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RESEARCH ARTICLE

CRITICAL REVIEW ON *Tecomella undulata*: A MEDICINALLY POTENT ENDANGERED PLANT SPECIES OF INDIAN THAR DESERT

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ABSTRACT

From time immemorial, man has remained dependant on plants and if we consider the historic perspective it is evident that the fascination for plants is as old as mankind itself. *Tecomella undulata* is a deciduous shrub or small tree, found in northwestern India and southern Pakistan. The plant is under threatened category due to its imprudent harvesting from wild. The plant is used to cure leucorrhoea, leucoderma, enlargement of spleen, traumatic wounds, hepatitis, piles, anorexia, flatulence, tumors, worm infestations and syphilis. Leaves of the plant contain certain compounds which are effective against HIV infection. Various compounds have been isolated from the plant parts mainly bark and leaves, viz Radermachol, lapachol, tecomaquinone-I, α-lapachone, β-lapachone, stigmasterol, β-sitosterol, oleanolic acid, ursolic acid and betulinic acid. In the present review, we have summarized the information concerning the occurrence, botanical description, applications, medicinal uses, biological activities and hepatoprotective studies on this plant.

INTRODUCTION

All over the world including both the developed and developing countries usage of various herbal medicines has gained momentum. Their efficacy has been established and millions of people have benefited due to them. *Tecomella undulata* is a member of the family Bignoniaceae, chiefly found in the arid zone regions. According to its distribution in India, family bignoneaceae is represented by 21 genera and about 25 species including non indigenous ornamental plants. Among these *Tecomella* is a monotypic genus and one of the most important deciduous, ornamental shrub or small tree of the dry regions (Shankarnarayan and Nanda, 1963). It flourishes well in dry districts and also at places where irrigation is not possible. The tree is locally known as Rohida, and produces quality timber. It is the main source of timber amongst the tree species of desert regions of Shekhawati and Marwar in Rajasthan, this makes the tree economically very important (Khan and Frost, 2001). The trade name of this species is Desert teak or Marwar teak. The tree has medicinal properties and has been mentioned in all ancient Samhita of Ayurveda. Bark of the tree is used in many ayurvedic preparations like Rohitakarista, Rohitaka ghrta, Rohitakadya choorna, Rohitaka loha etc. It has been used in treatment of syphilis, painful swellings and cancer traditionally. Wide ranges of therapeutic activities have been attributed to this plant like, antibacterial, hepatoprotective, immunomodulatory, anti-inflammatory activities etc. It is a very useful species for afforestation of the drier tracts due to its drought and fire resistant properties (Shankarnarayan and Nanda, 1963).

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It is a widely accepted tree species in agroforestry, because of its higher survival rates even in extreme conditions (Anonymous, 2003). It also acts as a soil binder. The plant has broad spectrum activities so, the present review focuses on the medicinal uses and pharmacology of *Tecomella undulata* along with its economic applications, distribution and commercial importance so that it can be grown enormously and can be used for various purposes especially by the desert people.

Botanical description

Tecomella undulata is a deciduous or nearly evergreen tree of arid and semi arid regions (Chopra *et al*., 1992). The plant is known by various names throughout India. It is called as desert teak in English, rugtrora in Hindi, rohira in Punjabi, lohira in Sindhi, rakhtroda in Marathi and rohita in Sanskrit (Sharma *et al*., 2001).

Plant description

Tecomella is a large shrub or small tree with drooping branches and greyish- green leaves. Tree attains a height of about 2.5 to 5m. The leaves are simple 5 to 12.5cm in length and 1 to 3.2cm in width, narrowly oblong, obtuse, and entire with undulating margins. Flowers are large, beautiful, orange-red and odourless. Flowers are present in corymbose few flowered racemes, terminating short lateral branches, pedicles are 6 to 13 mm long, Calyx 9.5 to 11mm long, campanulate. Flowers are beautifully coloured and found in yellow, red and orange colours. Flower is considered as the state flower of Rajasthan. Lobes are 3mm long, broadly ovate, obtuse, mucronate. Corolla is 3.8 to 6.3cm long, orange yellow,

campanulate, veined. Lobes are 5 subequal rounded. Stamens are exerted and filaments are glabrous. Stigma are 2 lamellate, lobes are spathulate-oblong, rounded. The tree blooms in the month of April-May and bears fruits, thereafter. Capsules are 20 by 1 cm slightly curved, linear-oblong, acute, smooth. Valves are thin. Seeds are 2.5 by 1 cm. Wings are very narrow round the apex of seed while absent at its base (Chal *et al*., 2011).

Environmental preferences and tolerances

Tecomella is widely adapted to the arid regions (Khan *et al*., 2003; Kar *at al*., 2009). The tree occurs on flat as well as undulating areas including gentle hill slopes and sometimes also in the ravines. Rohida can tolerate drained loamy to sandy loam soil having pH in the range 6.5 to 8.0. The species thrives very well on stabilized sand dunes, which experience extreme low and high temperatures. It grows in areas of scanty rainfall almost as less as 150 to 500mm annually and high temperature 35°C to 48°C. It can withstand extreme low temperature (0°C to −2°C) during winter and high temperature (48°C to 50°C) in summers. The tree is a strong light demander. It is drought, frost, fire and wind hardy.

Distribution

Tecomella undulata (Sm.) Seem is a medicinally and economically important plant that originated in India and Arabia (Randhawa and Mukhopadhyay, 1986). Distribution of *Tecomella undulata* is restricted to the drier parts of the Arabia, southern Pakistan and northwestern India up to an elevation of 1200 meters (Tewari, 2007). In Pakistan it is found in the regions of Sindh and Baluchistan. In India, it occurs naturally in Maharashtra, Gujarat, Rajasthan, Punjab and Haryana. The species is mainly found to occur in western parts of Rajasthan. In other states its population is scanty and very rare. In Rajasthan, *Tecomella undulata* is distributed throughout the districts of Barmer, Jaisalmer, Jodhpur, Pali, Ajmer, Nagaur, Bikaner, Churu and Sikar (Kritikar and Basu, 1993; Nadkarni, 2000).

Applications

The plant has various applications it is an important medicinal tree and also plays a major role in the ecology of the desert.

Ecological importance of the species

The tree is a key species of the drier regions and plays an important role in ecology of this region. The roots as well as the lateral roots of the tree spread on the top surface of the soil forming a network, thereby acting as a soil binder. It acts as a windbreak and helps in stabilizing shifting sand dune. Rao *et al*. (1986) observed a significant increase in carbon, nitrogen content and profuse growth of different microorganisms in the rhizosphere by *T. undulata* which is highly mycorrhizal in natural habitat. Mycorrhizal nature of Rohida makes it one of the most important tree species that can be used for research, including the 'bio-fertilizer' aspect as well as afforestation programme (Srivastava *et al*., 2004) in arid zones of the country. *Tecomella* has also been used for phytoremediation. Mathur *et al*. (2010) have reported its use in phytoremediation of soil contaminated with crude petroleum oil. It is a common agroforestry tree in region of Thar Desert (Rajasthan). The tree has played an important role in the amelioration of the conditions in arid and semi-arid lands and in providing livelihood support to the local communities. It can be observed growing in community land and forestland along with *Prosopis cineraria* (Singh, 2009).

Medicinal uses

Medicinal properties of the plant have been investigated both, in light of recent scientific developments as well as traditionally. The powder of bark is specially recommended in ascites with hepatosplenomegaly. It is an excellent blood purifier hence, rewarding in hepatitis. Bark forms a major constituent of various herbal formulations like Livo-plus, Liv-52, Herboliv, Amylcure, Livosan, Exol etc for curing inflammatory hepatic diseases. Besides it possesses significant anticancer (Ravi *et al.*, 2011), immunomodulatory (Choudhary, 2011), cytotoxic (Krishnarajua *et al.*, 2005), analgesic (Ahmad *et al*., 1994) and antibacterial activities (Parekh *et al*., 2005) etc. It is also used in the treatment of eczema (Shah *et al*., 2006). The bark of the plant has mild relaxant, cardio tonic, and chloretic (An agent, usually a drug, that stimulates the liver to increase output of bile) activities (Bhardwaj *et al*., 2010). The bark obtained from the young branches is often employed as a remedy for syphilis (Upadhyay *et al*., 2007). The bark is powdered and is used with hot milk for few days for abortion. Its seeds are crushed with extract of *Pinus* leaves, and taken to cure haemorrhoids (Ch *et al*., 2006). *T. undulata* leaves have oleanolic acid, ursolic acid and betulinic acid, compounds that are strong HIV prohibitors.

Ethnopharmacology

The local people exploit the plant extensively for medicinal purposes. In the indigenous system of medicine the drug has been extensively used for the treatment of leucorrhoea, leucoderma, enlargement of spleen and also used for treatment of urinary discharge due to kapha and pitta (Saxena, 2000). The paste of its bark is applied on traumatic wounds and in conjunctivitis the juice is instilled into eyes with great benefit. The traditional healers of Narharpur region use it in treatment of gynaecological troubles. As a keen stimulant for digestive system, powdered bark is used in the treatment for piles, anorexia, flatulence, tumors and worm infestations. People in the Shekhawati region and in the Churu districts use the pulp of the roots along with rice water to treat leucorrhea (Katewa and Galav, 2005). Meena tribes in the Aravalli hills report its use in allergies (Meena and Rao, 2005). Local people of garasia tribe use it as a remedy for syphilis (Meena and Yadav, 2010). The tribals of northern hilly region of Chhattisgarh consider Roheda useful in treatment of old wounds (Oudhia, 2005). Women of Kalat and Khuzdar regions Pakistan use flowers to make tea which is beneficial for sterile women. The tea is taken for 3-4 days during menses. The flowers are soaked in water and the extract is taken to reduce thirst. The fresh leaves are grinded and paste placed on the head for migraine (Tareen *et al.*, 2010).

Other applications and importance

T. undulata is one of the most useful trees of the arid zone. Wood obtained from the tree is known as 'desert teak'. It is

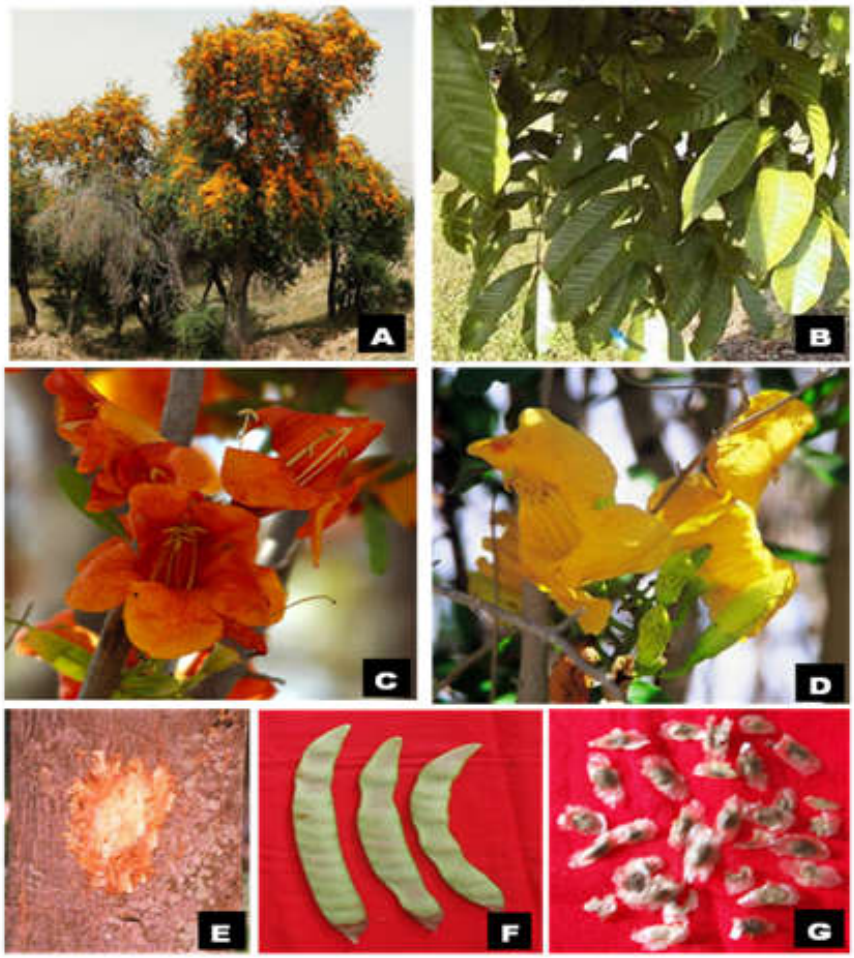


Fig.1: ***Tecomella undulata*** **and various other parts of the tree (A)** ***T. undulata*** **tree (B) leaves (C & D) Orange and yellow coloured flowers showing two different morphotypes (E) bark of rohida (F) fruits (G) seeds.**

Table I. Qualitative phytochemical tests, of different extracts obtained from bark of T. undulate (Bhardwaj et al., 2010; Goyal et al., 2010).

Tests	Petroleum ether extract	Ethyl acetate extract	Methanolic extract	Aqueous extract
Carbohydrates	–	–	–	–
Proteins and amino acids	–	–	–	–
Alkaloids	–	–	–	–
Tannins and phenolic compounds	+	+	+	+
Phytosterols	+	+	+	+
Glycosides	–	–	+	+
Saponins	+	–	+	+

soft, durable and takes a good polish it is therefore highly valued for engraved furniture, carvings, turnery and toys. The tree is economically valuable due to quality wood production (Bhandari, 1990; Singh, 1992). The tree is considered as the home of birds and provides shelter for other desert wildlife. The leaves are used as fodder for cattle and goats. The flowers and pods are relished by Camel, goats and sheep (Singh, 2010). The wood of this tree is an excellent source of firewood and charcoal (Kumar *et al*., 2008).

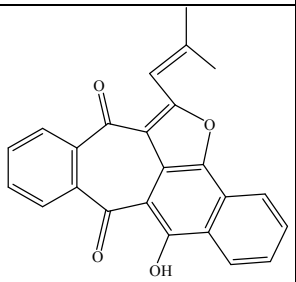
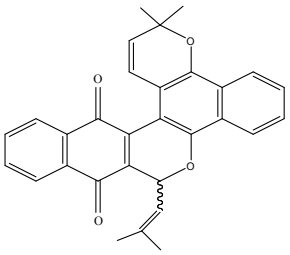
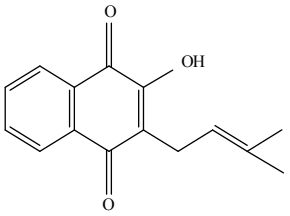
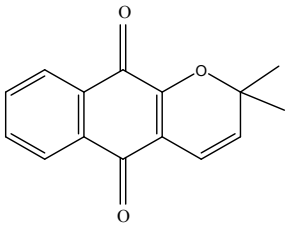
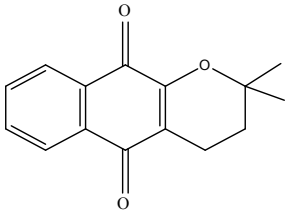
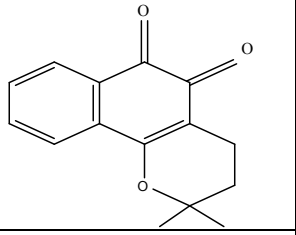
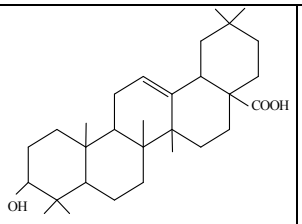
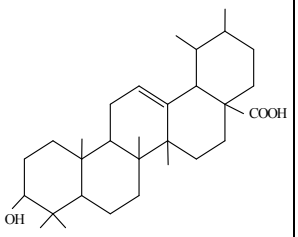
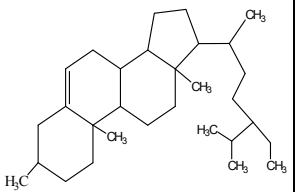
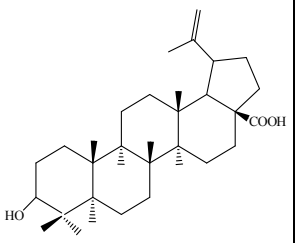
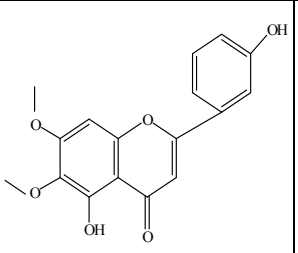
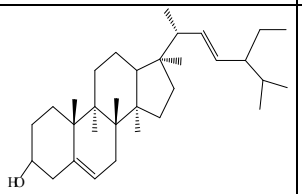
Bioactivity

Several experimental investigations have been undertaken in diverse *in-vitro* and *in vivo* models. Some pharmacological effects of *Tecomella undulata* have been reported such as hepatoprotective, immunomodulatory, anti-inflammatory etc.

Hepatoprotective Activity

Hepatoprotective activity of the bark of *T. undulata* has been validated by many workers. *T. undulata* leaves were tested against liver damage of albino rats. Levels of serum marker enzymes were monitored along with histopathological changes of liver sections. 30% alcohol and paracetamol induced significant increase in thiobarbituric acid reactive substances (TBARS) along with the alterations in the activities of enzymatic and non-enzymatic antioxidants and serum markers in the liver of serum treated rats. Simultaneously, oral treatment with *T. undulata* reversed all the serum and liver parameters, dose-dependently, in 30% alcohol and paracetamol treated rats. The biochemical results were also compared with the standard drug- silymarin. These findings

Table II. Tabular representation of important chemical compounds found in *Tecomella undulate*

Compound Name	Chemical Structure	Chemical formula & Medicinal properties
Radermachol		$C_{24}H_{16}O_4$. Radermachol is reported to processes anti-inflammatory activity.
Techomaquinone -I		$C_{30}H_{24}O_4$.
Lapachol		$C_{15}H_{14}O_3$. It is reported to have anticancer, antibacterial, antifungal and antivirus activities.
dehydro-α-lapachone		$C_{15}H_{12}O_3$. Dehydro-α-lapachone has anti-vascular activity.
α-lapachone		$C_{15}H_{14}O_3$. Possesses anti neoplastic activity.
β-lapachone		$C_{15}H_{14}O_3$. It is lethal against a variety of cancer cells.
Oleanolic Acid		$C_{30}H_{48}O_3$ Used as an oral drug for human liver disorders.
		
Ursolic Acid		$C_{30}H_{48}O_3$. It has been long-recognized to have anti-inflammatory and anti-hyperlipidemic properties.
β-sitosterol		$C_{29}H_{50}O$. exhibits anti-inflammatory, anti-neoplastic, anti-pyretic, and immunemodulating activities.
Betulinic Acid		$C_{30}H_{48}O_3$ Betulinic acid is a potent anti-human immunodeficiency virus (HIV) agent.
Cirsimaritin		$C_{17}H_{14}O_6$. It has adenosine antagonistic properties.
Stigmasterol		$C_{29}H_{48}O$

indicate the hepatoprotective potential of *T. undulata* leaves against liver damage might be due to the presence of flavonoids, quinones and other bioactive constituents (Singh and Gupta, 2011). Patel *et al*. (2010) report hepatoprotective effect of *Tecomella undulata* (Sm.) Seem., on paracetamol induced hepatotoxicity in rats. Significant hepatoprotective activity against paracetamol induced hepatic damage was evident by normalization of substantially elevated levels of aspartate amino transferase, alanine amino transferase, alkaline phosphatase, total bilirubin, decreased level of total protein, increased wet liver weight and volume, increased

thiopentone sodium induced sleeping time and abnormal histopathology. The study revealed that ethanolic extract of bark of *T. undulata* restored the physiological integrity of hepatocytes. Khatri *et al*. (2009) reported the hepatoprotective nature against thioacetamide induced hepatotoxicity. Ethanolic extract resulted in a significant reduction in serum aspartate aminotransaminase, alanine aminotransaminase, gamma glutamyl transpeptidase, alkaline phosphatase, total bilirubi, liver Malondialdhye (MDA) levels and significant improvement in liver glutathione. Histology of the liver sections of the animals treated with the extracts also showed dose-dependent reduction of necrosis. Rana *et al*. (2008) also report the hepatoprotective nature of the bark of Rohida.

Anti-inflammatory Activity

Butanolic extract prepared from the bark of *T.undulata* has significant anti-inflammatory activity against carrageenan induced paw edema and cotton pellet induced granuloma in rat. The activity was similar to that shown by the standard drug indomethacin (Goyal *et al*., 2010). Ahmad *et al*. (1994) evaluated the methanolic extract of plant for its anti inflammatory and analgesic potential by using rat paw edema and tail immersion method respectively. The extract showed significant analgesic potential with comparison to standard asprin.

Immunomodulatory Activity

G.P. Choudhary (2011) reports that ethanolic extract of *T. undulata* produces stimulatory effect on the humoral and cell mediated immune response. Cyclophosphamide induced suppression of humoral as well as cell mediated response were significantly attenuated by daily oral treatment of alcoholic extract of *Tecomella*, also the ethanolic extract was found to suppress delayed type of hypersensitivity reaction induced, by sheep red blood cells in mice.

Antimicrobial activity

Extracts of leaf and stem of *Tecomella* are also reported to be effective against *Salmonella typhi*, the causal organism of typhoid fever (Gehlot and Bohra, 2005). Yet another report reveals the use of cold macerated alcoholic and actone extract against gram positive and gram negative strains using cylinder plate technique. Alcoholic extract was active against *E. coli* while the acetone extract was active against both *B. subtilis and S. aurens* (Thanawala, 1993). Parekh *et al*. (2005) studied the antimicrobial activity against five important strains viz. *S. epidermidis, B. subtilis, P. pseudoalcaligenes, P. vulgaris,* and *S. typhimurium.* They showed the inhibition of *S. epidermidis* and *B. subtilis* by methanolic extract of *Tecomella.*

Anticancer activity

Anticancer potential of *Tecomella* has been reported traditionally. Scientific validation for the antitumor effects of Tecomella undulata bark has been done in chronic myeloid leukemia cell line, K562. Apoptosis was induced by chloroform extract of *Tecomella undulata* bark; following this the cell cycle analysis was done. Results clearly showed the induction of apoptosis by *Tecomella* extract in K562 cells. The effect was found to be dose dependent, having maximal inhibitory concentration (IC_{50}) of 30µg/ml. The bioactive extract of *Tecomella* was found to possess 0.03% (w/w) of quercetin. Quercetin was responsible for the anticancer activity (Ravi *et al*., 2011).

Other activities

Rohitakarista is a drug in Ayurvedic treatment and used traditionally for the treatment of pliha (disease of spleen), udara (disease of abdomen), gulma (localized abdominal swelling or tumour). Actually, it is the preparation of *Tecomella undulata* stem and bark with some other medicinal plants in small amount (Ullah *et al*., 2008). Among the other plants of this formulation are, the oil of *Cinnamomum zeylanicum, Piper longum, Terminalia bellerica, Emblica officinalis* etc. Ullah *et al*. (2008) carried out a study to investigate the safety profile as well as the effect of rohitakarista on various biochemical parameters of rats. Albumin content showed a marked increase while creatinine content decreased in both the sexes. Several biochemical parameters like bilirubin, alkaline phosphates, urea etc. showed an interesting sex dependency. All these parameters decreased in male rats but increased significantly in female rats. According to another report by Ullah *et al*. (2010), they have shown the effect of rohitakarista on lipid profile of albino rats. Oral administration of rohitakarista caused a decrease in triglycerides while a significant increase in the total cholesterol, VLDL (very low density lipoprotein) and HDL (high density lipoprotein) levels was observed.

Bioactive constituents

A notable number of bioactive compounds have been isolated from *T. undulata*. These compounds reportedly demonstrated a number of important activities, which are beneficial to human beings. Bark of *T. undulata* is the major source of the phytochemical constituents. Phytochemical screening of the crude powder of bark of *Tecomella* shows that the plant is rich in phytosterols, glycosides, tannins and phenolic compounds. The leaves of the plant contain flavones like oleanoic acid, ursolic acid, and betulinic acid. Rutin, quercetin, luteolin-7-glucoside and sitosterol are isolated from flowers. Root extracts reveal the presence of dehydrotectol, 6-O-veratryl catalposide and veratric acid.

Radermachol is a unique pentacyclic quinone isolated from the heartwood of the plant and reported to have anti-inflamatory activity (Singh *et al*., 2008). Other important compounds obtained from the heartwood are lapachol, tecomaquinone-I, dehydro-α-lapachone, α-lapachone, β-lapachone, stigmasterol and β-sitosterol. Lapachol [2-hydroxy-3-(3methyl-2-butenyl)-1,4- naphtoquinone] is a compound isolated from various species of bignoniaceae, including *T. undulata*. It is a yellow powder, weakly acidic, highly lipophilic, with limited solubility in water, but very soluble in alkaline solutions (Lira *et al*., 2008). It is reported to have anticancer, antibacterial, antifungal and antivirus activities (Hussain *et al*., 2007). The antitumor activity of the entire bignoniaceae is reported to be due to the presence of lapachol (Choudhury *et al*., 2011). Dehydro-α-lapachone is an antivascular agent, it induces vascular pruning and growth delay in orthotopic mammary tumors in mice (Garkavtsev *et al*., 2011). β-lapachone is active against many cancer cell line

and is very powerful when administered along with taxol (Pardee *et al*., 2002). α-lapachone possesses anti neoplastic activity (Renou *et al*., 2003). Leaves of *Tecomella* contain flavones like oleanolic acid, ursolic acid and betulinic acid. Flavones are a class of flavonoids based on the backbone of 2-phenyl-1-benzopyran-4-one. Tricantanol, crisimaritin, pentatricantanol and 4,5-dihydroxy-3,6,8-trimethoxy are some other flavones isolated from the leaves (Azam ,1999). Triacontanol is an effective plant growth regulator while both betulinic acid and ursolic acid are potent anti-human immunodeficiency virus (HIV) agents (Azam *et al*., 1997; Kashiwada *et al*., 1996). Oleanolic and ursolic acid are effective in protecting against chemically induced liver injury in laboratory animals. Both the compounds are also recognized to have anti-inflammatory, anti-hyperlipidemic (Liu, 1995) and anti-cancerous properties (Yan *et al*., 2010). Crisimaritin is a flavonoid with adenosine antagonistic properties in rats (Hasrat *et al*., 1997). β-sitosterol obtained from heartwood of the tree exhibits anti-inflammatory, anti-neoplastic, anti-pyretic, and immunemodulating activities (Bouic and Lamprecht, 1999).

Iridoid glucosides have also been isolated from Rohida. Verma *et al*. (1986) isolated Undulatin, which has been assigned the structure 4'- O-P-coumaroyl-7, 8-dihydro-8-dehydroxymethylbartsioside by chemical and spectroscopic analysis. These compounds, as cyclopentane monoterpenes, are biosynthesized *via* the mevalonic acid pathway. Iridoids have been linked to traditional uses such as treatment for tumors and antiseptic effects (Rao and Kingston, 1982). Another iridoid glucoside 6-O-veratryl catalposide, was reported by Joshi et al. Gujral *et al*. (1997) reported the presence of a new chromone glucoside in *Tecomella undulata*. Pandey *et al*. (1970) evaluated the plant bark for the presence of ester glucoside.

Conservation Status

To prevent extinction and derive maximum benefits from the indigenous plants of a nation, it is necessary to preserve the germplasm. Unscrupulous and unscientific management practices coupled with limited cultivation and insufficient attempts for replenishment of the wild stock of useful plant species has led to their depletion. Indiscriminate felling of *Tecomella* for timber and fuel, coupled with poor regeneration and sluggish growth has severely depleted the natural population of this valuable tree, with an associated loss of valuable germplasm. This species has been considered as threatened in Rajasthan province of India (Pandey *et al*., 1983; Sheety and Singh, 1987; Tripathi and Jaimini, 2002). The United Nations Environment Programme's World Conservation Monitoring Centre at Nairobi, Kenya has included *T. undulata* under category I – Indeterminate, to stop further exploitation of this species (Jain and Rao, 1983) . K.A Singh (2010) has placed the plant under the vulnerable category in many districts of Rajastahan. P.C. Trivedi (2009) reports that *Tecomella undulata* is also listed as rare at the international level (IUCN, 2000). In order to conserve this potential tree species quantification of genetic diversity in the existing populations of *T. undulata* can be the essential first step towards the objective. Very few attempts have been made to study the genetic diversity of this species. Jindal *et al*. (1992) employed different biochemical profiles to estimate the genetic diversity of this species. They studied the genetic variability of *T. undulata* from wide-ranging areas of Rajasthan, covering Jodhpur, Barmer, Jalore and Jaisalmer districts. Maximum variability with respect to protein content, neutral detergent fibre, acid detergent fibre, lignin, cellulose and hemi-cellulose was observed in Barmer District. The findings of this preliminary study indicated variation among the populations of different regions. Bhau *et al*. (2007) studied genetic diversity using AFLP markers in *T. undulata* populations collected from various parts of Western Rajasthan, and reported high level of variability attributed to its outcrossing nature. In another study conducted by Negi *et al*. (2011) they report genetic diversity at species level based on flower colour. They suggest that there occur two morphotypes of *Tecomella undulata*, one with yellow and the other with red flowers. The orange flowered morphotype seems to be the hybrid between these two morphotypes and is well manifested by its hybrid vigour like – highest plant density, plant height, fruit per plant and percentage of seed germination etc. Monitoring genetic diversity can help in identifying the candidate populations for *in situ* and *ex situ* conservation, and thus lead to proper planning strategy for the conservation of this species. The regeneration rates of this tree in natural surroundings is quite low, therefore alternative propagation methods would be beneficial in large scale multiplication, improvement and conservation of its elite clones. The use of biotechnology on trees has opened up new possibilities for rapid mass multiplication of existing stocks of germplasm, as well as conservation of important plants/plant parts (Bajaj, 1986; Haissig *et al*., 1987; Gupta and Agrawal, 1992; Anis *et al*., 2005; Husain *et al*., 2007). In general, woody taxa are difficult to regenerate under *in-vitro* conditions. Some success, however, has been achieved in a few woody tree species (Mathur *et al*., 2002; Mathur *et al*., 2008; Shekhawat *et* al., 2009).There are a few reports on regeneration of *T. undulata*. Rathore *et al*. (1991) and Robert *et al*. (2005) report a complete regeneration protocol through nodal shoot segments. Arya and Shekhawat (1982) developed a protocol for multiplication using axillary and terminal bud. A few other workers have reported the use of cotyledonary node explants and buds for *in-vitro* shoot multiplication (Nandwani *et al*., 1952; Bhansali, 1992). Very less *in-vitro* research has been performed on this potential plant species.

Conclusion and future prospects

Despite the great importance of *T. undulata* as economical, ethnobotanical and medicinally important tree, attempts for its conservation, sustainable utilization and/or genetic improvement, are by and large lacking. One of the serious problems with *T. undulata* is the poor seed germination which may be due to dormancy, seed infertility or quick loss of seed-viability, caused by denaturation of functional proteins after the extraction of seeds from the fruits (Singh, 2004). Several studies have been conducted to study its germination behaviour (Jain *et al*., 2006; Jaiswal and Chaudhary, 2005) but met with limited success. Inspite of all the efforts conventional breeding methods have met with limited success in improving this species. Tissue culture techniques used for propagation of tree species offers a rapid means of producing clonal planting stock for forestation programmes, woody biomass production and conservation. Apart from tissue culture techniques transgenic plants may be eventually developed using

molecular biotechnology approach. In these plants the entire pathway for medicinally active secondary metabolites has been enhanced and introduced. However, this approach necessitates the identification of several genes within a given pathway - the isolation, sequencing of the genes and reintroduction of genetic material into the plant species. It is believed that the phytoconstituents and biological activities mentioned in this review can help researchers to explore this plant to further extent. Its use in various other diseases can be tested and toxicity can be studied in detail with clinical trials. Its medicinal properties can be further exploited in future by pharmaceutical industries to treat diseases, especially against HIV virus.

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