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A COMPREHENSIVE INSIGHT ON PHYTOCHEMISTRY AND THERAPEUTIC POTENTIAL OF *TECOMELLA UNDULATA* (ROHIDA)

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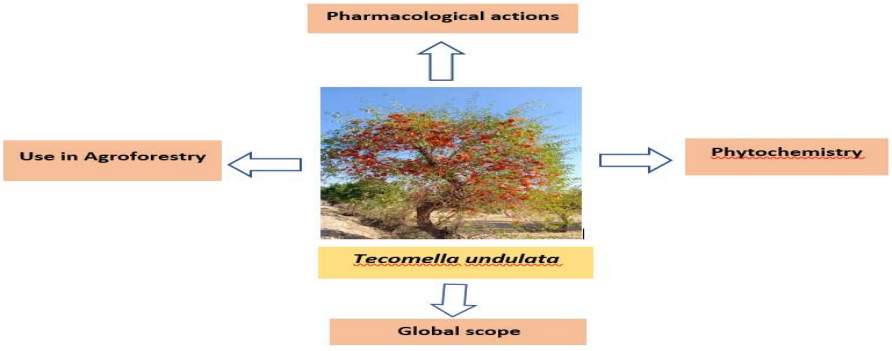
Tecomella undulata is a type of shrub in the family Bignoniaceae. It is a small tree that grows in the dry parts of India, Pakistan, and Arabia. It has a lot of commercial and medical value and can be used to make a lot of different things. In Rajasthan's desert area, the "Desert teak" or "Marwar teak" is the most important wood-producing tree species. *Tecomella undulata* is known in both conventional and folk systems of indigenous medicines to have important healing properties. Hepatoprotective, antibacterial, antimicrobial, antifungal, anti-termite, immunomodulatory, anticancer, cytotoxic, analgesic, anti-inflammatory, and anti-obesity activities are just a few of the plant's numerous, well-known therapeutic characteristics. The plant is the source of the ayurvedic drug rohitakarishta, which is used to treat liver, spleen, and blood disorders. This tree is in danger of going extinct because conservation efforts aren't as good as they could be and because the pharmaceutical and lumber industries want more of it. This species is now considered "threatened" in the Indian state of Rajasthan. One of the main problems with this tree is that it is susceptible to many diseases and pests. This makes it harder for it to grow and spread. Even though seeds are often used to spread it, natural plant growth isn't as common because seeds can be carried by the wind to faraway places, harsh weather can make it hard for seeds to spread, seeds can die if they are not harvested and stored properly, and there aren't as many seeds that can grow back. Because the tree grows so slowly, there are no good ways to speed up its reproduction through vegetative propagation. No one has tried to start breeding programmes to make *T. undulata* better. Even though there is some research on *T. undulata's* cytology, function in agroforestry and silviculture, association with vesicular arbuscular mycorrhiza, and use of biotechnological tools, the number of research papers on the identification of bioactive components and confirmation of pharmacological effects has grown exponentially in recent years.



Keywords: Pharmacology, Phytochemistry, Quinones, Rohida, *Tecomella undulate,* Triterpenes.

Introduction

Indigenous herbal treatments have been used for a long time, and recently, a lot of people have been interested in them because they might have health benefits. The World Health Organization says that more than 80% of the world's people live in countries that don't have enough money to take care of their basic health needs[1,2]. The Bignoniaceae family, which is made up of ornamental plants that are not native to India, has about 25 species and 21 genera. Because it can survive fire and drought, it is a great plant for reforestation in dry areas[3]. *Tecomella undulata* belongs to the family Bignoniaceae, but mostly known as "Rohida". It could look like a small bush or tree. The Thar Desert is in the northwest and west of India. This is where *Tecomella undulata* lives[4]. Traditional Ayurvedic texts called Samhitas all talk about the tree because it has healing properties. The tree's bark is used in many ayurvedic medicines, such as Rohitakarista, Rohitaka ghrta, Rohitakadya choorna, and Rohitakaloha[5].

Tecomella undulata's bark contains the ferulic esters octacosanyl acetylferulate and octacosanylferulate. Tectol, dehydrotectol, sitosterol, deoxylapachol, lapachol, and tectoquinone are also found in it. Iridoid glucosides called tecoside, undulatin, and tecomelloside are also found in the bark[6-8]. *Tecomella undulata* is a plant that has been used to treat tumours, conjunctivitis, hepatosplenomegaly, syphilis, gonorrhoea, hepatitis, as a blood purifier, and to heal wounds. Through phytochemical analyses of plant parts, compounds like iridoid glucoside, naphthoquinone, phytosterols, flavonoid glycoside, flavanol, fatty alcohol, fatty acid and triterpenoids have been found. Pharmacological studies have shown that it is anti-HIV, kills bacteria, relieves pain and inflammation, fights free radicals and protects the liver. So, we set out to make an up-to-date and thorough report that includes the most recent information on *Tecomella undulata*'s appearance, chemical makeup, traditional uses, and biological effects.

1. Traditional uses of Tecomella undulata-

Bark: In Sind, the bark of young branches is effective as a treatment for syphilis. The Indian Economy Additionally, bark is cooling, astringent, and anthelmintic. Leucoderma, leucorrhoea, fever, piles, urinary abnormalities, liver and spleen enlargement, worms, and anorexia are among the conditions for which it is prescribed[9,10]. Women in Samahni Valley tribal groups in Pakistan ingest bark powder and heated milk to induce abortions. Bark is also utilised as a choleretic, cardiotonic, and muscle relaxant[11].

Ayurvedic traditional writings state that *T. undulata* is specifically used to cure a variety of abdominal conditions, including ascites. In order to treat jaundice, anaemia, intestinal worms, and problems of the urinary system, Charaka recommended powder bark, its decoction, and its extract in clarified butter.

Seeds: The seeds are astringent, cooling, laxative, anthelmintic, and helpful for ulcers, blood disorders, eye, ear, and muscle pain. These have minimal sedative and cardiotonic effects. As well as being used to treat eczema, seeds are utilised to treat abscesses. To treat haemorrhoids, *Tecomella undulata* seeds are mashed with *Pinus* leaf extract[12].

Leaves: Leaves of the plant are used to treat migraine[13].

Root: Leucorrhoea is treated using *Tecomella undulata* root paste, which is occasionally combined with rice water[14].

Flowers: For infertile ladies and to quench their thirst, floral tea is beneficial. In folklore, the entire plant is used to treat various allergies and old wounds[15,16].

Table 1: Summary of the phytoconstituents isolated from the plant Compounds isolated from *Tecomella undulata*-

S.No.	Compound name and molecular formula	Plant part and references
NAPHTHOQUINONES		
1.	Lapachol ($C_{15}H_{14}O_3$)	Heartwood (Sandermann and Dietrichs 1957; Singh et al. 1989; Gupta and Singh 2004; Lukmandaru and Takahashi 2009; Khan and Mlungwana 1999), Roots (Joshi et al.1977)
2.	Deoxylapachol ($C_{15}H_{14}O_2$)	Heartwood (Smith and Thomson 1961; Windeisen et al. 2003; Sandermann and Simatupang 1963; Gupta and Singh 2004)
3.	5-Hydroxylapachol ($C_{15}H_{14}O_4$)	Root heartwood (Khan and Mlungwana 1999)
4.	α-Lapachone ($C_{15}H_{14}O_3$)	Roots (Joshi et al. 1977)
5.	β-Lapachone ($C_{15}H_{14}O_3$)	Roots (Joshi et al. 1977)
6.	Dehydro-α-lapachone ($C_{15}H_{12}O_3$)	Heartwood (Singh et al.1989; Gupta and Singh 2004; Khan and Mlungwana 1999), Roots (Joshi et al. 1977)
7.	Tecomaquinone ($C_{30}H_{24}O_{4)}$	Heartwood (Sandermann and Dietrichs 1959; Gupta and Singh 2004)
8.	Radermachol ($C_{24}H_{16}O_4$)	Stem bark (Kumawat et al.2012)
STEROLS		
9.	Stigmasterol ($C_{29}H_{48}O$)	Roots (Joshi et al. 1977; Dayal and Seshadri 1979)
10.	β-Sitosterol ($C_{29}H_{50}O$)	Roots (Joshi et al. 1977; Dayal and Seshadri 1979)
11.	Campesterol	Roots (Joshi et al. 1977; Dayal and Seshadri 1979)
FLAVANOIDS		
12.	Quercetin ($C_{15}H_{10}O_7$)	Leaves (Nayeem and Karvekar 2010)
13.	Rutin($C_{27}H_{30}O_{16}$)	Leaves (Nayeem and Karvekar 2010)
TRITERPENOIDS		
14.	Lupeol ($C_{30}H_{50}O$)	Heart wood (Saleem et al. 2009)
15.	β-amyrin ($C_{30}H_{50}O$)	Heart wood (Melo, Neves et al. 2010)
FATTY ACIDS		
16.	Linolenic acid ($C_{18}H_{30}O_2$)	Stem bark (Nagpal et al. 2010)

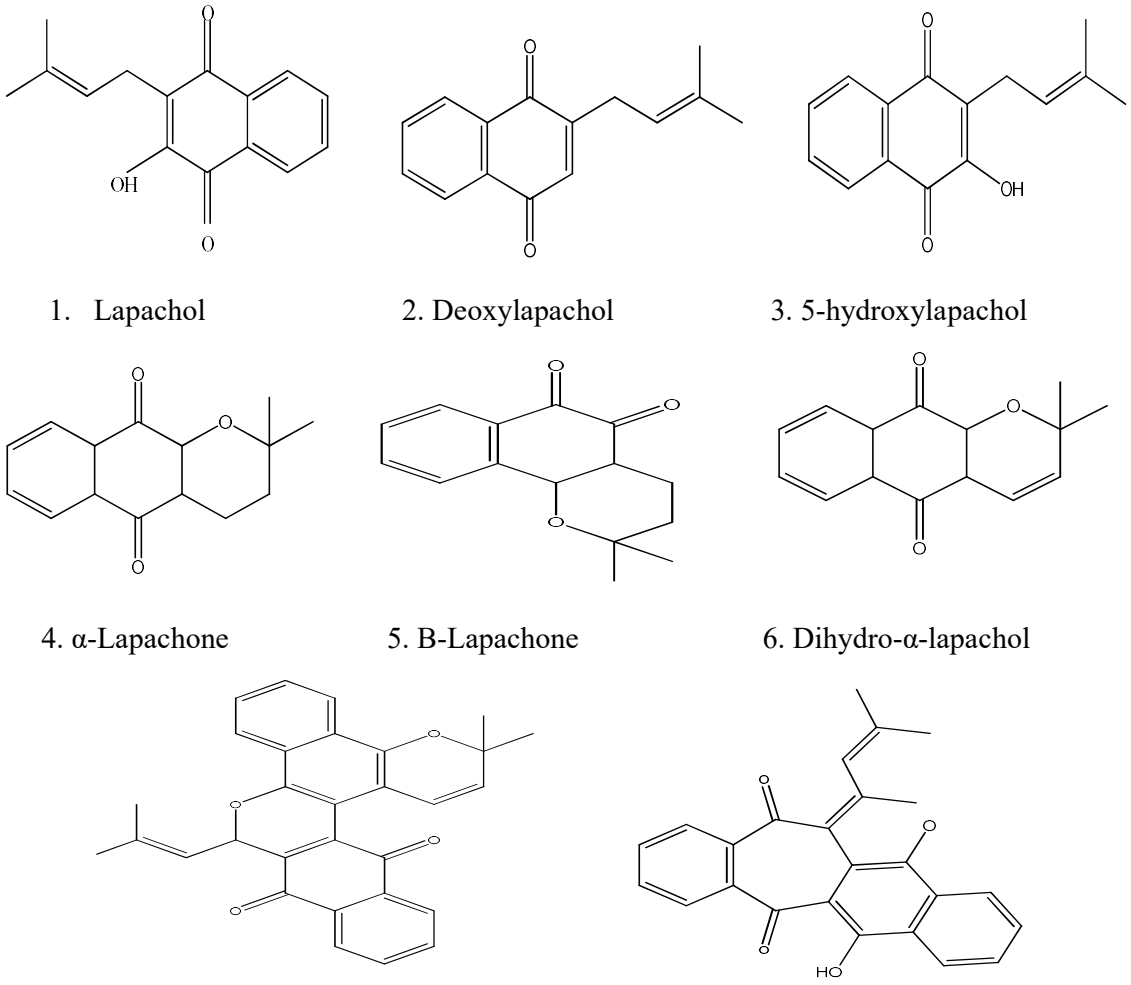
2. Taxonomy and cultivation:

It has drooping branches with beautifully tomentose grey leaves, giving it the appearance of a little tree or shrub. It is the solitary species in the monotypic genus *Tecomella*. In the arid regions of Shekhawati and Marwar in Rajasthan, it is a medium-sized tree that produces high-quality wood and is the main source of wood among the local tree species. Commercially, the tree is referred to as desert teak or Marwar teak. It is particularly lovely when the tree is completely blossomed from March to April[17].

Leaves: The leaves are simple 5-12.5 cm in length and 1-3.2 cm in width, narrowly oblong, obtuse, and entire with undulate margins.

Flowers: Corymbose few flowered racemes have calyxes that are 9.5-11 mm long and campanulate, and pedicles that are 6-13 mm long. The flowers on these racemes are inodorous. The lobes are 3mm long, generally oval-shaped, obtuse, and mucronate. The 3.8–6.3 cm long, orange–yellow, campanulate, and veined corolla is five lobes with identical spacing are present. The stamens are exserted, and the filaments are glabrous. There are two spherical, spathulate-oblong, lamellate stigmas. The capsules are linear-oblong, acute, smooth, and have thin valves.

Seeds: Size of seeds: 2.5 by 1 cm. At the base of the seed, wings are nonexistent and are very narrow around the apex. *Tecomella undulata* seeds have wings, and Rohitaka blooms and bears fruit between the months of April and May[18].



1. Lapachol 2. Deoxylapachol 3. 5-hydroxylapachol

4. α-Lapachone 5. B-Lapachone 6. Dihydro-α-lapachol

7. Tecomaquinone 8. Radermachol

Figure 1.:- Chemical structure of naphthoquinones.

3. Phytochemistry

Ursolic acid, oleanolic acid, and lapachone, lapachol, verbascoside, corymboside, lupeol, quercetin, apigenin, pomolic acid, and isoacteoside are some of the more common but pharmacologically significant bio-active constituents reported from Bignoniaceae family plants reviewed in the present study. The roots contain naphthoquinones (Figure 1), lapachol, tricontanol 1, β-sitosterol, tectol, veratric acid, 6 O-veratryl catalposide, and quinines. While the seeds have 7.14% tannin, the seed oil has 53% linoleic acid. Heartwood contains radermachol, lapachol[19,20]. *Tecomella undulata's* shell contains aphanamixin lactone and aphanamixolide along with dehydrolapachol. The plant produces cirsili and cirsimaritin in its leaves. In addition to this bark also contains Sterols (Figure 2). The bark also contains luteolin 7 glycoside, iridoid glucosides, tecomelloside, rutin, quercetin, and β-sitosterol in addition to lauric acid. Two examples of the chemical elements present in *Tecomella undulata* Linn. are lapachone and cluytyl frulate[21]. Apart from those flavonoids, triterpenoids and some fatty acids are also found (Figure 3, 4 and 5 respectively). (Table 1)

4. Pharmacology:

Tecomella undulata's effects have been the subject of numerous investigations in recent years. *Tecomella undulata* has historically been utilised by traditional healers and herbalists to treat ailments in both people and animals as well as to enhance the function of various body parts. Research has generally confirmed conventional experience and wisdom by pinpointing the mechanisms and modes of action as well as reiterating the therapeutic efficacy of plants or plant extracts in clinical tests[22-29].

Some interesting pharmacological properties are depicted below (Figure 6).

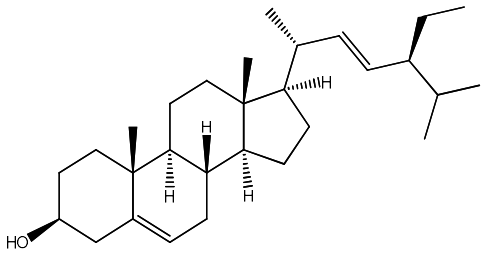
Anti-microbial activity: Salmonella typhi, the organism that causes typhoid fever, could not grow in leaf and stem extracts of *T. undulata* that were either water-based or alcoholic. *Tecomella undulata* extracts in both methanol and water have been shown to kill bacteria. We used the agar disc diffusion method and the agar well diffusion method to test how well aqueous and methanol extracts killed bacteria. The water extracts didn't work as well as the methanol extracts. Both aqueous and methanolic extracts have anti-microbial activity against *B. cereus*, *S. aureus*, *E. coli*, and *K. pneumonia* [30,31,32].

Anti-HIV potential: Oleanolic acid, ursolic acid, and betulinic acid—three potent HIV inhibitors—are present in *Tecomella undulata* leaves, according to biochemical research. The drug AZT, which is now used to suppress the development of AIDS, has been proven to be 24 times less efficient than compounds of oleanolic acid and betulinic acid octa dimethyl succinate. To develop a ground-breaking herbal medicine, more investigation is necessary to identify the underlying mechanism of *Tecomella undulata* effectiveness in treating AIDS[33].

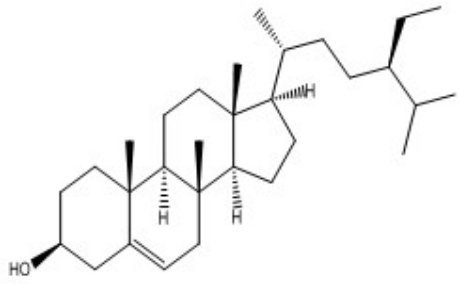
Anti-inflammatory activity: An experimental model of carrageenan-induced rat paw edoema was used to test the anti-inflammatory effects of a whole plant methanolic extract of *Tecomella undulata.* Scientists found that giving *T undulata* extract by mouth at doses of 300, 500, or 1000 mg/kg bodyweight decreased the amount of paw edoema in a way that changed with the dose [34,35].

Analgesic activity: The analgesic efficacy of the whole plant methanolic extract of *Tecomella undulata* was evaluated in mice using the hot water tail immersion test. Following oral treatment of *T. Undulate* extract (300, 500, or 1000 mg/kg), the results showed a significantly lower tail flick response.

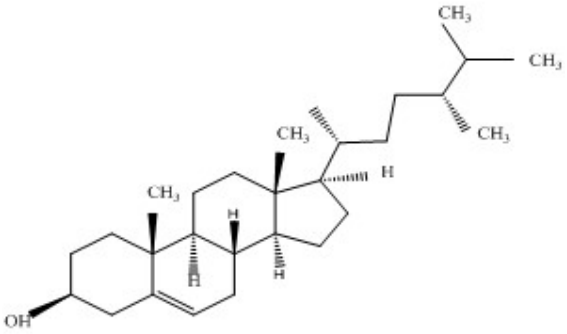
Hepatoprotective activity: Plants that protect you against paracetamol-induced toxicity. The oral dose of Rohitaka ghrita (3.6 and 7.2 g/kg, p.o. daily) for 7 days significantly reduced the need for paracetamol (3 g/kg, p.o.) on the third and fifth days. The first investigation on the hepatoprotective effectiveness of *Tecomella undulata* leaves against alcohol and paracetamol-induced liver injury in rats utilised a methanolic extract. They discovered that ingesting *T. undulata* extract orally for 15 days before alcohol and pain reliever treatments avoided increases in AST, ALT, ALP, GGT, and total bilirubin levels, falls in the activity levels of hepatic antioxidant enzymes, and increases in hepatic lipid peroxidation. Additionally, hepatocyte damage from alcohol and paracetamol was significantly lessened and necrotic cell death was prevented by pre-treatment with its extract[36]**.** Goyal *et al*. recently described the hepatoprotective effects of an ayurvedic drug named Rohitaka ghrita, which contains four other enzymes—AST, ALT, ALP, and bilirubin[37]. The histology of the liver improved in rats due to further decreases in hepatic lipid peroxidation as well as elevated glutathione levels, catalase activity, and Na^+-K^+ ATPase levels. These findings strongly support the *T. undulata'*s hepatoprotective abilities and its use in conventional and herbal treatments[37].



9. Stigmasterol

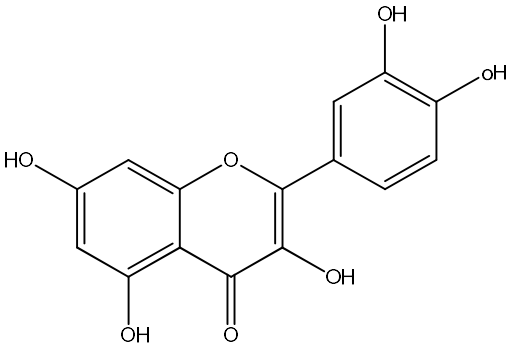


10. B-Sitosterol

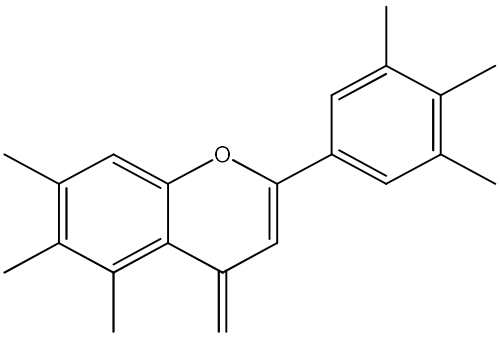


11. Campesterol

Figure 2.:- Chemical structures of sterols.

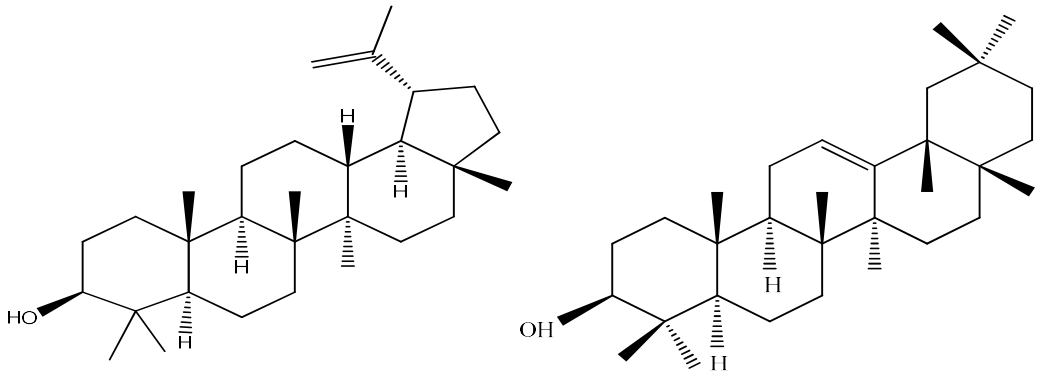


12. Quercetin



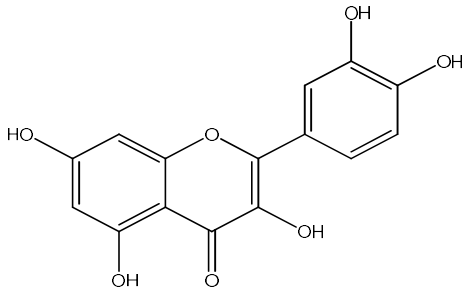
13. Rutin

Figure 3.:- Chemical structures of phenolic compounds and flavonoids.



14. Lupeol 15. B-amyrin

Figure 4.:- Chemical structures of terpenoids.



16. Linolenic acid

Figure 5.: - Chemical structure of fatty acid.

Anti-cancer potential: We recently found that an extract of plant stem bark in chloroform can help fight cancer. We used a chronic myeloid leukaemia cell line to test how well *Tecomella undulata* extract could fight cancer (K562). The work was made bigger so that quercetin could be used as a biomarker to standardise the extract. At concentrations between 10 and 100 g/ml, *Tecomella undulata* significantly slowed the process of cell division in K562, COLO-205, MDA-MB231, and HepG2 cells. Also, it was shown that the effect was dose-dependent. With an IC50 of 30 ng/ml, it turned on FAS, FADD, caspase 8, caspase 3/7, and DNA fragmentation. The conventional claim was proven to be true when the authors showed that *T. undulata* extract might be able to fight cancer. Savjiyani *et al.*, recently tested the anti-cancer effects of a mixture of herbs called SJT ONC, which was made from extracts of the stem bark of *Tecomella undulata*, *Bauhinia variegata*, *Oroxylum indicum*, and *Indigofera tinctoria*. The Caco-2 and MCF-7 cell lines were killed by SJT ONC-1 (1000 g/ml). Also, SJT ONC-1 (300 mg/kg, orally) was given to rats on a high-fat diet while they were given DMBA for 12 weeks. This caused the size of their breast tumours to decrease in a noticeable way. The results were similar to those of the drug 5-fluoro uracil, which is used by a lot of people [38,39].

Immunomodulatory activity: The herbal combination of plant with *Moringa oleifera, Boerhavia diffusa, Onosma bracteatum, Bauhinia variegata, Spheranthus indicus, Chlorophytum*

borivilianum, Ficus racemosa, and *Cyperus rotundus* can be used to treat a compromised or failing immune system. This herbal therapy has been shown to be particularly effective in treating all abnormalities brought on by subtle immunological imbalances, in managing immunological processes, and in preserving the immune system's normal physiological functioning[40].

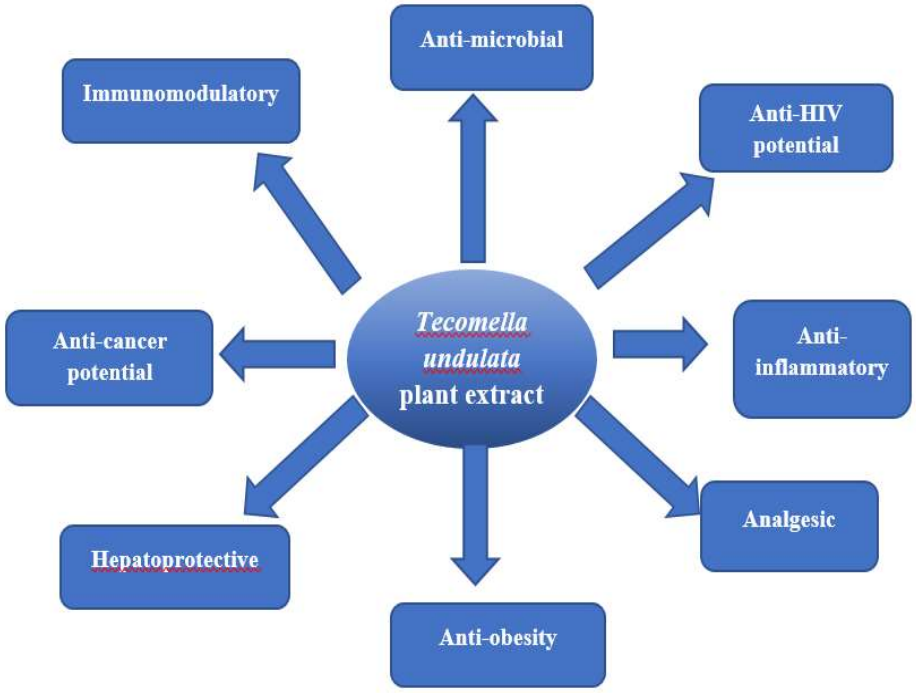


Figure 6.: - Pharmacological Properties.

Antiobesity: Alvala *et al.* investigated the potential anti-obesity effects of *Tecomella undulate* bark. 3T3 L1 cells were used in the initial research. The ethyl acetate extract underwent column fractionation, resulting in seven fractions, because it inhibited adipocyte development more effectively than the other two extracts (data not shown). Adipogenesis assays have been performed on all seven fractions. The results of adipogenesis are best in the first part[41].

Anti-diabetic and Anti-oxidant: In type 2 diabetic rats, streptozotocin and nicotinamide were employed to examine the anti-diabetic properties of *Tecomella undulata* ethanolic extract. The extract dramatically reduced blood glucose levels during the oral glucose tolerance test. Blood tests for glucose, cholesterol, glycogen content, glycosylated haemoglobin, and the anti-oxidant markers malondialdehyde and glutathione level can be performed using standard kits[42]. (Table 2)

With a Soxhlet extractor, 2 L of ethanol, and 48 hours, 350 g of coarse powdered *Tecomella undulata* bark was completely extracted. Extract were concentrated with a Rota vacuum evaporator at a temperature below 60 °C and under less pressure to get 84 g of *Tecomella undulata* extract and 40 g of *Tephrosia purpurea* extract that had the consistency of thick syrup. *Tephrosia purpurea* extract has a 5% (w/w) yield. *Tecomella undulata* extract has a 24% (w/w) yield. The doses were given by putting the extracts in distilled water with 2% (w/v) of gum *Acacia*.

Table 2: -Summary of *in vivo* studies of antihyperglycemic potential of *T. Undulate.*

Treatment	Dose	Mean blood glucose concentration (mg/dl) ± S.E.M			
		0 hr	2 hr	6 hr	24 hr
Control	----------	385.5 ± 12	404.8 ± 10.3	379 ± 6.1	341 ± 7.1
Metformin	100 mg/kg	393.4 ± 27.2	342 ± 8.9	280.8 ± 6.9**	363 ± 5.2
***Tecomella undulata* Eth.**	200 mg/kg	385 ± 26.4	381.1 ± 26.2	356 ± 29*	370 ± 2.3
***Tecomella undulata* Eth.**	500 mg/kg	379.8 ± 21.8	376.2 ± 20.7	330 ± 1.6**	371 ± 9.4

*Values are presented as Mean ± S.E.M.; n = 6 in each group. One way ANOVA followed by Dunnett's t test, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ vs. control; *Tecomella undulata* Eth.: Ethanolic extract of *Tecomella undulata* leaves.

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5. *Achievements made in Tecomella undulata through biotechnological approaches:*

Due to the limitations of conventional breeding and propagation techniques, the lack of a precise estimate of the diversity that is available, the requirement for elite planting material for commercial plantations, and the lack of established conservation strategies, the application of plant biotechnologies, such as plant tissue culture and genetic engineering, as well as the application of molecular markers for diversity assessment, are required for the improvement of *T. undulata*. The use of biotechnological methods has advanced, including plant tissue culture, genetic engineering, and study of the genetic diversity in *T. undulata.*

Micropropagation: The ultimate objective of the in vitro technique in a tree conservation project is the clonal replication of elite, mature genotypes or cultivars with demonstrated disease resistance or abiotic tolerance. The ability to apply a micropropagation technique developed using mature explants for fast cultivar development frequently results in a high level of commercial potential However, it may be difficult to regenerate woody plants in vitro when explants are derived from mature trees. Young tree tissues generally respond to in vitro alteration better than adult tree tissues do. Organogenesis or somatic embryogenesis

can be used for in vitro plant regeneration. However, there is no evidence of *T. undulata* somatic embryogenesis. In the past, explants from both seedlings and mature plants were utilised to promote callus or axillary shoot development in *T. undulata* to promote organogenesis[43.44,45].

Conclusion

The research on several aspects of *Tecomella undulata* and associated folklore traditions has been compiled in the current review. This plant has a great deal of potential for further study because it includes a range of intriguing compounds. Separated and refined plant-derived pure components are also required. Therefore, the likelihood of finding novel molecules with therapeutic usefulness will be greatly increased by comprehensive assessment of these pure compounds with standard claims. It would also be beneficial to assess the pre-clinical toxicity of various bioactive *Tecomella undulata* extracts and compounds. Because it is an endangered species, it is possible to develop methods for growing this plant in plant tissue to give a steady supply of the phyto-constituents it possesses.

Due to its phytotoxic activity, *T. undulata* cultivation has also developed into a productive tool for pest control in the direction of sustainable agriculture. Pharmacological and phytochemical research, however, were conducted independently and lacked the ability to identify or isolate active compounds. In order to produce viable potential medication candidates, more study is needed to associate its pharmacological activity with chemical components.

This rigorous assessment has led us to the conclusion that there is enough credible scientific data to support the claim that *T. undulata* is an intriguing source of bioactive chemicals.

However, pharmacological and phytochemical studies have been carried out independently and lack identification of isolation of active molecules. Hence, more research is required to correlate its pharmacological activity with chemical constituents, so that promising potential drug candidates could be developed. Based upon this critical review it can be concluded that there is sufficient scientifically valid evidence to state that, *Tecomella undulata* is an incredible source of bioactive compounds.

Declaration of Conflicting Interests

The author(s) declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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