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Review

Commiphora wightii (Arnott) Bhandari: A threatened plant of conservation concern

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Disappearance of *Commiphora wightii* (synonym-*Commiphora mukul*) over larger areas due to crude and destructive tapping for obtaining more and more oleo-gum resin in the Indian arid zone has attracted the attention of researchers and planners alike. Consequently, placing it in 'Data Deficient' category of International Union for Conservation of Nature requires detailed information on its spatial distribution and other related aspects. Many researchers in the recent past have generated enormous information on almost all aspects of *C. wightii* covering taxonomy, ultrastructure, tapping, regeneration, survival and spread. This information is scattered and needs to be related to the conservation efforts. Hence, we have attempted to review the entire gamut of information in this paper. This has revealed that genus *Commiphora* has worldwide distribution in tropical-subtropical climates and its other species besides *C. wightii* also yield oleo-gum resin of export value. Whether this oleo-gum resin has same medicinal properties, as that from *C. wightii* is yet to be confirmed. Source and location of oleo-gum resin in plant system is well understood: it is synthesized in leaves but placed in phloem. Cuts deeper than phloem injure the plant vasculature, ultimately killing the plant. All research so far has been directed to know how to save it while extracting oleo-gum resin and also increase its population in nature. This review presents a synthesis of all this information to have deeper understanding of the issues concerning sustained yield of oleo-gum-resin as well as its conservation.

Key words: *Commiphora wightii*, conservation, data deficient, ole-gum-resin, spatial distribution, tapping.

INTRODUCTION

Commiphora wightii (Arnott) Bhandari, a highly valuable medicinal plant yields an oleo-gum resin important in Ayurvedic medicines (Chakravarty, 1975). The plant is known as 'Indian bdellium' in English, as Mahisaksha, Guggulu, Amish, Palanksha and Pur in Sanskrit and as Guggul in most Indian languages (Anon, 1950). Its anti-arthritic, hypocholesterolaemic and hypolipidaemic properties have been established (Satyavati, 1990) and a commercial product 'guglip' has been marketed in India since 1988. Owing to the enormous demand for the drug, the plant is subjected to crude and destructive tapping procedures resulting in drastic shrinkage of its area of occurrence and abundance. On one hand demand for its oleo-gum-resin is increasing while its increasingly sparser populations are unable to meet the requirements. There are varying claims about its regeneration through seeds or stem cuttings as well as biotechnological needs. Newer knowledge on its medicinal uses is also becoming available. Hence, we present here a review of the entire gamut of information on its botany, ecology, distribution, propagation, chemistry, medicinal uses and cultivation to know deficiencies in our knowledge and arrive at future

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research directions, most importantly, the need to conserve its germplasm and ensure a sustained supply of the valuable raw material.

DISTRIBUTION IN WORLD

Genus *Commiphora* belongs to family Burseraceae which is a moderately sized family of 17 to 18 genera with about 540 species. All Burseraceae are resinous plants. There are over 200 species of *Commiphora* around Red Sea in East Africa, 20 species in Madagascar (Hanus et al., 2005) and 5 species in India (Pernet, 1972), 10 new species of *Commiphora* were reported from Somalia (Thulin, 2000). Vollesen (1989) have documented a full botanical account of more than 50 *Commiphora* species that occur in Eastern Africa, with the largest concentration of species in Northeast Africa, particularly in Ethiopia, Somalia and Kenya. Occurrence of *Commiphora* in Zaire was reported by Liswoski et al. (1972). The species is widely distributed in Arabia and Somalia (Dharmananda, 2003; Tucker, 1986). *Commiphora guillaumini* is found in dry deciduous forest of Western Madagascar (Bohning-Gaese et al., 1999). Occurrence of *Commiphora* spp., in South-West Africa has been confirmed (Vander Walt, 1974, 1975). Liswoski et al. (1972) recorded different species of *Commiphora* from Zaire. Petiole anatomy (Vander Walt et al., 1973) and branching pattern (Thomason, 1972) have formed the basis for identification of various species of *Commiphora* in Africa. *Commiphora* spp. is reported to occur in Arabia, Tropical and Southern Africa and India (Rajputana) (Khan, 1958; Kant et al., 2010). The genus *Commiphora* is an appropriate taxon with which to test biogeographic hypotheses regarding the origin and evolution of arid sub-Saharan (sub-) tropical vegetation. Linder (2001) stated that "*Commiphora* would be the ideal genus to indicate patterns of species richness and endemism in the arid zone flora across sub-Saharan Africa". Of the continental African species, the greatest diversity is found in the Somali-Masai region (White, 1983) of Northeast Africa ca. 100 spp. Endemic (Gillett, 1991; Thulin, 1999; Vollesen, 1989) with the bulk of the remaining species distributed in the Kalahari-Highveld and Karoo-Namib floristic zones. *Commiphora* dominates and lends its name to over 1.6 million km^2 of *Acacia-Commiphora* woodland in (sub-) tropical East Africa (Olson and Dinerstein, 2002). Outside continental Africa, fewer species are distributed in similarly dry habitats of Madagascar, the Middle East, India, Sri Lanka and South America. The species diversity and abundance of *Commiphora* would therefore appear to make it an ideal marker that should reject the patterns of expansion of dry tropical and desert habitats.

Its distribution further extends to Australia and Pacific Islands (Good, 1974). Bisabol myrrha, *Commiphora erythraea var. glabrescence* is found in Somalia (Surburg and Panten, 2006). Somalia is the major exporter of scented myrrh at present (Mabberley, 2008). *Commiphora myrrha* is found in South Arabia and Somalia. Ruthless exploitation of this species has led to decline in its population continuously making this plant vulnerable which has been categorized as 'Data Deficient' in assemblage of International Union for Conservation of Nature (IUCN) in 2008 due to lack of research in establishment of its conservation status. Though, *C. wightii* is assigned to the Data Deficient (DD) category ver. 2.3 (1994) of the Red Data Book of IUCN, the Government of India has included it under Rare, Endangered, Threatened (RET) category (Samantaray et al., 2011).

Distribution in Indian sub-continent

In Indian-subcontinent, *Commiphora* spp. occurs in India (Hooker, 1872), Pakistan (Choudhary, 1959) and Baluchistan (Hooker, 1872). In India, it occurs in the arid rocky tracts of Rajasthan, Gujarat, Madhya Pradesh, Karnataka and Kalat division of Andhra Pradesh (Soni, 2010a; Khan, 1958) as well as Sindh and Baluchistan states of Pakistan (Atal et al., 1975; Gupta et al., 1996).

In India, *Commiphora* spp. is represented by *C. myrrha*, *Commiphora stocksiana, C. wightii, Commiphora berryi, Commiphora agallocha* but out of them *C. myrrha* is well documented for its use values (Hocking, 1993; Kirtikar and Basu, 1935). *C. agallocha* is reported from Baragarh (Orissa) (Tiwari et al., 2001) while *C. berryi* in Tiruchirapalli, Coimbatore (Tamilnadu) (Selvamani et al., 2009) and *C. myrrha* in Anand (Gujarat) and Jabalpur (Madhya Pradesh) while *C. stocksiana* in Anand (Gujarat). Siddiqui (2011) reported the presence of four species yielding guggal in India, namely *C. wightii* (Arn.) Bhandari, *Commiphora mukul* Engl., *C. agallocha* Engl. and *C. berryi* (Arn.) Engl. Of these, *C. wightii* is now the correct and new name of *C. mukul*. On the other hand, Ramawat et al. (2008) reported that three species of *Commiphora* occuring in India, namely *C. wightii* (Arn.) Bhandari, *C. stocksiana* Engl. and *C. berryi* (Arn.) Engl. Apparently, spatial variability (heterogenesity) controls the distribution and abundance of *C. wightii* in Kuchcch Gujarat (Dixit and Rao, 2000). *C. wightii* has comparatively a wider distribution in the country. In Gujarat, *C. wightii* is mainly found in Kuchcch and some parts of Saurashtra regions (Sabnis and Rao, 1983). It is found in the whole Kuchcch division apart from Kara hills of Khawada region, in North of Bhuj, Zava, Dayapar, Rawapur, Nakhatrana, Lakhpat, Garoli, Besulpur, Muru, Amara, Ganjansar and ravines of Mahi river in Gujarat (Atal et al., 1975; Shah et al., 1983).

In Rajasthan, it is reported from Sawai-Madhopur, Bundi, Kota, Jalore, Sirohi, Pali, Nagaur, Sikar, Churu, Bikaner, Ajmer, Alwar, Jaipur, Jaisalmer, Udaipur, Jodhpur, and Jhunjhunun (Tiwari et al., 2001). Kulloli et

al. (2011) gave geospatial distribution of guggal in Western Rajasthan. Reddy et al. (2012) has reported its associates, area of occurrence and occupancy based on satellite data of 2007 and field sampling up to 2009 and inferred its endangered status. But his datasets, based on Jaisalmer, Jodhpur and Jalore districts out of 12 arid districts in Western Rajasthan, cover inadequate area to reach a conclusion. It also occurs at Morena, Bhind, Shivpuri, Sheopur, and Damoh districts in Madhya Pradesh (Billore et al., 1991; Thomas and Shrivastava, 2010). Bhatnagar et al. (1973) also reported *C. berryi* from Gwalior (Madhya Pradesh). Hills and piedmonts are natural habitats of *C. wightii*. It is associated with tropical *Euphorbia* scrub which is major subtype of desert thorn forest of India (Champion and Seth, 1968). Though, so many workers have reported occurrence of *C. wightii* from a number of localities in India, its abundance, relationships with its associates and invasive as well as spatial distribution is yet inadequately known. Using GIS along with satellite data and modern cartographic tools would perhaps be the most desirable approach to know quantitative extent of guggal.

MORPHOLOGY

C. wightii (Arnott) Bhandari belongs to family Burseraceae. It is slow growing, much branched, and shrubby plant. It is 2 to 3 m high with silvery and paper like grayish or grayish-brown bark peeling off in small pieces (Barve and Mehta, 1993). The plant with branches spirally ascending spinescent with young parts glandular and pubescent (Varier, 1994). Leaves1 to 3 foliate, leaflets sessile to sub sessile, terminal one largest rhomboid to ovate. Lateral leaflets present only less than half size of the terminal one (Tiwari et al., 2001; Varier, 1994). Margin serrate to dentate. Flowers small, maroon-pinkish. It exists in three forms, that is, male, female and polygamous having male and bisexual flowers both (Plate-1); petals 4 to 5, ligulate, brownish red recurved at the tip and four to five times as long as sepals. The calyx has glandular hairs forming cylindrical cup. Stigma inconspicuously bilobed, stamens 8 (4+4) in male flowers slightly exerted the corolla, in female flowers staminodes, fruit drupe, reddish ovate with 2 celled stone, rarely three or four valved and red when ripe, stone covered with four strips of yellow aril (Varier, 1994). Seeds are lustrous and brown. Sobti and Singh (1961) reported its chromosome number (2n = 26). Kulloli et al. (2009) also reported its morphological variability.

REPRODUCTIVE BIOLOGY

The ultrastructural details of secretion, seasons of production and methods of enhancing the yield have been reported (Bhatt et al*.,* 1989). However, there is no critical information on the reproductive biology, natural means of seed dispersal and seedling establishment of this plant. The embryological account of *Commiphora* is sketchy and ambiguous (Wiger, 1934; Mauritzon, 1935; Shukla, 1954). It is uncommon to see seedlings in the vicinity of wild adult plants.

Extensive investigations have been carried out to elucidate the structural and functional aspects of pollen-pistil interaction in a number of sexually reproducing flowering plants (Shivanna and Johri, 1985). However, there are very few studies on the structural details of the pistil and of pollen-pistil interaction in apomictic species (Richards, 1990). The breeding system of *C. wightii* shows the species is a sporophytic apomict showing nucellar polyembryony. The apomixis is independent of pollination stimulus, that is, non-pseudogamous (Gupta et al*.,* 1996) although the plants produce morphologically normal pollen and pistils. The structure of the pistil and details of pollen-pistil interaction was described by Gupta et al. (1998). In depth understanding of reproductive biology and pollination ecology is needed to enhance setting of seeds which remain viable and can be used to raise seedlings for large scale plantation.

PROPAGATION

Propagation through seeds is more advantageous because seedlings have a deeper root system compared to the plants established through cuttings (Yadav et al., 1999). Poor germination rates coupled with high mortality rate of seedlings limits propagation of *Commiphora* by this method. Fruit set and yield of fruits per plant are very low in natural conditions. Poor seed set, very poor seed germination (5%) and harsh arid conditions are responsible for complete failure of plant establishment from seeds in nature. Natural regeneration through seeds has been rarely observed below the parent plants in the farm and in the forests (Yadav et al*.,* 1999; Reddy et al., 2012).

C. wightii has been successfully propagated through stem cuttings of 25 cm length and 1 cm thickness (Mertia and Nagrajan, 2000; Chandra et al*.,* 2001; Kumar et al*.,* 2002). Earlier, 1 m long and 10 mm thick woody stem cuttings were reported suitable for raising of *C. wightii* (Dalal and Patel, 1995), thus requiring a large number of plant material for propagation. Indole-3-butyric acid (IBA) is still the most widely used auxin for rooting in stem cuttings and to increase the success percentage of cuttings (Al-Saqri and Alderson, 1996). Effect of callusing on rooting is likely to have some effects on rooting which needs further confirmation (Kulloli et al., 2011). The cuttings are usually planted during late summer from healthy and disease free branches, when the plant is almost leafless. With the onset of monsoon, when foliation growth/flowering starts, the plant becomes physiologically active and the cuttings also show signs of

sprouting in 25 to 50 days. Treatment with root hormones, namely, Credik-1 and Credik-2 in July and August, was found beneficial for development of roots. After establishment in nursery beds, the plants are transferred to polybags and then planted in the field during rainy season in the second-third week of June or early July (Yadav et al., 1999). Raising its large scale plantation has been met with many bottlenecks, termite attack being the major cause of the death of the plants. Requirements of manure, fertilizers and irrigation are yet to be understood and standardized for its successful transplantation.

TAPPING METHODS AND TREE HEALTH

Sabnis (1920) reported that phloem of larger veins of the leaf and in the soft bast of the stem has balsam canal. Metcalf and Chalk (1957) also mentioned the presence of secretary canals in the phloem. Ultra structural studies of the gum resin duct of *C. wightii* by Setia et al. (1977) confirmed it. Secretory canals development and widening of gum-resin canal in young stem occurs schizogenously (Setia et al*.,* 1977; Bhatt, 1987). The secretory ducts occur in association with secondary phloem in the main stem. They are discontinuous, oriented parallel to the longitudinal axis of the stem and anastomose tangentially. April and May are the peak months for gum tapping as established by localization of resin in the section material using bright field and epiflourescence microscopy (Bhatt et al*.,* 1989). Associated anatomical characteristics are well documented (Setia et al*.,* 1977; Nair et al*.,* 1981; Shah et al*.,* 1982).

Effect of IAA, kinetin and morphactin (each at 25, 50 and 100 parts/10^{-6} concentrations) on gum-resin canals of *C. wightii* were studied by Setia and Shah (1977). Details on its tapping, yield, chemistry and clinical trials were summarized in an excellent review by Kumar and Shankar (1982).

The traditional tapping methods and tools used for obtaining Guggal from *C. wightii* are unproductive and destructive (Plate-2). Tapping is discontinued during rainy season, because yields are low and the resin is washed away from the stem (Krishna-Murthy and Shiva, 1997). Commercial tapping of trees for gum or resin affects its growth process (Dijkman, 1951; Karkkainen, 1981) which also causes premature tree death and susceptible to insect, fungus infection (Torquebiau, 1984; Jamal and Huntsinser, 1993).

Excessive collection of resin and latex can be destructive as it may weaken the tree and causes carbohydrates to be spent on exudates that might otherwise have been allocated to growth and reproduction (Dijkman, 1951; Karkkainen, 1981). Small trees would suffer more from tapping treatments than large trees, as the former generally have fewer stored carbohydrates available. The greater overall carbon budget of large sized trees yield more resins (Mason, 1971; Ruel et al., 1998). In juvenile trees, resin production originates from current photosynthesis, as the supply of stored carbohydrates is not sufficient (Lieutier et al*.,* 1993). It highlights the reason for premature death of young trees due to excessive tapping. The resin is tapped during winter and each guggal tree yields about 700 to 900 g of resin (Satyavati, 1988; Siddiqui, 2011). The ultra-structural details of secretion, seasons of production and methods of enhancing the yield have been studied by using different plant growth regulators. Of different plant growth regulators applied on the stem with lanolin paste, only kinetin increased the lumen size, while auxin and morphactin had adverse effect causing increase in the number of epithelial cells (Setia and Shah, 1979), whereas ethephon enhanced 22 times oleo-gum production (Bhatt et al*.,* 1989). Recently, Siddiqui (2011) reported that guggal production can be enhanced by up to 22 times with an improved tapping technique using ‘‘Mitchie Golledge knife’’ coupled with ethephon (2-chloroethyl phosphoric acid), a plant growth regulator. There has also been an attempt to induce gum production by infecting it with a strain of *Xanthomonas* bacterium (Samanta, 2012). Again, contrasting claims have been made about two technologies, that is, with and without *Xanthomonas* infection. Multi locational trials are needed on many genotypes in diverse agro-climatic situations to arrive at final package of practices (PoPs) on gum induction without causing death of guggal plants. In view of conflicting results, the studies on tapping are still needed for in-depth understanding and sustainable gum production.

CHEMICAL COMPOSITION OF OLEO-GUM RESIN AND SEED OIL

Majority of the published research on the plant *C. wightii* and its extracts have originated from India (Thompson and Ernst, 2003). Guggal contains resin, volatile oils and gum (Table 1). Guggal gum is the mixture of 61% resin and 29.3% gum (Ghosh et al., 1942), in addition to 6.1% water, 0.6% volatile oil and 3.2% foreign matter (Anon, 1950). Several pharmacologically active compounds have been identified in the plant including E and Z guggulusterones (Singh et al*.,* 1990) and guggulipids both found in the ethyl acetate extract of the plant (Gopal et al., 1986; Mesrob et al*.,* 1998; Nagarajan et al., 2001).

The seeds of *C. wightii* (Arnott) Bhandari contain 9.8 ± 0.7% oil. Two types of seeds, namely, black and white have been recorded. Of these, the black seeds are found to be viable and contain 5.7% oil with four different types of fatty acids (Kakrani, 1981). The fatty acid composition and chemical properties of the extracted oil were determined. Gas liquid chromatography of the methyl esters of the fatty acids shows the presence of 46.62% saturated fatty acids and 51.40% unsaturated fatty acids.

Table 1. Different chemical compounds isolated from guggal gum.

Fraction of guggal	Chemical compound isolated	ReferenceS
Oleo fraction	Myrcene Dimyrcene Polymyrcene compound (with 0.37% essential oil)	Ashram (1950)
Gum fraction A7	α-arabinose	Bose and Gupta (1963)
	D-galactose	Bose and Gupta (1963)
	L-fucose	Bose and Gupta (1963)
Gum fraction B	6-D-D-galacto pyranose	Bose and Gupta (1963)
Resin fraction	Guggal sterol-I: m.p. 225-228°C	Patil et al. (1972)
	Guggal sterol-II: m.p. 231-233°C	Patil et al. (1972)
	Guggal sterol-III: m.p. 181-183°C	Patil et al. (1972)
	Guggal sterol-IV: Cholestane-5oc-ol-3,6-dione	Purushothaman and Chandrashekharan (1976)
	Guggal sterol-V: Cholestane-3β,5oc-diol-6- β-acetate	Purushothaman and Chandrashekharan (1976)
	Guggal sterol –Z:m.p. 192-193°C	Patil et al. (1973)
	Guggal sterol –E:m.p. 168-170°C	Patil et al. (1973)
	Nonadecan-1,2,3-4-tetrol	Patil et al. (1973)
	Diterpene alcohol: m.p. 37-38°C	Patil et al. (1973)
	Octadecan-1,2-3,4-tetrol	Patil et al. (1973)

The fatty acid composition is as follows: capric acid 3.50%, myristic acid 14.51%, palmitic acid 6.68%, stearic acid 4.70%, arachidic acid 3.18%, behenic acid 14.05%, myristoleic acid 1.34%, palmitoleic acid 12.07%, oleic acid 14.15%, eicosenoic acid 0.11%, linoleic acid 22.34% and alpha linoleic acid 1.37%. (Patel et al., 2009).

MEDICINAL USES

Medicinal importance of *C. wightii* is known since ancient times as it is mentioned by Sushruta 3000 years ago as a valuable drug in Ayurveda (Joshi, 1980). The multifarious medicinal and therapeutic values of *Commiphora* were known as early as 2000 B.C. in the Atharva Veda, one of the four well-known ancient classic scriptures (Vedas) of India (Ramawat et al., 2008; Shishodia et al., 2008). Guggal was first introduced to the scientific world in 1966 by an Indian medical researcher (Satyavati 1966). Some traditional uses were compiled by Gupta et al. (1965) and Atal et al. (1975). It exhibits interesting biological activities like ant-inflammatory, anti-bacterial, anti-microbial, anti-oxidant, anti-arthritic, anti-malarial, anti-mycobacterial, anti-schistomal, hepatoprotective, muscle relaxing, larvicidal, and mollucidal (Kirtikar and Basu, 1935; Hocking, 1993; Kumar and Shankar, 1982; Francis et al., 2004; El-Ashry et al., 2003; Al-Howriny et al., 2004, 2005; Claeson et al., 1991; Abbas et al., 2007; Massoud et al., 2001, 2004; Allam et al., 2001; Shen et al., 2007; Satyavati, 1990; Goyal et al., 2011; Wang et al., 2004). Some traditional uses were compiled by Gupta et al. (1966) and Atal et al. (1975). In 1987 guggulipid, the petroleum extract of guggal was officially recognized in India as a lipid lowering remedy (Atal et al., 1975) and is widely used for this indication. Guggulipid a purified ketonic fraction is presently used in India and Europe for hyperlipidemia and hypercholesterolemia (Singh et al., 1994). It is used as hypolipidaemic (Patra et al., 2003; Kumari and Augusti 2007; Nityanand et al., 1989; Deng, 2007; Siddiqui, 2011), anti-inflamatory drug (Sharma and Sharma, 1977; Singh et al., 2001; Panda and Kar, 1999; Patil et al., 1972; Saxena et al., 2007; Arya, 1988; Satyavati, 1988). *C. wightii* has been shown to down-regulate inflammatory cytokines in *in vitro* model (Raut et al., 2007). However, the risk of drug interaction linked to guggal is yet to be studied, because its cholesterol lowering property has also been questioned in some recent trials (Personal communication). 'Vatari-Guggalu' is used effectively against lower backache, rheumatism, gout and sciatica (Pradhan and Dash, 2011). It is also beneficial in diabetes and arthritis (Lather et al., 2011). The anti-inflammatory activity of guggal was first documented in 1960 (Gujral et al., 1960), and subsequently in 1977 by Sharma and Sharma (1977), and now by Goyal et al. (2011). Guggal has potential role in cancer prevention (Ramavat et al., 2008; Urizar et al., 2002; Cui et al., 2005). Several studies have reported the cardiac and neuronal protective activity of guggulusteron (Kaul and Kapoor, 1989). Herbal extracts from *C. wightii* (guggal) have been widely used in Asia as cholesterol-lowering agents and their popularity is also increasing in the United States (Jachak and Saklani, 2007). Hammer

et al. (1999) evaluated the inhibition of Gram-positive bacteria by the essential oil of *C. myrrha.* Romero et al. (2005) reported similar results while studying the antibacterial activity of *C. myrrha.* The ethyl acetate extract of aerial parts of *Commiphora opobalsamum* L. was found moderately active against *Staphylococcus aureus* as studied by Abbas et al. (2007). Herbal extract of *C. wightii* acts as growth inhibitor of struvite crystals (Chauhan et al., 2009).

In the Arab world, experts recorded many medicinal uses for *Commiphora molmol* (locally known as myrrha) such as treating wounds, intestinal parasites, diarrhea, cough and chest aliments (Ghazanfar, 1994). It has been used as anti-parasitic (Al-Mathal and Fouad, 2004) in treating gingivitis and anti-microbial (El-Ashry et al., 2003; Abdallah et al., 2009). Apart from its lipid lowering properties (Satyavati et al*.,* 1969; Tripathi et al., 1968), and reducing obesity (Francis et al*.,* 2004), oleo-resin of *C. wightii* increases leucocytes in the blood and stimulates phagocytosis (Sastri, 1950) helping resistance in the system to fight diseases. Antiproliferative and apoptosis inducing effects of guggulusteron have also been documented in other cell types including human lung, acute myeloid, leukemia and breast cancer cells (Shishodia and Aggarwal, 2004; Samudio et al*.,* 2005). Guggulusteron is an antagonist of farnesoid × receptor (Sinal and Gonzalez, 2002; Urizar et al*.,* 2002; Wu et al., 2002; Cui et al*.,* 2003). The Z-guggulusteron induced apoptosis in human prostate cancer cell is initiated by reactive oxygen intermediate-dependent activation of c-Jun NH_2-terminal kinase (Singh et al*.,* 2007).

CONSERVATION IMPLICATION

Apart from the demographic and genetic constraints; the major threat to the species is overexploitation for its medicinally important resin (Haque et al., 2010). In view of so many clinical applications discussed earlier. Designing conservation strategies for rare and endangered species requires a good knowledge about the levels and distribution of genetic diversity (Hamrick and Godt 1989; Holsinger and Gottlieb, 1991; Qiu et al*.,* 2006). In the present study, high levels of genetic structure were seen among populations of *C. wightii* and there seems to be little gene flow among them, the genetic variation shared among the population may largely represent common ancestry rather than recurrent gene flow. Conservation management in these species should aim not only at the large but also the small populations as reduced levels of genetic diversity will affect the ability of the species to adapt to changes in habitat (Luijten et al*.,* 2000). Vegetative reproduction, by stem cuttings, may postpone extinction but is basically an evolutionary dead end. Plans should be developed to encourage seedling recruitment in the small populations, especially those harboring low genetic variation (GH and HD). For this suitable habitats need to be identified for reintroduction in nature. Alternatively, this could be brought into cultivation on field margins in a participatory mode. Standardizing package of practices for its cultivation in a variety of agro-climates will therefore need a deeper study.

MICROPROPAGATION

Since *C. wightii* populations' exhibit high population differentiation, crossing the populations may bear a high risk of out breeding depression, which can be attributed to the disruption of local adaptation (Amos and Balmford, 2001). Considering that low seed set was observed in this species, a good strategy to encourage seed set, improved seed germination, and seedling recruitment needs to be considered. Zygotic embryo rescued by *in vitro* tissue culture techniques may also be useful. The modern biotechnological tools can be exploited to improve the content and quality of guggulusteron, only when a protocol for regeneration of complete plantlets *in vitro* is available (Kalia et al., 2011). Two distinct patterns of *in vitro* differentiation, that is, organogenesis and somatic embryogenesis have been used for micro propagation of *C. wightii.*

There has been no outcome from different programs on micro propagation of *C. wightii* since 1979 (Kumar et al., 2003; Sharma et al., 1998). Sterilization of explants collected from the field grown plants remains a major limitation in establishment of *C. wightii in vitro* due to the presence of oleo-gum resin in explant (stem, leaf and petiole) and bacteria in the resin canals (Ramawat et al., 2008). Organogenesis has been induced through axillary shoot proliferation from nodal segments (Barve and Mehta, 1993; Soni, 2010a), seedling explants (Yusuf et al*.,* 1999; Kant et al*.,* 2010) and shoot tips, nodes, internodes and leaves (Singh et al*.,* 2010). However, Kant et al. (2010) reported efficient rooting on White's medium without any hormones and high concentration of charcoal. The process of somatic embryogenesis can be scaled up in a bioreactor using cell cultures, and development of artificial seeds through immobilization (Jain et al*.,* 2002). Kumar et al. (2003) achieved somatic embryogenesis by repetitive reciprocal transfer of callus cultures of *C. wightii* between basal medium and MS medium containing 2, 4, 5-trichlorophenoxy acetic acid (2, 4,5T) and kinetin. They found that immature zygotic embryos were the only suitable explants for somatic embryogenesis. The somatic embryos germinated into plantlets which were successfully transferred to field conditions. Kumar et al. (2006) reported secondary somatic embryogenesis in *C. wightii* on basal medium. Singh et al. (2011) quantified primary metabolites in the callus and different plant parts. Maximum soluble sugars were found in callus, while maximum amount of starch, protein and phenolic contents were found in stem and

maximum lipid, in leaf. Thus, a standardized protocol for large scale production of plantlets/saplings from tissue culture has yet to come out for commercial adoption.

SELECTION OF DESIRED PLANT TYPE

Sanghamitra et al. (2010) reported the identification of random amplification of polymorphic DNA (RAPD) markers associated with sex determination among male, female, and hermaphrodite plants in *C. wightii*. Analysis of nucleotide sequences of the internal transcribed spacer of r-DNAs revealed low genetic diversity and high population structure. Parsimony based assessment and Bayesian analyses were conducted on the dataset. Mantel's test showed a statistically significant positive correlation between genetic and geographic distance. Anthropogenic overexploitation of *C. wightii* for its natural resources has resulted in population fragmentation (Haque et al., 2009). However, its exact impact on its endangerment status is yet to be understood. Marker assisted selection (MAS) is an excellent tool for selecting beneficial genetic traits in crops and forest trees at an early stage as well as for assessing the genetic potential of specific genotypes prior to phenotypic evaluation (Kalia et al., 2011).

CONCLUSION

Fairly good understanding exists about taxonomy, morphology, ultrastructure, molecular analysis and medicinal importance of guggal. Its DD status by IUCN entails an intensive field based assessment of its population status using GIS tools to assess its area of occurrence and area of occupancy. Intraspecific variability should be collected, evaluated and conserved both *ex-situ* and *in-situ*. Further, conflicting claims about different methods of its propagation demand a detailed in-depth understanding of rooting of cuttings and seed germination process, so that it can be multiplied easily. In order to be successful during its reintroduction, it is essential to understand its agronomic requirements including integrated nutrient management, integrated fertilizer management and integrated pest management on different landscapes in a variety of agroclimates. Different aspects of tapping for its ole gum resin such a depth and orientation of cut, application of gum inducers and after effects deserve an investigation to resolve conflicting claims. Focused research efforts need to be directed to save this plant while tapping for gum, so that it does not become critically endangered and extinct in near future.

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