyretical	Fruits	22
5	Spasmolytic	Fruits	23
6	Appetizer	Fruits	24
7	Aromatic blend (Tonic)	Seeds	25
8	Respiratory condition	Fruits	26,23
9	Bronchial inflammation	Stem bark, fruits	26,27
10	Anti-flatulence agent	Fruits	28
11	Pulmonary infection	Fruits	29
12	Vibrio cholerae infection	Fruits, bark	28,30
13	Cough and congestion	Fruits	31
14	Culinary additive	Seeds	6,30
15	Psychological distress	Seeds	32
16	Hyperglycemia	Fruit	4,33
17	Diuretic (Urine-promoting agent)	Bark	34
18	Vertigo	Fruit pickle	35
19	Dysenteric illness	Seeds boiled in water	36
20	Functional dyspepsia	Fruits	37
21	Pyrexia	Bark and seeds	30
22	Fish toxin	Fruits, thorns	38
23	Flatulent condition	Seeds	32
24	Gastroenteric disorder	Fruits	39

Table 3. Continued...

S. No.	Conventional Applications	Flora Parts Applied	References
25	Gum infection	Young shoots, fruits	40
26	Headache	Fruit pickle	35
27	Mountain sickness	Fruit pickle	35
28	Domestic fly repellent	Fruits	41
29	Slow digestion	Fruits, seeds	42
30	Pest control	Branches	36
31	Leech protection	Fruits	43
32	Numb limb	Fruits pickle	35
33	Hemorrhoids	Fruits	21
34	Fish Catching	Roots, fruits, bark, leaves	44
35	Bronchopneumonia (sheep)	Aerial parts	45
36	Rheumatic disease	Fruits	46
37	Dermatological disorder	Fruits	46
38	Tick invasion (Cattles, Buffalo)	Aerial parts	45
39	Timur hag (soup)	Fruit	21
40	Swollen tonsils	Fruit pickel	35
41	Dental brush	Young shoots or Branches	40
42	Tooth pain	Fruits or Seeds	47
43	*Mycobacterium tuberculosis*	Seeds	34
44	Spider veins	Stem bark, fruits, seeds	48
45	Wooden stick for walking	Woods	49

glycosides. The essential oil from the plant mainly contains monoterpenes like limonene and linalool. The seeds are known to have compounds like enolic acid and other volatile substances. A detailed analysis of the essential oil using GC-MS (Gas Chromatography-Mass Spectrometry) revealed that it contains significant amounts of linalool (53.05%) and bergamot mint oil (12.73%), along with other compounds such as epoxide-limonene (11.39%) and α-pinene. Other components include myrcene (3.69%) and limonene (3.10%), which are also important ingredients[51,52]. Scientists have found several alkaloids and coumarins in different parts of *Z. armatum*. Some of the alkaloids include berberine, fagarine, magnoflorine, laurifoline, nitidine, chelerythrine, tambetarine, and candicine. In addition, coumarins such as xanthyletin, zanthoxyletin, and alloxanthyletin have also been discovered in plant[53]. Two lignans, asarinin and

fargesin, and a novel amide called armatamide have been extracted from the bark extract. Additionally, a novel flavonoid glycoside has been identified from the stem barks alcoholic extract[54]. Oleic acid, palmitic acid, methyl ester of linoleic acid, limonene, and linalool are the principal ingredients of the oil[55]. In Table 4, different kinds of phytoconstituents are compiled.

Table 4. Phytoconstituents present in *Z.armatum*

S. No.	Compounds Identified	Flora Parts	References
A. Terpenoids			
1	α-Fenchol+	Seeds	55
2	α-Terpinene	Seeds	55
3	α-Thujene	Seeds	55
4	α-Thujone	Seeds	55
5	α-Pinene	Seeds	55
6	α-copaene	Leaf oil	55
7	α-Terpineol	Seeds	55
8	α-Phellandrene	Leaf oil	55
9	β-Pinene	Seeds	55
10	β-Myrcene	Leaf oil	55
11	β-Cymene	Leaf oil	55
12	β-Phellandrene	Seeds	55
13	β-Terpeneol	Leaf oil	55
14	Camphene	Seeds, Leaf oil	55
15	Carvone	Seeds	55
16	Citral	Dry Fruits	55
17	Citronellol	Seeds	55
18	Citronellal	Seeds	55
19	1,8-Cineole	Seeds	55
20	β-ocimene	Leaf oil	55
21	Trans-beta-ocimene	Leaf oil	55
22	Cis-beta-ocimene	Seeds, Leaf oil	55
23	Geraniol	Dry Fruit	55
24	γ-terpinene	Seeds/ Leaf oil	55
25	(E)-Linalool oxide	Seeds	55
26	(E)-Carveol	Seeds	55
27	Limonene	Seeds/ leaf oil	55
28	D-Limonene	Leaf oil	55
29	Bornyl acetate	Leaf oil	55
30	Linanyl acetate	Dry fruits	55
31	Myrcene	Seeds	55

Table 4. Continued...

S. No.	Compounds Identified	Flora Parts	References
32	Terpinolene	Leaf oil	55
33	α-terpinolene	Leaf oil	55
34	Nerol	Seeds	55
35	1- α-phellandrene	Seeds	55
36	cymene	Leaf oil	55
37	p-Cymene	Seeds	55
38	Piperitone	Seeds	55
39	Sabinene	Seeds	55
40	Tagetonol	Seeds	55
41	Terpinen-4-ol	Seeds	55
42	(Z)-Sabine hydrate	Seeds	55
43	(Z)-Pinene hydrate	Seeds	55
44	allo-Aromadendrene	Seeds	55
45	α-Caryophyllene	Seeds	55
46	Trans-caryophyllene	Leaf oil	55
47	(E)-Nerolidol	Seeds	55
48	α-Amyrins	Bark	55
49	β-Amyrone	Bark	55
50	β-Amyrines	Bark	55
51	Lupeol	Bark	55
52	Eucalyptol	Fruit	55
B. Flavonoid			
53	Catechin	Leaf	54
54	Hesperidine	Leaf	54
55	Vitexin	Leaf	54
56	Isovitexin	Leaf	54
57	3,5-Diactyltambulin	Bark	54
58	Kaempferol	Bark	54
59	Tambulin	Bark	54
60	3,5,3′-Trihydroxy-6,7-dimethoxy- 4′-(7″-hydroxygeranyl-1″-ether) flavone	Seeds	13
61	3,5,3′,4′-Tetrahydroxy-7,8-dimethoxy flavone	Seeds	13
62	Tambuletin	Seeds	13

Table 4. *(Continued)*

S. No.	Compounds Identified	Flora Parts	References
C. Alkaloids			
63	Berberine	Bark	[53]
64	Dictamnine	Root	[53]
65	γ-fagarine	Bark	[53]
66	β-fagarine	Bark	[53]
67	Chelerythrine	Bark	[53]
68	Magnoflorine	Root	[53]
69	Nevadensin	Seeds oil	[53]
70	Skimmianine	Bark	[53]
71	Zanthonitrile	Bark	[53]
D. Lignins			
72	Asarinin	Bark, Leaf	[53]
73	Eudesmin	Leaf	[53]
74	Epieudesmin	Leaf	[53]
75	Fargesin	Barf ,Leaf	[53]
76	Kobusin	Leaf	[53]
77	Planispine-A	Leaf	[53]
78	L-Asarinin	Bark	[53]
79	L-Sesamin	Bark	[53]
80	L-Planinin	Bark	[53]
81	Magnolin	Bark	[53]
82	Phylligenin	Bark	[53]
83	Planinin	Bark	[53]
84	Sesamin	Leaf/Bark	[53]
E. Sterols and Steroids			
85	β-Daucosterol	Bark	[55]
86	β-Sitosterol	Bark	[55]
87	Stigmasta-5-en-3β-Dglucopyranoside	Seeds	[55]
88	β-Sitosterol-β-D-glucoside	Bark	[55]
F. Amides			
89	Armatamide	Bark	[53]
90	α-Sanshool	Leaf	[53]
91	Hydroxyl-α-sanshooil	Pericarp	[53]

Table 4. *(Continued)*

S. No.	Compounds Identified	Flora Parts	References
G. Coumarins			
92	xanthyletin	Bark	[56]
93	zanthoxyletin	Bark	[56]
94	alloxanthtin	Bark	[56]
95	Bergapten	Bark	[56]
96	Umbelliferone	Bark	[56]
97	psoralen	Leaf	[56]
98	Cuminol	Bark/ Fruit	[53]
99	Cuminaldehyde	Seeds	[53]
100	Phellandral	Seeds	[53]
101	2-Tridecanone	Leaf-oil	[56]
102	Undecan-2-one	Aerial parts	[56]
H. Aromatic Compounds			
103	1-Hydroxy-6,13-anthraquinone	Seeds	[13]
104	2-Hydroxybenzoic acid	Seeds	[13]
105	2-Hydroxy-4-methoxy benzoic acid	Seeds	[13]
106	trans-Cinnamic acid	Seed oil	[13]
107	Vanillic acid	Bark	[13]
108	(E)-Methyl cinnamate	Seeds	[13]
109	Methyl cinnamate	Seeds/ Fruit	[13]
110	(Z)-Methyl cinnamate	Seeds	[13]
111	3-Methoxy-11-hydroxy-6,8-dimethylcarboxylate biphenyl	Seeds	[13]
112	3,5,6,7-Tetrahydroxy-3′,4′-dimethoxy flavones-5-β-D-xylopyranoside	Seeds	[13]
113	Monoterpenetriol-3,7-dimethyl-1- octane-3,6,7-triol	Seed oil	[13]
114	1-Methoxy-1,6,3-anthraquinone	Seeds	[13]

2.3 Pharmacological Activity

2.3.1 Hepatoprotective Activity

Zanthoxylum armatum has been shown to protect the liver from damage caused by carbon tetrachloride. It helps restore normal liver function by increasing the levels of important liver enzymes. The herb also reduces the leakage of these enzymes, which indicates less damage to liver cells, and helps protect the liver cell membranes from becoming fragile. Overall, it helps shield the outer membrane of liver cells, keeping them healthy[57].

2.3.2 Anti-diabetic Activity

It is known from earlier research that this plant exhibits positive effects on diabetic activities. It demonstrates the anti-diabetic action against rats with diabetes that were streptozotocin-induced. Glibenclamide served as the typical reference medication. The 21-day oral drug regimen significantly lowers blood glucose levels, which in turn lowers triglycerides, LDL, and VLDL cholesterol. also demonstrate the anti-diabetic action[58].

2.3.3 Anti-depressant Activity

Numerous studies have found that this plant has strong antidepressant properties as well. A portion of this plants depressant activity is examined using a bioassay-guided fraction. The hexane extract generally exhibits strong antidepressant effects. Significant findings from molecular and biochemical research indicate that the plant *Z. armatum's* seeds possess antidepressant properties[59].

2.3.4 Memory Enhancing Property

Thus yet, *Z. armatum's* neurological properties have not been investigated. It was once used to treat toothaches. Then, using a variety of hydroalcohlic extracts, researchers conducted a detailed study on memory enhancers for the first time. Thus, it can be concluded that *Z. armatum* is a useful plant for enhancing memory[60].

2.3.5 Cytotoxicity

Various researches show that plants have the ability to be both cytotoxic and antioxidant. Studies have shown that ethyl acetate extract of stem cells exhibits good cytotoxicity. The various malignant cells were used to study the cytotoxicity of ethyl acetate[66]. Mostly, the pancreatic and lung cell lines respond well to this plant extract. Additionally, the plant extract of *Z. armatum* can be used to boost the effectiveness of chemotherapy medications including camptothecin, cisplatin, and mitomycin C[61].

2.3.6 Anti-spasmodic Ativity

According to research findings, *Z. armatum* has an anti-spasmodic action through the Ca antagonist mechanism, which is the basis for its pharmacological activity and yields positive effects in respiratory and cardiovascular illnesses[62]. Hexane extract from *Z. armatum* has good anti-spasmodic properties. The complete set of samples undergoes testing against both spontaneously generated smooth muscle and potassium chloride that is extracted from rabbit jejunum[63,64].

2.3.7 Mosquito and Insect Repellent

The essential oil of the *Z. armatum* plant has the ability to repel leeches and insects. Studies have demonstrated that leech-repelling properties of N, N-Diethyl Phenyl Acetamide (DEPA), N, N-Diethyl-m-Toluamide (DEET), 3-acetyl-2 (2,6-dimethyl-5-heptenyl), oxazolidine (citronyl), Dimethyl Phthalate (DMP), and N-Benzoyl Piperidine (NBP) have been examined. The research's findings are matched to its volatile oil, and its repellent properties are then assessed[65].

2.3.8 Anti Nociceptic and Anti-convulsant Activity

The herb *Z. armatum's* essential oil, which was extracted by steam distillation, was assessed for its anti-convulsant, antitoxin, and toxicity properties. *Z.armatum* reduces inflammation and neurogenic discomfort[66].

2.3.9 Anti-proliferative Activity

The methanolic extract derived from *Z. armatum* has anti-proliferative properties that target human keratinocytes. Based on research, it appears that this methanolic extract is effective against four distinct species of *Z. armatum*. Studies indicate that the anti-proliferative properties stem from their ability to ward off damage caused by radicals rather than having a cytotoxic impact[67].

2.3.10 Calming Effect on Skin

When applied topically, the lipophillic extract of *Z. armatum* combined with alcohol has a calming effect on the skin and inhibits sensory responses to UV exposure, insect stings, shaving, *etc*[68].

2.3.11 Some other Effects

There are also some toxicological effects of the plant *Z. armatum*. Extract, decoction, pastes like prepration shows some toxicities which is studied by many researchers. Research also suggests that the aqueous extract of the *Z. armatum* which are used in traditional herbs medicine remedy exerts their toxic potential by inducing the membrane damage of cellular organs also show chromosomes clumps and nuclear DNA damage[69].

2.3.12 Anti-inflammatory Activities

Zanthoxylum armatum may have antioxidant qualities; in Wistar rats, this has been achieved *via* cyclooxygenase inhibition using stem bark extract. The plants fruit extract is also used to prevent Wistar rats from producing carrageenan[70]. It could contain a range of ingredients. Among them is lignans, which may potentially have analgesic properties[71,72].

2.3.13 Antioxidative Activities

Methanolic and ethanolic fruit extract of plant shows *in vitro* activities in Wistar rats and due to presence of free radical scavenging, it may shows the antioxidants activities against the Wistar rats[73].

2.3.14 Antimicrobial Activities

Activities might demonstrate the impact against microbes. *Bacillus subtilis* has a minimum bactericidal concentration and a zone of inhibition. The fungicidal properties of the oil composition may also be seen against *Alternaria brassicicola*[74].

2.3.15 Larvicidal Activities

Zanthoxylum armatum refers to its ability to kill or inhibit the growth of larvae, typically insects or pests, such as mosquitoes. This property is particularly significant in controlling vector-borne diseases like malaria, dengue, and filariasis, where larvicides are crucial in managing the spread of the mosquito populations It has larvacidal properties against *C. pipenes*, *Anopheles stephensi*, and *Aedes aegypti*[75].

2.3.16 Piscicide Activities

The fruit of *Z. armatum* may hold potential for use in fish nursery management due to its piscicidal properties. Research suggests that the plants alcoholic extract contains essential minerals like magnesium, sodium, and potassium, which have been detected in various tissues of air-breathing catfish. These findings indicate that the fruit could be useful for managing fish populations in aquaculture settings. Several studies also highlight its potential in controlling fish through piscicidal activity, making it a promising natural alternative in fisheries management[76].

2.3.17 Hepatoprotective Activities

The ethanolic extract of *Z. armatum* leaves has shown potential hepatoprotective effects in mice, particularly in cases where liver damage was induced by Carbon tetrachloride (CCl4). The study observed that this extract helped reduce liver inflammation and supported the livers recovery. Additionally, the bark extract of the plant was found to regulate key enzymes, including antioxidant enzymes, further contributing to its hepatoprotective properties.In the study, 6 rats were divided into 4 groups and administered varying doses of the extract *via* gastric incubation over 7 days. On the 8th day, CCl4 combined with liquid paraffin was introduced to induce liver damage. Afterward, the rats livers were dissected, and blood samples were taken from the cardiac region for centrifugation. The results demonstrated that *Z. armatum* extracts could positively influence liver health, protecting against CCl4-induced damage[77].

2.3.18 Antitumor Activity

Zanthoxylum armatum is also noted for its anticancer properties. Both the fruits and leaves of the plant contain a compound called monoterpene leupol, which has demonstrated therapeutic and chemoprotective effects. This suggests that *Z. armatum* could play a role in cancer prevention and treatment, making it a promising candidate for further research in the field of oncology. Its natural compounds may contribute to protecting cells from cancerous changes and support overall health[78].

2.3.19 Immunomodulation Activities

The crude extract from the timber of *Z. armatum* has been found to have various beneficial effects on health. It shows promise in supporting gastrointestinal and cardiovascular health by influencing potassium and calcium levels in the body. Additionally, this extract

has demonstrated positive effects on circulation and the mucous membranes, and it may also help alleviate conditions like fibrosis and rheumatism. Overall, these properties highlight the potential of *Z. armatum* as a natural remedy for a range of health issues[61].

2.3.20 Cardiovascular Activity

Zanthoxylum armatum has shown potential antispasmodic and antiarrhythmic effects in its crude extract. These benefits are believed to be due to its calcium antagonistic mechanism, which could make it useful for treating gastrointestinal, respiratory, and cardiovascular disorders. This mechanism is similar to how verapamil, a well-known calcium channel blocker used to treat heart conditions, works. These findings suggest that *Z. armatum* may hold promise as a natural alternative for managing conditions related to muscle spasms and heart rhythm irregularities[25].

3. Modern Applications

3.1 Molecular Docking

The bioactive compounds from *Z. armatum*, particularly its alkaloids and flavonoids, can interact with bacterial proteins through computational molecular docking. Researchers tested 13 phytochemicals from the plant, alongside 3 standard antibiotics, against 2 crucial bacterial proteins: Penicillin-Binding Protein 2a (PBP2a) from *Staphylococcus aureus* and the transcription regulator TcaR from *Staphylococcus epidermidis*.

The results revealed that compounds like nitidine, nevadensin, and tambuletin demonstrated a stronger binding affinity to these proteins compared to conventional antibiotics such as penicillin, chloramphenicol, and oxacillin. These natural compounds formed various interactions, including hydrogen and pi-alkyl bonds, at key active sites on the bacterial proteins. This indicates the promising potential of *Z. armatum* extracts as natural inhibitors, offering a possible alternative to combat antibiotic-resistant bacteria[79].

3.2 The Swiss ADME Predictions and Toxicity Analysis

The Swiss ADME predictions and toxicity analysis of phytocompounds from *Z. armatum* were conducted to assess their potential as therapeutic agents, particularly in terms of drug-like properties, bioavailability, and safety. This computational study focused on key phytochemicals, including alkaloids and flavonoids, evaluating their suitability for use in drug development.

Key findings showed that most of the compounds adhered to Lipinski's rule of five, indicating good drug-like properties. However, one compound, Tambuletin, exhibited some deviations, such as higher molecular weight and more hydrogen bond acceptors and donors, which resulted in lower bioavailability compared to others.

In terms of bioavailability, most of the phytochemicals demonstrated strong potential for absorption in the gastrointestinal tract. Some compounds were found to be P-glycoprotein (P-gp) substrates, which is beneficial for controlled drug delivery and minimizing toxicity risks.

The pharmacokinetics analysis revealed that certain compounds were able to cross the blood-brain barrier and interact with key cytochrome enzymes responsible for drug metabolism. This highlights their potential for broader therapeutic applications.

The toxicity analysis provided encouraging results, with compounds like magnoflorine, nevadensin, kaempferol, and tambulin classified as non-toxic. However, a few, such as nitidine, showed some mutagenic or cytotoxic effects, which would need careful consideration in further studies.

Overall, this analysis identified several phytocompounds with promising drug-like characteristics and low toxicity, paving the way for further research into their use as natural antibiotics against resistant bacteria[79].

3.3 Gold Nano-particle of *Z. armatum*

Gold Nanoparticles (GNPs) were successfully synthesized using a reaction between a gold solution and *Z. armatum* leaf extract. Various advanced techniques, including SEM, UV-vis, XRD, DLS, and FTIR, were employed to thoroughly characterize the nanoparticles. The FTIR analysis revealed the presence of plant functional groups, confirming that the active components in the plant extract played a key role in reducing and stabilizing the GNPs. SEM and DLS analyses further confirmed that the nanoparticles were less than 30 nm in size.

In burn wound healing experiments, the application of an ointment containing these GNPs significantly accelerated the healing process. The treatment led to a marked reduction in wound area and an increase in wound contracture, demonstrating the GNPs effectiveness. These results highlight the broad therapeutic and antibacterial potential of GNPs, particularly in controlling wound infections and promoting faster recovery from burn wounds[80].

3.4 *Zanthoxylum armatum* on Blood Glucose Levels

The study on *Z. armatum* extracts explored their potential to regulate blood glucose levels, with a focus on diabetic mice. Extracts from the fruit, bark, and leaves of the plant were tested, with diabetes induced in the mice using alloxan monohydrate. Over 15 days, the extracts were administered to various groups of diabetic and normal mice, and fasting blood glucose levels were regularly monitored.

3.4.1 Significant Reduction in Blood Glucose

All the extracts led to a notable reduction in blood glucose levels when compared to the diabetic control group. The leaf extract, in particular, exhibited the strongest hypoglycemic effect, almost matching the standard drug, Glibenclamide, indicating *Z. armatum's* strong antidiabetic potential.

3.4.2 Fruit and Bark Extracts

The fruit extract also significantly lowered blood glucose levels in diabetic mice, while the bark extract had a more moderate but still effective impact. Both demonstrated strong antidiabetic activity.

3.4.3 Long-term Effects

The blood glucose reduction was sustained over the course of the study, suggesting that these plant extracts could offer long-term benefits in managing diabetes[81].

3.5 Hepatoprotective Activity

Hepatoprotective activity of ethanolic extracts of bark of *Z. armatum* in CCl4 induced hepatic damage in rats investigates the potential liver-protecting properties of *Z. armatum* (ZA). The study aims to scientifically validate the traditional *Ayurvedic* claims about its hepatoprotective effects. The experiment used ethanolic bark extracts of ZA administered to male Wistar rats with Carbon tetrachloride (CCl4)-induced liver toxicity. The results showed that the extract significantly restored liver function by normalizing elevated levels of serum enzymes such as Alanine aminotransferase (ALT) and Aspartate aminotransferase (AST), and increasing antioxidant enzyme levels like Superoxide Dismutase (SOD) and Catalase (CAT). Phytochemical analysis revealed the presence of berberine, flavonoids, and phenolic compounds, which likely contributed to the observed hepatoprotective effects. The findings support the use of ZA in traditional medicine for liver disorders, as its extract demonstrated significant protection against liver damage, comparable to the standard drug silymarin[82].

3.6 Karyotype and Phylogenetic Relationship Analysis

Exploring the genetic makeup and evolutionary relationships of 5 varieties of *Z. armatum*, a plant known for its economic value. Using advanced oligonucleotide fluorescence *in situ* hybridization (Oligo-FISH) techniques, the researchers identified and differentiated the varieties by analyzing three genetic markers: 5S rDNA, (AG3T3)3, and (GAA)6. The study revealed variations in chromosome numbers and structures, indicating that these varieties are evolving toward polyploidy, a condition where organisms have multiple sets of chromosomes. The notable differences in chromosome numbers and karyotype structures, with the chromosome count ranging from 98 in *Z. armatum* 'Tengjiao' to 136 in other varieties. Additionally, the research highlighted the close genetic relationship between certain cultivars, such as *Z. armatum* 'Tengjiao' and *Z. armatum* var. novemfolius. These findings not only enhance the understanding of the plants genetic diversity but also offer valuable insights for the future cultivation and classification of *Z. armatum* varieties[83].

3.7 Nutraceutical

Chemical composition of *Z. armatum* leaves highlights notable differences in mineral and nutritional content influenced by factors like plant age, shoot type, and leaf position.

- Mineral content: The carbon content in the leaves varied from 356 to 407 g/kg, with younger,

two-year-old plants typically having higher nitrogen levels, ranging from 14.6 to 22.7 g/kg. Interestingly, phosphorus levels were more pronounced in four-year-old plants, reaching up to 1.385 g/kg. Generally, vegetative shoots showed elevated levels of carbon and nitrogen, while fruit-bearing shoots had higher phosphorus concentrations.

- Nutritional components: Soluble protein levels were found to be between 2.48 and 4.81 mg/g, with the top and middle leaves showing richer concentrations. Amino acid content varied from 24.87 to 36.99 mg/g, again with younger plants upper leaves holding more[93].
- Phenolic compounds: The total phenol content was more variable in two-year-old plants, ranging from 55.53 to 65.24 mg/g. In contrast, the highest total flavonoid content of 69.44 mg/g was observed in four-year-old plants, particularly in the fruit-bearing shoots[84].

3.8 Zinc-doped Titanium Dioxide (TiO_2) Nanoparticles

The eco-friendly synthesis of zinc-doped titanium dioxide (TiO_2) nanoparticles using leaf extract from *Z. armatum*. By employing a simple hydrothermal method, the researchers optimized key factors like concentration, temperature, and reaction time to create these nanoparticles. The addition of zinc to TiO_2 enhanced its ability to absorb visible light, significantly boosting its antimicrobial and antifungal properties. The zinc-doped nanoparticles demonstrated strong effectiveness against both Gram-positive and Gram-negative bacteria, including *Salmonella*, *E. coli*, *Staphylococcus epidermidis*, and *Staphylococcus aureus*, as well as fungi such as *Candida albicans* and *Aspergillus niger*. Advanced analysis techniques like FTIR and SEM revealed that the nanoparticles had a spherical shape and stable surface interactions. These findings highlight the potential of zinc-doped TiO_2 nanoparticles for use in antimicrobial therapies[85].

3.9 Agriculture Applications

Zanthoxylum armatum, is highly valued in agriculture for its ability to thrive in harsh conditions, such as drought, and for its rapid growth, making it ideal for afforestation and land restoration projects. One innovative approach to cultivating Z. armatum involves using a combination of organic manure and reduced chemical fertilizers (MNPK). This strategy has been shown to significantly enhance the growth and biomass accumulation of *Z. armatum* seedlings by improving nutrient use efficiency.

By integrating organic manure with chemical fertilizers, farmers can cut chemical inputs by up to 50%, which not only increases plant productivity but also promotes healthier soil. This balanced fertilization method boosts biomass production, enhances soil fertility, and plays a crucial role in carbon sequestration-helping to mitigate climate change. It's a sustainable strategy that supports long-term agricultural productivity while minimizing environmental impact, making it ideal for the cultivation of *Z. armatum* in managed plantations[86] .

4. Future Prospective

In recent years, there has been an increased focus on discovering natural products as safer alternatives for managing human diseases. Medicinal plants, traditionally used for health remedies, are now being investigated to scientifically validate their therapeutic claims. *Zanthoxylum* species, in particular, have been a source of interest, with over 500 secondary metabolites identified from these plants, many of which exhibit promising biological activities. However, the molecular mechanisms behind most of these bioactive compounds remain unclear, necessitating further research to bridge this gap. Additionally, the exact active components in many *Zanthoxylum* extracts are yet to be identified.

Some species within the *Zanthoxylum* genus have shown toxicity at high doses, highlighting the need for studies focusing on safe dosage ranges. Long-term animal studies are crucial to establish safety profiles. Moreover, while *in vitro* studies show the potential of these compounds, their efficacy *in vivo* must be confirmed, as factors like bioaccessibility and bioavailability could limit their effectiveness in target tissues.

Compounds such as hesperidin, sesamin, berberine, and others have demonstrated significant biological activities, and their mechanisms of action are well-understood. These compounds hold promise as candidates for clinical trials, potentially paving the way for new nutraceuticals or therapeutic agents. By exploring their medicinal properties further, these compounds may serve as foundations for future drugs,

offering a natural and effective alternative to synthetic medicines[87].

5. Conclusion

Zanthoxylum armatum is recognized for its broad spectrum of uses across traditional medicine and modern scientific fields. Historically, it has played a significant role in the treatment of various health conditions. Contemporary research continues to uncover its potential in areas such as pharmacology, sustainable agriculture, and ecological restoration. Its diverse array of bioactive compounds is responsible for its notable therapeutic effects, including anti-inflammatory, antimicrobial, and antioxidant properties- positioning it as a promising natural source for future drug development.

In agriculture, the cultivation of *Z. armatum* using eco-friendly practices is particularly promising. Integrating organic fertilizers with minimal chemical inputs not only enhances plant productivity and soil fertility but also aids in carbon storage. This approach not only improves sustainability but also supports broader environmental conservation goals.

By merging age-old traditional knowledge with advancements in scientific research and green farming methods, *Z. armatum* emerges as a highly valuable plant with significant applications in both healthcare and agriculture- paving the way for further exploration and innovation.

6. Acknowledgements

The authors sincerely acknowledge Dev Bhoomi Uttarakhand University, Department of Pharmacy, for providing academic support and access to relevant resources during the preparation of this review. Special thanks to all researchers and authors whose studies formed the foundation of this article.

7. Author Contribution

Harshvardhan Chauhan conceptualized the review topic, conducted the literature review, and prepared the initial manuscript draft. Dr. Jaya Martolia provided critical guidance on structuring the article, contributed to the interpretation of traditional and modern applications, and performed the final review and editing of the manuscript.

Both authors read and approved the final version of the manuscript.

8. References

1. White AE, Dey KK, Mohan D, Stephens M, Price TD. Regional influences on community structure across the tropical-temperate divide. Nat Commun. 2019; 10:2646. https://doi.org/10.1038/s41467-019-10253-6
2. Hasler CM, Blumberg JB. Phytochemicals: Biochemistry and physiology. J Nutr. 1999; 129:756S-757S.
3. Mahan LK, Stump SE. Krause's food, nutrition, and diet therapy. 10thEdition. 2000: p. 271-275.
4. Geweli MB, Awale S. Aspects of traditional medicine in Nepal. Institute of Natural Medicine, University of Toyama. 2008: p. 140-142.
5. Ullah B, Ibrar M, Hussain F. Ethnobotanical studies of plants of Charkotli Hills, Batkhela District, Malakand, Pakistan. Front Biol China. 2009; 4(4):539-548. https://doi.org/10.1007/s11515-009-0045-2
6. Abbasi AM, Khan MA, Ahmed M, Zafar M. Herbal medicines used to cure various ailments by the inhabitants of Abbottabad district, North West Frontier Province, Pakistan. Indian J Trad Know. 2010; 9:175-183.
7. Larkcom J. Oriental vegetables. 1971.
8. Dirr MA, Heuser MW. The reference manual of woody plant propagation. Varsity Press. 1987.
9. Sheat WG. Propagation of trees, shrubs, conifers. Macmillan and Co Ltd. 1948: p.479.
10. Vana PD. Agro-technique study carried out by regional station. National Bureau of Plant Genetic Resources. Teri Press. 2008: p. 231-234.
11. Singh TP, Singh OM. Phytochemical and pharmacological profile of *Zanthoxylum armatum* DC: An overview. Indian J Nat Prod Resour. 2011; 2(3):275-285.
12. Ahmad A, Misra LN, Gupta MM. Hydroxyalk-(4z)-enoic acids and volatile components from the seeds of *Zanthoxylum armatum*. J Nat Prod. 1993; 56(4):456-460.
13. Barkatullah M, IbrarMIM, Rehman IU, Rehman MU, *et al*. Chemical composition and biological screening of essential oils of *Zanthoxylum armatum* DC leaves. J Clin Toxicol. 2013; 3(5):1-6.
14. Kala CP, Farooquee NA, Dhar U. Prioritization of medicinal plants on the basis of available knowledge, existing practices and use value status in Uttaranchal, India. BiodiversConserv. 2004; 13:453-469.
15. Negi JS, Bisht VK, Bhandari AK, Singh P, Sundriyah RC. Chemical constituents and biological activities of the genus *Zanthoxylum*: A review. Afr J Pure Appl Chem. 2011;5(12):412-416.

16. Singh G, Kapoor IPS, Singh P, Carola SH, Lampasona MP, *et al*. Chemistry and antioxidant properties of essential oil and oleoresins extracted from the seeds of Tomer (*Zanthoxylum armatum* DC). Int J Food Prop. 2013; 16(2):288-300. https://doi.org/10.1080/10942912.2010.551311
17. Tiwary M, Naik SN, Tewary DK, Mittal PK, Yadav S. Chemical composition and larvicidal activities of the essential oil of *Zanthoxylum armatum* DC (*Rutaceae*) against three mosquito vectors. J Vector Borne Dis. 2007; 44(3):198-204. PMID: 17896622
18. Rijal A. Surviving on knowledge: Ethnobotany of Chepang community from midhills of Nepal. Ethnobot Res Appl. 2011; 9:181-215. https://ethnobotanyjournal.org/index.php/era/article/view/249
19. Kala CP, Farooquee NA, Dhar U. Traditional uses and conservation of Timur (*Zanthoxylum armatum* DC) through social institutions in Uttaranchal Himalaya, India. Conserv Soc. 2005; 3(1):224-230.
20. Akhtar N, Rashid A, Murad W, Bergmeier E. Diversity and use of ethnomedicinal plants in the region of Swat, North Pakistan. J Ethnobiol Ethnomed. 2013; 9(25):1-13.
21. Baral SR, Kurmi PP. A compendium of medicinal plants in Nepal. International Union for the Conservation of Nature and Natural Resources. Mass Printing Press. 2006.
22. Balami NP. Ethnomedicinal uses of plants among the Newar community of Pharping village of Kathmandu District, Nepal. Trib Univ J. 2004; 24(1). https://www.nepjol.info/index.php/TUJ/article/view/251/251
23. Alamgeer TA, Rashid M, Malik MNH, Mushtaq MN, Khan J, Qayum R, *et al*. Ethnomedicinal survey of plants of Valley AlladandDehri, Tehsil Batkhela, District Malakand, Pakistan. Int J Basic Med Sci Pharm. 2013; 3(1):23-32.
24. Kanjilal UN, Kanjilal PC, De RN, Das A. The flora of Assam. Pra Basi Press. 1997; 4.
25. Gilani SN, Khan AU, Gilani AH. Pharmacological basis for the medicinal use of Zanthoxylum armatum in gut, airways and cardiovascular disorders. Phytother Res. 2010; 24(4):553-558. PMID: 20041426. https://doi.org/10.1002/ptr.2979
26. Department of Plant Resources (DPR). Medicinal Plants of Nepal.2nd Edition. Ministry of Forest and Soil Conservation, Government of Nepal. 2016.
27. Islam MS, Akhtar M, Rahman MM, Rahman MA, Sarker KK, Alam FM. Antitumor and phytotoxic activities of leaf methanol extract of *Oldenlandiadiffusa* (willd.) Roxb. Glob J Pharmacol. 2009; 3(2):99-106.
28. Malla B, Gauchan D, Chhetri RB. Medico-ethnobotanical investigations in Parbat district of Western Nepal. J Med Plants Res. 2014; 8(2):95-108. https://doi.org/10.5897/JMPR2013.5228
29. Singh TP, Singh OM. Phytochemical and pharmacological profile of *Zanthoxylumarmatum* DC - An overview. Indian J Nat Prod Resour. 2011; 2(3):275-285.
30. Zaidi SFH, Yamada K, Kadowaki M, Usmanghani K, Sugiyama T. Bactericidal activity of medicinal plants employed for the treatment of gastrointestinal ailments against *Helicobacter pylori*. J Ethnopharmacol. 2009; 121(2):286-291. PMID: 19041711. https://doi.org/10.1016/j.jep.2008.11.001
31. Khan MH, Yadava PS. Antidiabetic plants used in Thoubal district of Manipur, Northeast India. Indian J Tradit Knowl. 2010; 9(3):510-514.
32. Council of Scientific and Industrial Research (CSIR). A dictionary of indian materials and industrial products-raw materials series. Publications and Information Directorate, CSIR. 2005.
33. Subedi R. Ethnobotanical study of panchase protected forest, Kaski district, Central Nepal. Tribhuvan University, Central Department of Botany. 2017.
34. Ahmed E, Arshad MA, Ahmad M, Saeed M, Ishaque M. Ethnopharmacological survey of some medicinally important plants of Galliyat Areas of NWFP, Pakistan. Asian J Plant Sci. 2004; 3(4):410-415. https://doi.org/10.3923/ajps.2004.410.415
35. Rasaily NK. Production, processing and marketing of potential Non-Timber Forest Products (NTFP) in Parbat, Micro-enterprise Development Program. 2003.
36. Sigdel SR, Rokaya M, Timsina B. Plant inventory and ethnobotanical study of Khimti hydropower project, Central Nepal. Sci World. 2013; 11(11). https://doi.org/10.3126/sw.v11i11.8563
37. Hamayun M. Ethnobotanical studies of some useful shrubs and trees of district Buner, NWFP, Pakistan. Ethnobot Leafl. 2003; 7:31-43.
38. Gaur RD. Flora of the district Garhwal, North Western Himalaya (with ethnobotanical notes). Transmedia; 1999.
39. Rajbhandary S, Ranjitkar S. Herbal drugs and pharmacognosy- monographs and commercially important medicinal plants of Nepal. ESON. 2006.
40. Manandhar NP. Traditional practice for oral health care in Nepal. J Econ Taxon Bot. 1996; 12:408-413
41. Abbasi AM, Khan MA, Zafar M. Ethno-medicinal assessment of selected wild edible fruits and vegetables of lesser-Himalayas, Pakistan. Pak J Bot. 2013; 45(S1):215-222.
42. Mathur AC, Srivastava JB, Chopra IC. Insecticidal properties of *Zanthoxylum alatum* Linn. Curr Sci. 1961; 30(6):223-224.
43. Sindhu ZD, Iqbal Z, Khan MN, Jonsson NN, Siddique M. Documentation of ethnoveterinary practices used for treatment of different ailments in a selected hilly area of Pakistan. Int J Agric Biol. 2010; 12(3):353-358.
44. Kunwar RM, Uprety Y, Burlakoti C, Chowdhary CL, Bussmann RW. Indigenous use and ethnopharmacology of medicinal plants in Far-West Nepal. Ethnobot Res Appl. 2009; 7:005-028. https://ethnobotanyjournal.org/index.php/era/article/view/223

45. Kunwar RM, Mahat L, Acharya RP, Bussmann RW. Medicinal plants, traditional medicine, markets and management in far-west Nepal. J Ethnobiol Ethnomed. 2013; 9:24.
46. Gurung A. A study on medicinal plants and their traditional uses in Chitre VDC and Bhadhure VDC (Kaski), Western Nepal. Tribhuvan University, Central Department of Botany. 2002.
47. Kirtikar KR, Basu BD. Indian medicinal plants. Archaeological Survey of India. 1933; 2.
48. Iqbal I, Hamayun M. Studies on the traditional uses of plants of Malam Jabba Valley, district Swat, Pakistan. Ethnobot Leafl. 2004; 1(15):32. https://opensiuc.lib.siu.edu/ebl/vol2004/iss1/15
49. Paul A, Kumar A, Singh G, Choudhary A. Medicinal, pharmaceutical and pharmacological properties of *Zanthoxylum armatum*: A review. J PharmacognPhytochem. 2018; 7(4):892-900.
50. Kokate SD, Venkatachalam SR, Hassarajani SA. *Zanthoxylum alatum* extract as *mosquito larvicide*. Proc Nat Acad Sci India Sect B Biol Sci. 2001; 71:229-232.
51. Neetu J, Srivastava SK, Aggarwal KK, Ramesh S, Sushil K. Essential oil composition of *Zanthoxylum alatum* seeds from Northern India. Flavour Fragr J. 2001; 16(6):408-410. https://doi.org/10.1002/ffj.1024
52. Luong NX, Hac LV, Dung NX. Chemical composition of the leaf oil of *Zanthoxylum alatum* Roxb. from Vietnam. J Essent Oil Bear Plants. 2003; 6(3):179-184. https://doi.org/10.1080/0972-060X.2003.10643348
53. Perry LM. Medicinal plants of East and Southeast Asia. MIT Press. 1980: p. 447-493.
54. Li H, Li P, Zhu L, The chemical constituents of *Zanthoxylum armatum* DC. Zhongguo Yaofang. 2006; 17:1035-1037.
55. Yoshihito U, Yuriko N, Masayoshi H, Shuichi H, Seiji H. Essential oil constituents of fuyu-sanshoo (*Zanthoxylum armatum* DC.) in Nepal. 2000; 44:59-61.
56. Verma N, Khosa RL. Hepatoprotective activity of leaves of *Zanthoxylum armatum* DC in CCl_4-induced hepatotoxicity in rats. Indian J Biochem Biophys. 2010; 47(2):124-127. PMID: 20521628
57. Karki H, Upadhayay K, Pal H, Singh R. Antidiabetic potential of *Zanthoxylum armatum* bark extract on streptozotocin-induced diabetic rats. Int J Green Pharm. 2014; 8(2):77-83.
58. Barua CC, Haloi P, Saikia B, *et al. Zanthoxylum alatum* abrogates lipopolysaccharides-induced depression-like behaviours in mice by modulating neuroinflammation and monoamine neurotransmitters in the hippocampus. Pharm Biol. 2018; 56(1):245-252. https://doi.org/10.1080/13880209.2017.1391298
59. Saikia B, Barua CC, Sarma J, *et al. Zanthoxylum alatum* ameliorates scopolamine-induced amnesia in rats: Behavioral, biochemical and molecular evidence. Indian J Pharmacol. 2018; 50(1):30-38. PMID: 29861525. PMCID: PMC5954630. https://doi.org/10.4103/ijp.IJP_417_17
60. Barkatullah B, Ibrar M, Muhammad NMN. Evaluation of *Zanthoxylum armatum DC* for *in-vitro*and *in-vivo* pharmacological screening. Afr J Pharm Pharmacol. 2011; 5(14):1718-1723.
61. Saikia B, Barua CC, Haloi P, *et al.* Anticholinergic, antihistaminic, and antiserotonergic activity of n-hexane extract of *Zanthoxylum alatum* seeds on isolated tissue preparations: An *ex vivo* study. Indian J Pharmacol. 2017; 49(1):42-48. PMID: 28458421. PMCID: PMC5351237. https://doi.org/10.4103/0253-7613.201025
62. Hemming JM, Guarraci FA, Firth TA, *et al.* Actions of histamine on muscle and ganglia of the guinea pig gallbladder. Am J Physiol Gastrointest Liver Physiol. 2010; 279(3):622-630. PMID: 10960363. https://doi.org/10.1152/ajpgi.2000.279.3.G622
63. Matsumoto T, Horiuchi M, Kamata K, *et al.* Effects of *Bidens pilosa* L. var. radiata SCHERFF treated with enzyme on histamine-induced contraction of guinea pig ileum and on histamine release from mast cells. J Smooth Muscle Res. 2009; 45(2-3):75-86. PMID: 19602852. https://doi.org/10.1540/jsmr.45.75
64. Dube S, Kumar A, Tripathi SC. Antifungal and insect repellent activity of essential oil of *Zanthoxylum armatum* Linn. Ann Bot. 1990; 65(4):457-459. https://doi.org/10.1093/oxfordjournals.aob.a087956
65. Muhammad I, Naveed M, Barkatullah, Khan H, *et al.* Antinociceptive and anticonvulsant activities of essential oils of *Zanthoxylum alatum*. Phytopharmacol. 2012; 3(1):191-198.
66. Kumar S, Muller K. Inhibition of keratinocyte growth by different Nepalese *Zanthoxyllum* species. Phytother Res. 1999; 13(3):214-217. PMID: 10353160. https://doi.org/10.1002/(SICI)1099-1573(199905)13:3<214::AID-PTR431>3.0.CO;2-2
67. Guglielmini G, Crtoni A. *Zanthoxylum armatum* extract inhibits skin sensitivity. C and T. 2002; 117(7):47-54.
68. Kharshiing EV. Aqueous extracts of dried fruits of *Zanthoxylum armatum* DC (*Rutaceae*) induce cellular and nuclear damage coupled with inhibition of mitotic activity *in vivo*. Am J Plant Sci. 2012; 3(11):1646-1653. https://doi.org/10.4236/ajps.2012.311200
69. Sati SC, Sati MD, Raturi R, New flavonoidal glycoside from stem bark of *Zanthoxylum armatum*. IJPI's J Pharm Herb Form. 2011;1(2):29-32.
70. Kaur V, Kumar T, Bora SK. Pharmacological evaluation of *Zanthoxylum armatum* root extract on analgesic and antiinflammatory activity. J Pharm Res. 2011; 4(8):25-61.
71. Guo T, Deng YX, Xie H, Yao CY, Cai CC, Pan SL, Wang YL. Antinociceptive and anti-inflammatory activities of

ethyl acetate fraction from *Zanthoxylum armatum* in mice. Fitoterapia. 2011; 82(3):347-351. https://doi.org/10.1016/j.fitote.2010.11.004

72. Batool F, Sabir SM, Rocha JBT, Shah AH, Saify ZS, Ahmed SD. Evaluation of antioxidant and free radical scavenging activities of fruit extract from *Zanthoxylum alatum*: A commonly used spice from Pakistan. Pak J Bot. 2010; 42(6):4299-4311.
73. Upadhyaya KUK, Kumar AP. Concentration-dependent antioxidant activity of *Zanthoxylum armatum*. J Pharm Res. 2010; 3(7):1581-1582.
74. Parajuli RR, Tiwari RD, Chaudhary RP, Gupta VN. Fungitoxicity of the essential oils of some aromatic plants of Manang against *Alternaria brassicicola*. Sci World. 2005; 3(3):39-43.
75. Yun ZYZ, Ying-Hui PYHP, Dong-Qin Z, Fei-Fei C, Qio-Hui Q, Yi H. Insecticidal activity of essential oil from *Zanthoxylum armatum* fructification against two mosquito species. Science Press. 2010; 30(2):274-279.
76. Ramanujam SN, Ratha BK. Effect of alcohol extract of a natural piscicide- fruits of *Zanthoxylum armatum* DC.on Mg^{2+}- and Na^{+}, K^{+}-ATPase activity in various tissues of a freshwater air-breathing fish, *Heteropneustes fossilis*. Aquaculture. 2008; 283(1-4):77-82. https://doi.org/10.1016/j.aquaculture.2008.07.033
77. Verma N, Khosa RL. Hepatoprotective activity of leaves of *Zanthoxylum armatum* DC in CCl_4 induced hepatotoxicity in rats. Indian J Biochem Biophys. 2010; 47(2):124-127. PMID: 20521628
78. Galigher AE, Kozloff E. Essentials of practical microtechnique. 2nd Edition. Lea and Febiger. 1971: p. 77.
79. Gilani SN, Khan A, Gilani AH. Pharmacological basis for the medicinal use of *Zanthoxylum armatum* in gut, airways, and cardiovascular disorders. Phytother Res. 2010; 24(4):553-558. PMID: 20041426. https://doi.org/10.1002/ptr.2979
80. Sharif S, Lodhi M, Nayi;a I, Irshad A. Phyto-fabrication and characterization of gold nanoparticles by using Timur (*Zanthoxylum armatum* DC) and their effect on wound healing. 2024. https://doi.org/10.1515/chem-2024-0047
81. Alam F, Saqib QNU, Ashraf M. Zanthoxylum armatum DC extracts from fruit, bark and leaf induce hypolipidemic and hypoglycemic effects in mice- *in vivo* and *in vitro* study. BMC Complement Altern Med. 2018; 18(1):68. PMID: 29463309. PMCID: PMC5819252. https://doi.org/10.1186/s12906-018-2138-4
82. Ranawat L, Patel J, Bhatt J. Hepatoprotective activity of ethanolic extracts of bark of *Zanthoxylum armatum* DC in CCl_4 induced hepatic damage in rats. J Ethnopharmacol. 2010; 127(3):777-780. PMID: 19874881. https://doi.org/10.1016/j.jep.2009.10.019
83. He Z, Lei Y, Gong W, Ye M, Luo X. Karyotype and phylogenetic relationship analysis of five varieties and cultivars of *Zanthoxylum armatum* based on Oligo-FISH. Genes. 2023; 14(7):1459. PMID: 37510363. PMCID: PMC10379346. https://doi.org/10.3390/genes14071459
84. Hu YY, Qian WZ, YI L, Mao YD, *et al*. Chemical composition and antioxidant activity of *Zanthoxylum armatum* leaves in response to plant age, shoot type and leaf position. Forests. 2023; 14(5):1022. https://doi.org/10.3390/f14051022
85. Okagu IU, Ndefo JC, Aham EC, *et al*. Zanthoxylum species: A comprehensive review of traditional uses, phytochemistry, pharmacological and nutraceutical applications. Molecules. 2021; 26(13):4023. PMID: 34209371. PMCID: PMC8272177. https://doi.org/ 10.3390/molecules26134023
86. Batool A, Azizullah A, Ullah K, *et al*. Green synthesis of Zn-doped TiO_2 nanoparticles from *Zanthoxylum armatum*. BMC Plant Biol. 2024; 24(1):820. PMID: 39215226. PMCID: PMC11365237. https://doi.org/10.1186/s12870-024-05525-3
87. Saba T, Saleem F, Liu W, *et al*. Combined application of organic manure and reduced-rate chemical fertilizer improved growth, nutrient use efficiency, biomass accumulation, and carbon sequestration of *Zanthoxylum armatum* seedlings. CJFR. 2023; 54(3):349-356. https://doi.org/10.1139/cjfr-2023-0115