Traditional uses and pharmacological activities of *Sterculia villosa* Roxb. - an underutilized tree of south east Asia

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Review

Abstract

Background: *Sterculia villosa* Roxb., is a multipurpose, fast-growing, underutilized tree species. Almost all parts of the trees are traditionally used across its geographically distributed regions by ethnic communities to treat a variety of human ailments and for ethnoveterinary purposes.

Methods: Despite extensive ethnomedicinal and pharmacological investigations on *S. villosa*, there is a notable absence of a comprehensive article consolidating reviews of published literature. So, herein, we designed this review article to provide a systematic and comprehensive analysis of the current research progress on S. villosa, to provide new insights and a broad field of view for future research. Extensive literature searches using “*Sterculia villosa*," “ethno-veterinary use," “ethnomedicinal use," “phytochemicals," and “pharmacological” were performed on PubMed, ScienceDirect, Scopus, and Web of Science.

Results: This plant contains a wide variety of phytochemical constituents (alkaloids, glycosides, steroids, flavonoids, polyphenols, tannins, saponins, and terpenoids). Flavonoids such as Diosmetin, Chrysoeriol and its glucosides derivatives, triterpenoids such as lupeol and cyclopropenoid fatty acids such as palmitoleic acid, oleic acid, linoleic acid, and palmitic acid are beneficial to human health, and are responsible for their antioxidant, anticancer, antimicrobial, immunomodulatory, and anti-inflammatory effects. It is widely reported for treating skin ailments, rheumatism and urinary problems, seminal weakness, impotency, and gastric troubles.

Conclusions: *S. villosa* can be a potential raw material for pharmaceuticals, plywood, pulp and paper industries, and waste water treatment, besides its significant ethno-medicinal uses. Henceforth, the socio-cultural, economic, and ecological values of *S. villosa* enhance the livelihood of local inhabitants and achieve sustainable developmental goals.

Keywords: Diosmetin, palmitoleic acid, antioxidant, premature ejaculation, impotency

Background

Trees are integral and key components of forests and able to meet local people's needs in their daily lives, including foods, traditional medicines, fuel, shelter, fibres, clothes, and livelihood options especially in tropical regions of the world. Human society significantly utilized indigenous tree flora in one form or another since time immemorial (Sofowora *et al.* 2013). In the present scenario of global change, multipurpose trees are gaining high significance due to their potential in realizing sustainable developmental goals, biodiversity conservation and climate change amelioration. Still more than two thirds of rural population in the world depend on traditional system of ethnomedicine for their primary healthcare (Kuniyal *et al.* 2015; Caniago & Stephen 1998). Indigenous system of medicines mainly dependent plant-based resources. Emerging diseases, antimicrobial resistance and side effects of synthetically derived allopathic medicines lead to renewed interest in search of novel, safer and green medicines from nature and natural resources. Underutilized tropical forest tree species with significant traditional uses as ethnomedicine could be a potential candidate in search for newer and safer medicines/compounds.

Sterculia villosa Roxb. (also known as Udal, Odal, or Udar, Elephant rope tree) is a tropical deciduous tree species found in India up to an elevation of 1000 masl. *S. villosa* is a very drought-tolerant species (Veach *et al.* 2003). It thrives in light sandy or gravelly soils with annual precipitation ranging from 750 to 4000 mm. *S. villosa* is one of the indigenous, underutilized, fast-growing tropical tree species with multiple utilities to forest-dwelling communities/local people in forest/rural land settings in Southeast Asian regions (Nandy & Das 2013).

S. villosa have been used as traditional medicine in Indian subcontinent for thousands of years to treat various disease, especially the leucorrhoea, menstrual cramp or pain, male sterility and weakness, rheumatism, urinary problems and kidney stones, dysentery, cholera, jaundice, diabetes, heart diseases, arthritis and asthma. Modern pharmaceutical studies showed that the extract and their phyto-compounds from *S. villosa* exhibited amounts of activities, such as anti-tumor (Zhao *et al.* 2021), showed good potential against SARS-CoV-2 Mpro (Khan *et al.* 2021), anti-osteosarcoma (Ning *et al.* 2021), anti-rheumatoid arthritis agent (Wu *et al.* 2022), antileukemic (Ninomiya *et al.* 2013), antioxidant activity (Uddin *et al.* 2015; Haque *et al.* 2014), antimicrobial activity (Haque *et al.* 2014; Tania *et al.* 2013), antileishmanial activity (Das *et al.* 2017) and so on.

The primary goal of this review is to explore the traditional uses, ethno-pharmacological, phytochemistry, commercial values, biological significance, as well as reliance of local peoples for their subsistence, ethnobotanical utilities along with prospective ecological and economical potentials of *S. villosa* through available literature so far.

Materials and Methods

Exhaustive scientific literature concerning the botanical description and distribution, cultivation and propagation, traditional utilities, ecological and environmental management potential, and economic potential of *S. villosa* were collected and derived from ethnobotanical books, published articles, electronic sources, and scientific databases such as Plants of the World Online (https://powo.science.kew.org/), Scopus, Wiley, Web of Science, PubMed (https://pubmed.ncbi.nlm.nih.gov/), Science direct, and NISCAIR Online Periodicals Repository (NOPR) (http://nopr.niscair.res.in/) to provide uptodate information. The name and synonyms of the plant that are presently recognised were validated using "World Flora Online" (https://www.worldfloraonline.org/). Keywords such as "*Sterculia villosa*," "ethno-veterinary use," "ethnomedicinal use," "botanical distribution," "distribution," "socio-cultural uses," "phytochemical," "pharmacological," "food source," and "economic potential" were combined during the search for relevant literature. They were exhaustively performed and rechecked for accuracy. By utilizing keywords, relevant articles were compiled through the Mendeley web importer, which is an internet-based reference manager. Chem Draw Ultra 12.0 has been used to draw the chemical structures and formulas of compounds, and the PubChem database has been used to source and validate them. Arc GIS Desktop version 10.8.1 has been used to draw map.

Results and Discussion

Botanical description and distribution

S. villosa is a moderate-sized tree belonging to the family Malvaceae (Table 1 and 1) that grows up to 15-20 m in height and a girth of 1.2-1.5 m with the bark thickness of about 2.50-2.65 cm in mature trees (Baruah *et al.* 1992; Kanjilal *et al.* 1934). Wood is very light and smooth, with a pale yellowish or greyish white to light greyish or brown coloration (Morton 1977). In young trees, the bark is glossy and smooth, with horizontal wrinkles; as the tree grows older, the bark becomes rougher, with prominent lenticels with thin papery outer bark. Leaves are 25-40 cm long, wide, and heart-shaped at the base, with lobes that are oblong or obovate in shape and are held aloft by even longer stalks; palmately 5-7 lobes, sometimes broken up into small, pointy sub-lobes; the base is deeply heart-shaped; under surface velvety long hairs beneath, progressively becoming more or less smooth on top. Panicles of 15-30 cm long, rusty velvety, pendulous flowers are produced. Flowers are unisexual and have stalks that are 4-8 mm long. Bell-shaped sepal cup, five partite, 6-10 mm long, 10-15 mm wide, yellow with a pinkish throat. Sepals are pointed, lance-shaped, and 4-6 mm long. The stamen column is 4- 5 mm long and recurved. Male and female flowers are mixed, and there are no petals; calyx yellow with dark pink veining inside at base, bell-shaped with five spreading, petaloid lobes, hairy outside; male flowers have ten anthers; female sections are placed on a hairy, cylindric column; stigma is five-lobed. Fruits are 3-5 boat-shaped follicles about 3-5 cm long, leathery, rusty pubescent, many-seeded, radiating out from where they are attached to a typical stalk; covered all over with long, soft hairs; grey green at first, turning bright red when mature. The seeds are black, oblong, and smooth.

Table 1. *Sterculia villosa* Roxb. Classification System

Kingdom	:	Plantae
Phylum	:	Tracheophyta
Class	:	Magnoliopsida (Dicotyledons)
Sub-class	:	Dilleniidae
Order	:	Malvales
Family	:	Malvaceae
Genus	:	*Sterculia*
Species	:	*villosa*

61. *Sterculia villosa*, A- A mature full bloomed tree with flowers, B- dehiscent and indehiscent fruits with seeds, C- young leaves, D- bark

S. villosa is one of the most widespread tree species in the Indian sub-continent and Southeast Asian regions and known by vernacular names in the respective regions (Figure 2 and Table 2). It flourishes well in India's north-eastern hilly regions. It is common throughout the deciduous forest of Assam (Verma & Kharakwal 1977). It is seen in forested areas where *Terminalia tomentosa* Wight & Arn. is grown, as well as in the alluvial savanna forests of India (Dholariya *et al.* 2019).

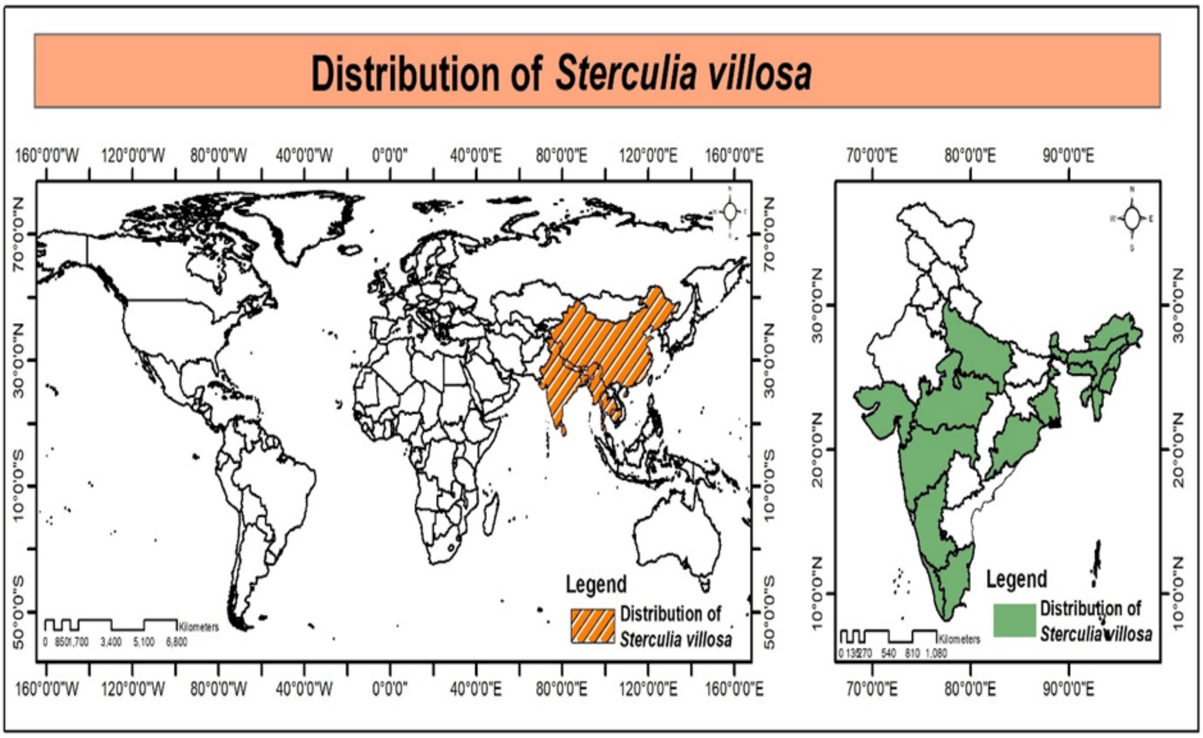


Figure 2. Map showing the geographical distribution of *S. villosa*

Table 2. *Sterculia villosa's* vernacular names used in different parts of India, Nepal and Myanmar

Country	Dialect/ Tribe		Vernacular name	Reference
India	Adi	:	Sarjok	Jeyaprakash *et al.* 2017
	Angami	:	Ketsho	NEPED & IIRR 1999
	Ao	:	Ajunem	NEPED & IIRR 1999
	Assamese	:	Oudal, Odal, Udal	Reddy 2015, Rao & Kumar 2024
	Bengali	:	Udal	Reddy 2015
	Chakhesang	:	Mechachi	NEPED & IIRR 1999
	Chakma	:	Udolgach	Uddin *et al.* 2014
	English	:	Hairy Sterculia	Sawmliana 2003
	Garo	:	Ubak	Rao & Kumar 2024
	Gujarati	:	Sardol	Khanna & Singh 2009
	Hindi	:	Katira, Udal	Reddy 2015, Rao & Kumar 2024
	Kannada	:	Kaitaale, Bilidali	Rao & Kumar 2024
	Karbi	:	Chekong	Paitiri & Borah 2007
	Khasi	:	Dieng star	Reddy 2015, Rao & Kumar 2024
	Kokborak	:	Phatibarak	Das *et al.* 2009
	Konyak	:	Zimzao	NEPED & IIRR 1999
	Malayalam	:	Vakka	Reddy 2015, Rao & Kumar 2024
	Manipuri	:	Laangjan	Singh *et al.* 2000
	Marathi	:	Sardol, Kardul	Reddy 2015, Rao & Kumar 2024
	Mishing	:	Sargikesing	Paitiri & Borah 2007
	Mishmi	:	Aagyoo	Moyong *et al.* 2019
	Mizo	:	Khau-pui	Sawmliana 2003
	Nepali	:	Khava, Odani, Odal	Miya *et al.* 2021
	Oriya	:	Kodalo	Rao & Kumar 2024
	Punjabi	:	Massu	Gamble 1881

	Reang	:	Phatchhi, Fathi	Reang *et al.* 2016
	Rengma	:	Aghazi	NEPED & IIRR 1999
	Sumi	:	Qhechobo, Akuchhobo	NEPED & IIRR 1999
	Tamang	:	Pat	Uprety *et al.* 2016
	Tamil	:	Anai-nar, Vakkai	Reddy 2015, Rao & Kumar 2024
	Telugu	:	Kummaripuliki, Kavili, Narapoliki, Vakkunara	Rao & Kumar 2024
Myanmar	Burmese	:	Shaw-ni	Shinya 2017
Nepal	Nepali	:	Khava, Odani, Odal	Miya *et al.* 2021

Cultivation and propagation

S. villosa grows in lowland, subtropical, and tropical areas. It prefers areas with yearly daytime temperatures of 30-42°C, though it can withstand temperatures of 7-47°C but cannot survive at -2°C (Fern 2022). . It thrives in a mean annual rainfall of 1300 - 1900 mm, light, well-drained environment. It grows in the regions where there is a distinct dry season due to its deciduous nature (Fern 2022) . Seedlings are shade tolerant. *S. villosa* can withstand poor, rocky soils and prefers a pH of 6.5-7.5 but can tolerate 6.0-8.0. Drought tolerance is high in established trees (Fern 2022).

S. villosa readily grows from seed, with a fast rate of growth in the early stages and forming long taproots (Dholariya *et al.* 2019). The seeds are dispersed by wind (Wangpakapattanawong & Elliott 2008). A high percentage (80%) of seed germination was recorded in the propagator house (a greenhouse with a bed made of Sylhet sand and a temperature and humidity control system) (Hasnat *et al.* 2019). It can be propagated through seeds and stem cuttings (Dholariya *et al.* 2019; Ghosh & Baruah 1997).

Traditional Utilities of *S. villosa*

Different parts of *S. villosa* which include bark, stem, leaves, seed, fruit, gums, etc. are utilized in various herbal preparations for curing certain diseases and health problems like heart problems, dysentery, gastric problems, jaundice, diabetes, asthma, arthritis, mensuration related problems, skin related problems, male reproductive problems, etc. (Figures 3 - 4).

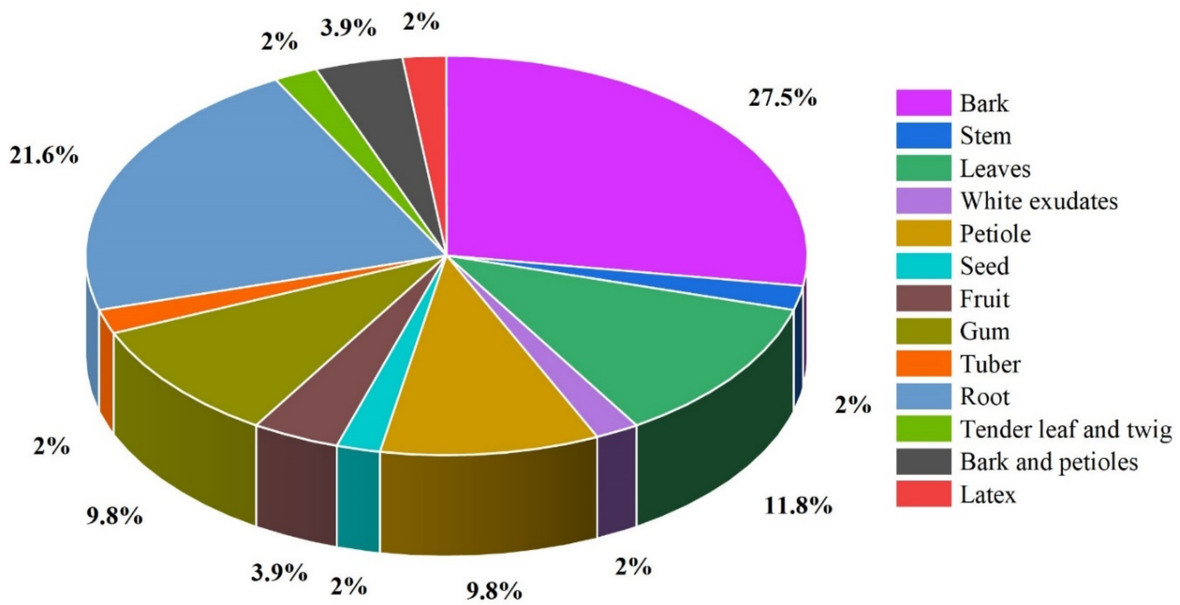


Figure 3. Plants parts *of S. villosa* utilised in various herbal preparations (n=51)

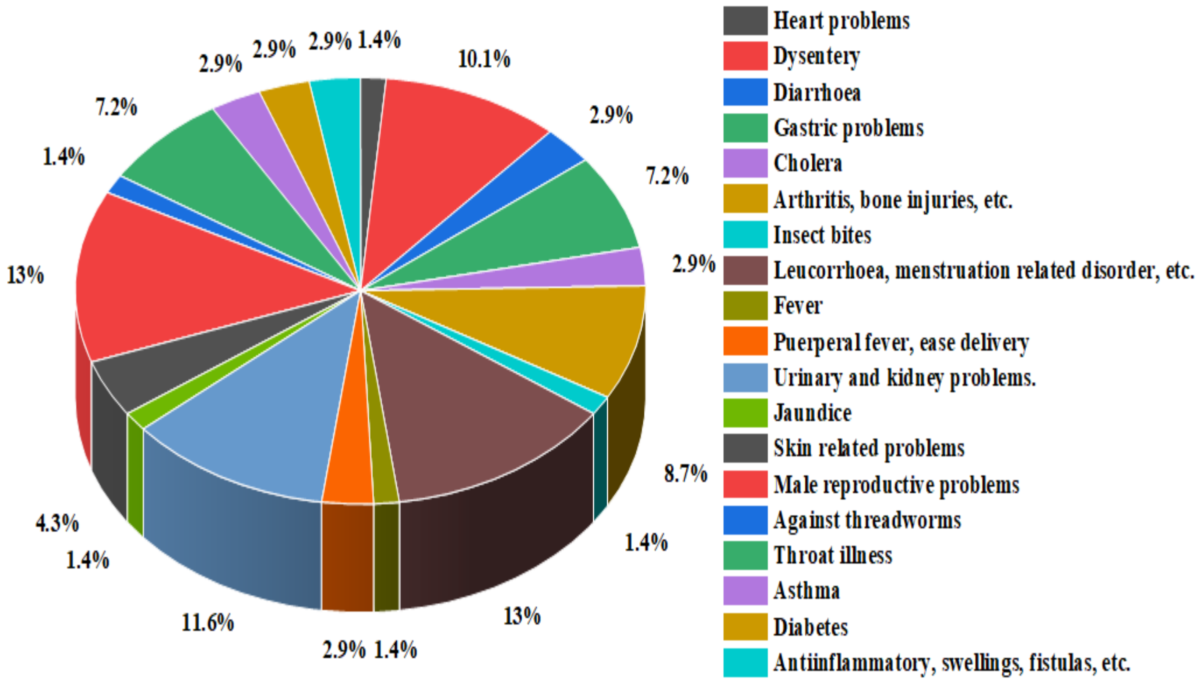


Figure 4. Pie chart depicting the percentage of diseases and health problems that can be cured using parts of *S. villosa* (n=69).

Ethno-medicinal uses

Different parts of the *S. villosa* are used as ethnomedicine for treating certain diseases throughout the Indian subcontinent, particularly by tribal peoples in remote areas. Table 3 shows the traditional ways of making dosage and applications of this species. The dried powder, extracts, tinctures, and decoctions made from various parts of the *S. villosa* tree were used as a resource for traditional medicine to treat a wide variety of illnesses (Silva *et al.* 2014). In traditional Indian medicine, inflammation and skin conditions are typically treated with *S. villosa* plants. The infusion made from the roots is used as a nutritional supplement, while the extract made from the whole plant is used to treat various skin ailments (Kunwar *et al.* 2010; Baral & Kurmi 2006). In the village of Dimoria, which is located in the Kamrup district of Assam, the locals use bark powder as a treatment for eczema (Borthakur & Goswami 1995). The stem's bark of *Cochlospermum religiosum* (L.) Alston in combination with the bark of *Sterculia colorata* Roxb., *S. villosa*, *Hymenodictyon excelsum* (Roxb.) Wall., and *Dillenia indica* L., blended with mustard oil, is used by the tribals of Sonaghati, Uttar Pradesh's Sonbhadra district, to treat septicemia poisoning sores as well as on fistulas (Singh *et al.* 2002). The root paste of *S. villosa* is used by the people of Madhya Pradesh's Shahdol District to minimise swellings in inflamed regions of the body (Bharti *et al.* 2015). People in the Brahmanbaria district of Bangladesh heal acne and red patches on the skin of the face by taking leaves paste orally with molasses made from sugarcane juice for seven days on an empty stomach in the morning (Mannaf *et al.* 2013).

A mixture of sherbet, juice, and sugar that is prepared from the petioles of *S. villosa* is used to cure rheumatism as well as problems with the urinary tract. This concoction is used by the local people of Bangladesh (Dholariya *et al.* 2019; Tania *et al.* 2013; Rahman *et al.* 2007; Hossain *et al.* 2013). The Jalgaon district in Maharashtra is known for its success in treating arthritis with a pulverised bark poultice that is applied topically to the affected areas (Mali & Bhadane 2008). The inhabitants of the Baitadi, Dadeldhura, and Darchula districts in the westernmost part of Nepal have found that the white exudates produced by the tree are particularly effective in treating throat infections (Baral & Kurmi 2006; Hossain *et al.* 2013; Kunwar *et al.* 2010). Mizoram's indigenous tribes use the bark juice as a throat paint to treat throat illnesses (Sharma *et al.* 2001). The communities of Northern Bengal in India make use of the bark and petioles of the *S. villosa* tree as a medicine for the treatment of diarrhoea, dysentery, and seminal weakness (Raj *et al.* 2018). Traditional treatments for seminal weakness in the Tripuri and Reang tribes of Tripura involve chopping three to four young petioles into very small pieces, soaking the pieces in a glass of water overnight, and then ingesting the mixture orally in the morning and evening for twenty-five to thirty days (Das *et al.* 2009). People in the Habiganj district of the Sylhet division in Bangladesh use the bark and petiole to treat seminal weakness. However, they use the leaves to treat impotency (Tania *et al.* 2013). Fresh roots are ingested twice a day by members of the Bhilla tribe in Maharashtra as a means of warding against male sterility and weakness (Kamble *et al.* 2010). The people of the Habiganj District in Bangladesh use tender leaves and twigs as a treatment for stomach pain, stomach disorders, and premature ejaculation in males (Chowdhury & Koike 2014). In order to treat impotence, the indigenous people of the Chittagong hill tracts in Bangladesh recommend taking pills made from the roots of *S. villosa* and *Bombax ceiba* L., as well as *Aloe indica* Royle leaves. These pills are taken orally (Yusuf *et al.* 2007). Overnight water-soaked roots of *S. villosa* are taken on an empty stomach for urinary problems and kidney stones (Debbarma *et al.* 2017). The juice is extracted from *S. villosa* stems that have been chopped into smaller parts and steeped in water. *Hyptis suaveolens* (L.) Poit. roots are steeped in juice and consumed on an empty stomach in the morning once daily. This goes on for seven days in a row for treatment of burning sensations during urination (Mannaf *et al.* 2013). Leaves are employed in the treatment of conditions such as dysuria and scanty micturition (Kamble *et al.* 2008).

To reduce the severity of menstruation cramps, soak the bark in water for a full night. In the morning of the following day, the water is taken orally with mishri, which is crystalline sugar, on an empty stomach. The people of Bangladesh who belong to the Var tribe do this for ten to twelve days to alleviate menstrual cramps (Nipu *et al.* 2014). Women in the Tripuri tribal belts of the South and West districts of Tripura who suffer from leucorrhoea as well as menstrual cramp are given four to five fresh petioles that have been sliced into small pieces after having been soaked in half a glass of water overnight (Majumdar & Datta 2007). Women who are suffering from menstrual cramps or pain are encouraged by the Tripuri tribe of Tripura to soak the fresh leaves in a full glass of water overnight, and then drink them on an empty stomach the following morning (Debbarma *et al.* 2017). In order to alleviate symptoms of leucorrhoea, members of the Chakma community in Rangamati District, Bangladesh, consume a leaf paste that has been diluted with water (Uddin *et al.* 2014). The natives of Southern Assam crush bark to extract its medicinal properties and utilise them to treat gastrointestinal conditions (Choudhury *et al.* 2015). In cases of dysentery and cholera, the native tribal people of Mizoram administer orally a decoction of the bark at a dosage of 10-15 ml, two to three times each day (Sharma *et al.* 2001). The Gujjar people of Uttarakhand have developed a treatment for bleeding dysentery that consists of the juice of the root combined with honey (Bhandari 2021; Das *et al.* 2008). Oral consumption of a bark decoction is common practise among members of the Mizo tribe of Mizoram for the treatment of cholera, dysentery, diarrhoea, and tonsillitis (Sawmliana 2003). The people who live in and near Khadimnagar National Park in Bangladesh have found that using the latex that is collected from *S. villosa* can help alleviate a variety of diseases, including skin illness, stomach pain, and burning (Rahman *et al.* 2011). The tribal people of the West Garo Hills district in Meghalaya soak the bark in cold water for a few minutes until it softens, and then they massage the softened bark against the insect stings on the affected area. This helps alleviate the pain caused by the stings (Hazarika *et al.* 2016).

Table 3. Traditional uses *of Sterculia villosa* among different ethnic groups of people

Region and people/tribes	**Traditional uses**
Adi tribes of Arunachal Pradesh	Bark fibre is used for making traditional ropes and bags (Kumar *et al.* 2015).
Mishmi tribes of Lohit District in Arunachal Pradesh	Raw seeds are eaten (Moyong *et al.* 2019).
Tangsa community of Changlang district of Arunachal Pradesh	Water from roots is extracted during the dry period. Seeds are fried and roasted. Bark is used for making ropes (Lungphi *et al.* 2018).
Bodo tribes of Assam	Used for making traditional musical instruments: Serja and Kham (Brahma *et al.* 2015).
Local people of Lakhimpur and Dhemaji districts of Assam	Stem bark is used for rope making (Das *et al.* 2020).
People of Dhemaji district of Assam	Decoction of root is given every day in dysentery to cattle (Sharma & Sapcota 2003).
Rural community of Dhemaji district of Assam	As an anti-diabetic recipe/dosage, one teaspoonful of fruit powder combined with around 50 ml water is taken three times a day after meals for 15 days (Tarak *et al.* 2011).
People of Dimoria, Kamrup district of Assam	Bark powder is used to cure eczema (Borthakur & Goswami 1995).
Local people of Southern Assam	Crushed extract of the bark is used to treat digestive system disorder (Choudhury *et al.* 2015).
Local people of Mizoram	In the case of a throat illness, the bark juice is utilised as throat paint. In dysentery and cholera, a decoction of the bark is administered orally (Sharma *et al.* 2001). Roasted seeds are eaten (Kar *et al.* 2013).

Reang tribe of Tripura	Bone injuries are treated using tuber paste (Reang *et al.* 2016). Root decoction is used as a health tonic (Shil *et al.* 2014). Bark is used for rope making (Das *et al.* 2008).
Debbarma community of Tripuri tribe in Khowai district of Tripura	The bark is used as a rope to make belt of "Langa" (a traditional basket used by the Debbarma community) or for tying animals (Sharma *et al.* 2013).
Tribes of Cachar district, Assam	The juice of the roots is utilised as a health tonic, and a mixture of root juice and honey is administered orally to treat blood dysentery (Das *et al.* 2008).
Tribes of Tripura	The root is steeped overnight in water and taken as an empty stomach for urinary problems and kidney stones. Soaked fresh leaves are taken to cure menstruation pain (Debbarma *et al*. 2017).
Tripuri folk medical practitioners	Soak fresh leaves overnight are consumed on an empty stomach to treat leucorrhoea and menstrual cramps (Majumdar *et al.* 2007).
Tripuri tribes of Tripura	Flower are used in Saraswati puja (Sharma *et al.* 2013)
Local people of Odisha	Bark is used for making ropes (Sahu *et al.* 2013).
Adivasis in Andhra Pradesh's Eastern Ghats	Used for treating menorrhea (Ratnam & Raju 2005).
Jalgaon district of Maharashtra	Root powder with milk is given internally to facilitate delivery. A small quantity of gum mixed with honey taken in the morning is reported to be good for throat problems. Pulverized bark poultice is applied externally over affected parts in arthritis. Seed powder and jaggery are used to prepare tablets, which are eaten on an empty stomach for a week to treat heart diseases and asthma (Mali & Bhadane 2008).
Bhilla tribe of Maharashtra	To combat male sterility and weakness, fresh roots are consumed twice a day (Kamble *et al.* 2010).
People of Shahdol District of Madhya Pradesh.	To minimise swellings, the root paste is only supplied and administered to the inflamed regions of the body, and also bark is used in asthma (Bharti 2015).
Bhoxa community of district Dehradun, Uttarakhand	In the case of dysentery, gum is given together with curd (Gairola *et al.* 2013).
Gujjars community of Uttarakhand	The root juice is used to cure bleeding dysentery when coupled with honey (Bhandari 2021).
Tribals of Sonaghati, Uttar Pradesh's Sonbhadra district	Bark is administered on septicaemial poisoning sores as well as fistulas (Singh *et al.* 2002).
Local people of Andaman and Nicobar Islands	Leaves are used for ailments such as dysuria and scanty micturition (Kamble *et al.* 2008).
Chakma Community of Rangamati District, Bangladesh	To cure leucorrhoea, paste of leaves is mixed with water and taken (Uddin *et al.* 2014).
Chakma tribe in Hill Tracts districts, Bangladesh	Petiole water extract is given to drink with sugar to cure rheumatism; root extract is consumed as a vitamin source (Rahman *et al.* 2007).
Folk medicinal practitioners in Bangladesh	For people who have burning sensations during urination and urine, stem juice is taken on an empty stomach. Leaves are eaten to diagnose acne and red patches on the skin of the face (Mannaf *et al.* 2013).
Rai Clan of the Tipra tribe of Sylhet district, Bangladesh	Puerperal fever is treated with a bark decoction (Nahar *et al.* 2013).
Tribal of Chittagong hill tracts, Bangladesh	Orally, pills derived from the root, *Bombax ceiba* L. root, and *Aloe indica* Royle leaves are suggested for impotency (Yusuf *et al.* 2007).
Var tribe of Bangladesh	To treat menstruation discomfort, soak the bark in water overnight and take it orally with mishri (crystalline sugar) (Nipu *et al.* 2014).
Tamang people of Nepal	Root is used for treating fever (Tamang 2003).
Local people of Sri Lanka	Gum and root are used for ailments such as rheumatism, diuretic, cooling, and aphrodisiac (Kamble *et al.* 2008).

Tablets, made with seed powder and jaggery in a ratio of 1:2 by weight (approximately 50 g), are consumed on an empty stomach for a week in order to treat heart diseases and asthma by the local population of the Jalgaon district in the state of

Maharashtra (Mali & Bhadane 2008). In order to prevent jaundice, the residents of the West Garo Hills district in Meghalaya consume fruits that have been boiled first (Hazarika *et al.* 2016). In the native Dhemaji district of Assam, India, an anti-diabetic recipe or dose that consists of one teaspoonful of fruit powder blended with around fifty millilitres of water and is taken three times a day after meals for fifteen days is also suggested (Tarak *et al.* 2011). In the Sylhet district of Bangladesh, members of the Tipra tribe from the Rai Clan administer a bark decoction to patients suffering from puerperal fever (Nahar *et al.* 2013). Injuries to the bones are treated with tuber paste by members of the Reang tribe from Tripura (Reang *et al.* 2016). The Mizo tribe of Mizoram uses the juice that is derived from the bark fibre to expel thread worms from the body through oral consumption (Sawmliana 2003).

The Reang tribe of Tripura and tribes in Assam's Cachar area (the northeastern states of India) uses root decoction/ juice as a health tonic (Shil *et al.* 2014; Das *et al.* 2008). The people who dwell in the Jalgaon area of Maharashtra provide a root powder and milk concoction to the mother during labour and delivery in order to aid childbirth (Mali & Bhadane 2008). Powdered root bark is mixed with the leaves of *Clerodendrum thomsoniae* Balf. and then applied in the gap between the nail tips and the fingertip by members of the Lohit community in Arunachal Pradesh. This helps to ease the discomfort and inflammation that are caused by the touch of metallic items (Namsa *et al.* 2009). Root infusion of *S. villosa* is utilized as a food supplement due to its high nutritional value (Hossain *et al.* 2013). The whitish pellucid gum exudes from the bark, known locally as katila gum, is utilized as a base for salicylic acid patches and as a dental fixative, and also as an adhesive for colostomy equipment (Anderson *et al.* 1982; Dholariya *et al.* 2019). Locally, gum is utilised to maintain a healthy balance of blood sugar and plasma lipids (Dholariya *et al.* 2019). In the treatment of sore throats, the gum is frequently consumed in the form of lozenges, either on its own or combined with honey (Dholariya *et al.* 2019). Kamble *et al.* (2008) reported that gum and root of *S. villosa* are used for ailments such as rheumatism, diuretic, cooling, and aphrodisiac. In cases of dysentery, members of the Bhoxa community in Uttarakhand's Dehradun area administer the gum of *S. villosa* together with curd (Gairola *et al.* 2013) (Table 3).

Ethno-veterinary use

The *S. villosa* plant is employed in the practise of ethnoveterinary medicine in Northern India (Reang *et al.* 2016). Antiseptic properties can be found in gum, which makes it useful in veterinary medicine. Decoction of 15 g of the root, produced with 60 ml of water, and administered in doses of 20 ml daily to calves suffering from dysentery (Sharma & Sapcota 2003).

Food and nutritional security to local people

The powdered root is mixed with rice flour and used to prepare a bread-like doughnut, it enhances the taste and softness of bread (Manandhar 2002). Roots of the *S. villosa* plant are eaten after being roasted (Jadhav *et al.* 2015). The root powder is used as a soda powder (Shaheen *et al.* 2017). The Chakma tribe, who live in the Hill Tracts region of Bangladesh, use an extract made from the root as a source of vitamins (Rahman *et al.* 2007). It is possible to eat seeds in their raw, roasted, or baked forms (Stephen 1998; Sarkar & Devi 2017; Sharma *et al.* 2013; Moyong *et al.* 2019; Kar *et al.* 2013; Lungphi *et al.* 2018; Dholariya *et al.* 2019). In far-west Nepal, stem bark is used to make bread (Kunwar *et al.* 2010). Fruits are also edible (Shaheen *et al.* 2017; Subedi *et al.* 1993). During the dry season, the water stored in the roots is drawn out (Lungphi *et al.* 2018) (Table 3).

Socio-cultural uses

S. villosa is utilised in the production of a variety of craft and decorative goods (Kumar *et al.* 2015). Flowers are used in Saraswati puja (worship of goddess Saraswati) (Sharma *et al.* 2013). Fibre obtained from bark is used to make Serja (traditional musical instrument) by the Bodo tribes of Assam, and used at marriage ceremonies, Boisagu festivals, and Domashi festivals (Brahma *et al.* 2015). Kham (the traditional drum of Bodo tribes), a large drum with a length and diameter of $2^{1/2}$ to 3 inches and $3^{1/2}$ to 4 inches is made from the trunk of *S. villosa*, is played on ceremonial occasions of Kherai puja and Garja puja (Brahma *et al.* 2015) (Table 3).

S. villosa in Agro-forestry

S. villosa are used for intercropping in an agro-forestry system (Tamang *et al.* 2019). *S. villosa* is cultivated by the Khasi people in the Paan jhum gaps (traditional shifting cultivation; a type of agro-forestry system) in the Barak valley in northeast India (Nandy & Das 2013). *S. villosa* used as a fodder tree species; withstand sustainable lopping (Chettri *et al.* 2002). It is also used to make ropes and clappers, and as a fence material around the shifting cultivation fields to check wild boars for upland rice and barking deer against chili peppers damage. The clappers made of it are used to scare deer away in Bago mountains regions of Myanmar (Shinya 2017). *S. villosa* species are also planted as an ornamental plant (Tamang *et al.* 2019). *S. villosa* has the ability to contribute significantly to forest biodiversity conservation (Dholariya *et al.* 2019).

Phytochemical compositions

The phytochemistry of *S. villosa* was studied sparingly qualitatively, with gaps in the pharmacological activities of isolated phytochemicals. Various classes of compounds extracted from different parts of *S. villosa* encompass flavonoids, alkaloids, glycosides, steroids, tannins, saponins, terpenoids, polyphenols, triterpenes, and miscellaneous constituents (Figure 5). The presence of alkaloids, glycosides, steroids, flavonoids, tannins, saponins, and terpenoids was recorded in the methanol extract, whereas glycosides, steroids, flavonoids, tannins, saponins, and terpenoids were found in the ethyl acetate fraction of bark of *S. villosa* (Uddin *et al.* 2015).

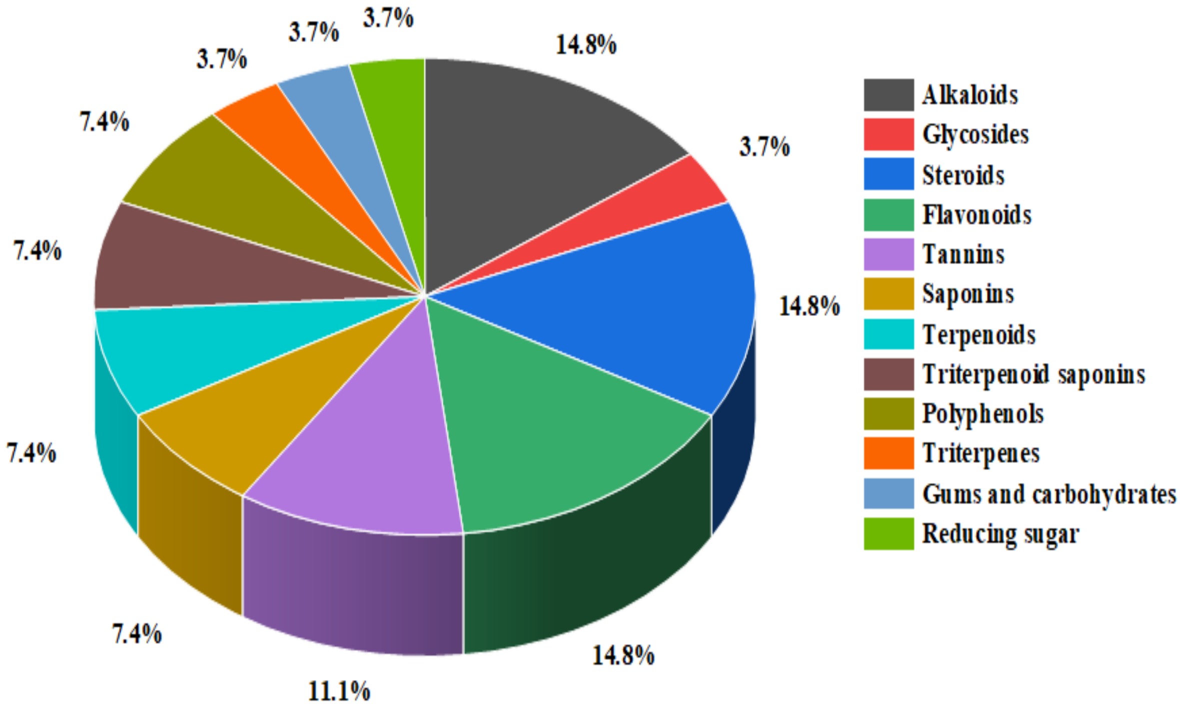
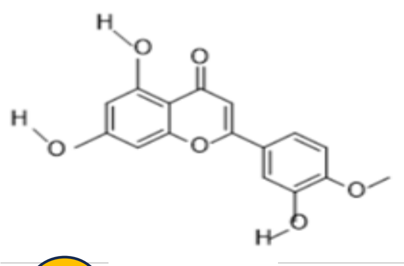


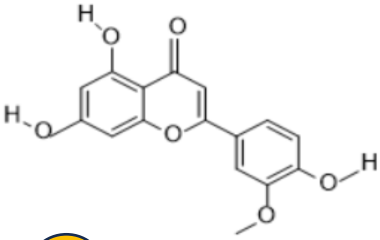
Figure 5. Chemical classes and amounts of phytochemicals substances identified and characterized from *S. villosa* (n=27).

Leaves metabolites such as steroids, saponins, triterpenoid saponins, alkaloids, flavonoids, tannins, and polyphenols were detected in hexane extract; steroids, saponins, triterpenes, alkaloids, flavonoids, tannins, and polyphenols were recorded from ethyl acetate extract; while steroids, triterpenes, triterpenoid saponins, alkaloids, flavonoids, tannins, and polyphenols were reported from ethanolic extract (Lakshmi & Pullaiah 2015).Crude methanolic extract of *S. villosa* seeds contained flavonoids, gums and carbohydrates, steroids, alkaloids, reducing sugar, and terpenoids, but no tannins or saponins (Ullah *et al.* 2015).

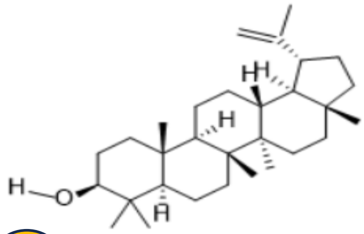
The presence of 5.8 % cyclopropenoid fatty acid in *S. villosa* was determined using the HBr titration method (Badami *et al.* 1980). In addition to the typical fatty acids, gas-liquid chromatography revealed that the seeds of *S. villosa* included sterculic acid (2.5 %) and malvalic acid (3.2 %) (Badami *et al.* 1980; Sebedio & Grandgirard 1989). Flavonoids such as Diosmetin, Chrysoeriol, and its derivatives such as Diosmetin-7-O-b-D-glucoside, Chrysoeriol-7-O-b-D-glucoside were reported from *S. villosa* (Seetharaman 1990). Chemically, Diosmetin is a monomethoxyflavone while Chrysoeriol is a 4',5,7-trihydroxy-3'-methoxyflavone both are close derivative naturally-occurring flavonoid Luteolin (Figure 6). Diosmetin is reported to possess pharmacological activities such as antioxidant, anticancer, antimicrobial, oestrogenic, and anti-inflammatory (Patel *et al.* 2013). Lupeol, a pentacyclic triterpenoid was purified and detected in the petroleum ether fraction of methanolic Diosmetin-7-O-b-D-glucosidep extract of bark of *S. villosa* with significant anti-leishmanial and immunomodulatory activities (Das *et al.* 2017). Lupeol exhibited diverse pharmacological activities such as anti-inflammatory, anti-cancer, chemopreventive, anti-protozoal, and anti-microbial (Gallo & Sarachine 2009).



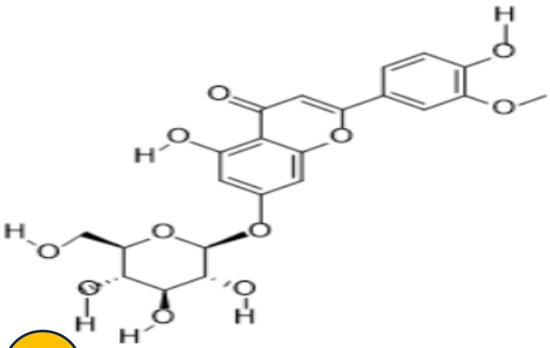
A Diosmetin



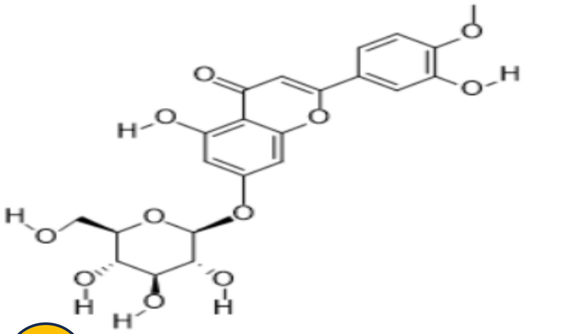
B Chrysoeriol



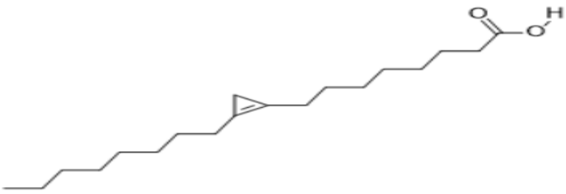
C Lupeol



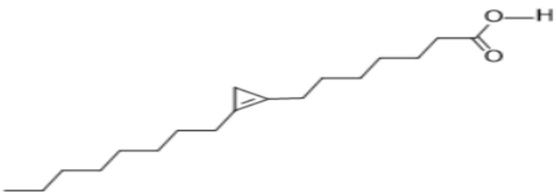
D Chrysoeriol-7-O-b-D-glucoside



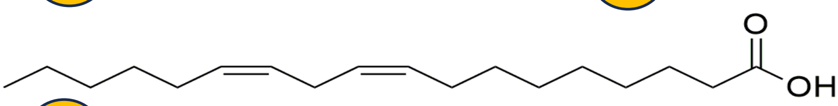
E Diosmetin-7-O-b-D-glucoside



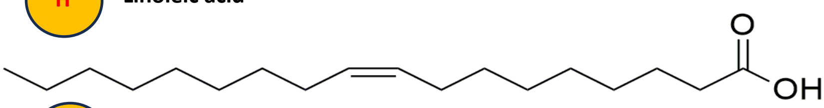
F Sterculic acid



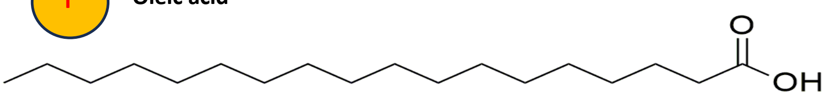
G Malvalic acid



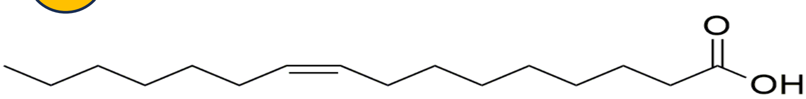
H Linoleic acid



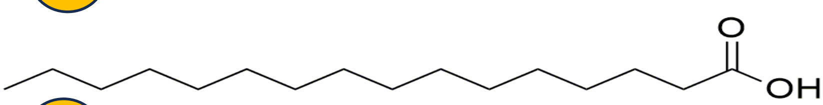
I Oleic acid



J Stearic acid



K Palmitoleic acid



K Palmitic acid

Figure 6. Chemical structure of phytochemicals detected from *S. villosa*, **A-** Diosmetin**, B-** Chrysoeriol, **C-** Lupeol, **D-** Chrysoeriol-7-O-b-D-glucoside, **E**- Diosmetin-7-O-b-D-glucoside, **F-** Sterculic acid, **G**-Malvalic acid, **H**- Linoleic acid, **I**- Oleic acid, **J**- Stearic acid, **K**- Palmitoleic acid, **L**- Palmitic acid

Diosmetin-7-O-b-D-glucoside, a flavonoid glycoside renowned for its antioxidant properties, has been studied extensively (MingShun *et al.* 2015; Wang *et al.* 2008). Sterculic acid (SA), a monounsaturated fatty acid containing a cyclopropene ring, exhibits notable anti-inflammatory properties (Peláez *et al.* 2020; Huang *et al.* 2012). Lupeol, a triterpenoid compound, demonstrates potent antioxidant, antimutagenic, anti-inflammatory, and antiarthritic characteristics, making it a promising candidate for pharmaceutical applications (Parsaeimehr *et al.* 2017; Vasconcelos *et al.* 2008). Additionally, lupeol has shown beneficial effects against various health conditions including cancer, diabetes, heart diseases, renal toxicity, and hepatic toxicity (Bradford & Awad 2007; Bani *et al.* 2006; Setzer & Setzer 2003; Sultana *et al.* 2003). Diosmetin, a monomethoxy flavonoid, exhibits diverse biological activities, including anti-tumor, anti-angiogenesis, antioxidant stress reduction, and analgesic properties (Meephat *et al.* 2021; Mo *et al.* 2020; Adamante *et al.* 2019; Choi *et al.* 2019). Chrysoeriol, another flavonoid present in various herbs, is of significant interest due to its medicinal properties, which encompass antioxidant, antimicrobial, anti-inflammatory, neuroprotective, cardioprotective, and cancer preventive activities (Lan *et al.* 2020; Wu *et al.* 2020; Takemura *et al.* 2010).

Linoleic acid, the simplest omega-6 fatty acid, serves as a substrate for the biosynthesis of eicosanoids, which are essential physiological regulators. Eicosanoids encompass prostaglandins, prostacyclins, thromboxanes, and leukotrienes, acting as potent mediators in numerous biochemical processes. They play pivotal roles in regulating blood clotting, blood pressure, blood lipid levels, immune function, inflammation, pain perception, fever, and reproduction (Field 2003). Oleic acid, a monounsaturated omega-9 fatty acid, finds utility as an excipient in pharmaceutical formulations and as an emulsifying or solubilizing agent in aerosol products. It has been implicated in potentially impeding the progression of adrenoleukodystrophy, a fatal neurodegenerative disease affecting the brain and adrenal glands and may contribute to memory enhancement (Rizzo *et al.* 1986). Furthermore, oleic acid may underlie the hypotensive effects observed with olive oil consumption (Teres *et al.* 2008).

Stearic acid is a saturated monobasic acid. Its consumption typically yields a neutral or cholesterol-lowering effect, contrasting with the impacts observed with lauric, myristic, and palmitic acids (Monsma & Ney 1993). Palmitoleic acid is a 16-carbon monounsaturated fatty acid (MUFA) with a double bond positioned in the seventh position, which can exist as cis or trans isomers. It is hypothesized to possess anti-thrombotic properties, potentially mitigating stroke risk (Abraham *et al.* 1989). Palmitoleic acid has been associated with beneficial effects on insulin sensitivity, cholesterol metabolism, and hemostasis. It has been suggested that palmitoleic acid may mitigate beta-cell apoptosis induced by glucose or saturated fatty acids (Morgan & Dhayal 2010). Additional reported positive effects include reduced low-density lipoprotein cholesterol (LDL) and increased high-density lipoprotein cholesterol (HDL) levels (Mozaffarian *et al.* 2010).

Pharmacological activities

S. villosa demonstrated a wide range of biological and pharmacological activities that are beneficial to human health. Pharmacological activities that have been recorded in *S. villosa* are listed in Table 4 and Figure 6 and mentioned as follows.

Antioxidant activity

The in vitro antioxidant activities of the bark of S. villosa have been recorded as crude methanolic extract and its various fractions viz. petroleum ether, carbon tetrachloride, dichloromethane, and ethyl acetate. These extracts were tested using the DPPH assay at doses ranging from 500 to 0.977 µg/ml (Haque *et al.* 2014). The highly effective free radical scavenging activity was observed in the ethyl acetate fraction (IC_{50} 3.76 µg/ml) comparable to BHT (tert-butyl-1-hydroxytoluene) (IC_{50} 31.72 µg/ml) but there is no free radical scavenging activity in petroleum ether (IC_{50} 177.62 µg/ml) fraction as compared with the standard BHT (Haque *et al.* 2014).

Table 4. Pharmacological activities studied in *Sterculia villosa*

Part of plant or extract used	Observations	Pharmacological activity studied
Ethyl acetate fraction of bark	Shown good free radical scavenging activity compared to standard BHT (31.72 µg/ml)	Antioxidant activity (Haque *et al.* 2014).
Ethanolic extract of bark	Effective in reducing both acute and chronic inflammatory reactions.	Anti-inflammatory activity (Hossain *et al.* 2012).

Petroleum ether fractions of bark	Petroleum ether fractions inhibited 51.72 % (P <0.001) which is equivalent to aspirin (71.03 percent inhibition).	Analgesic activity (Hossain *et al.* 2013)
Ethanolic extract of bark	Showed significant anthelmintic activity against adult earthworms, *Pheretima posthuman.*	Anthelmintic activity (Alam *et al.* 2012)
Crude methanol bark extract	Shown to have antileishmanial activity against *Leishmania donovani*, a protozoan that causes visceral leishmaniasis(kala-azar) and exhibited immunomodulatory effect.	Antileishmanial activity (Das *et al.* 2017)
Ethanolic extract of the bark	Showed potent diuretic efficacy in a dose-dependent manner, with results equivalent to those of the reference drug furosemide (20 mg/kg)	Diuretic activity (Alam *et al.* 2012)
Bark crude methanolic extract	Demonstrated efficacy against several of the examined species when tested with ciprofloxacin as a positive control.	Anti-microbial activity (Haque *et al.* 2014)
Methanolic bark extract	Enhanced insulin secretion from existing b cells and boosting glucose consumption in peripheral tissues.	Antidiabetic activity (Hossain *et al.* 2012)
Ethyl acetate fraction of bark	47.88 percent clot lysis was obtained, which was significant (P< 0.05) when compared to the negative control	Fibrinolytic Activity (Uddin *et al.* 2015)
Methanol leaf extract	Compared to normal diazepam, the extract shows excellent CNS depressant efficacy, reducing locomotor activity in mice in every test.	Sedative activity (Hossain *et al.* 2016)
Crude ethanol leaf extract	100µl of crude ethanol extract resulted in 19.62% clot lysis.	Antiatherothrombosis activity (*Tania et al.* 2013)
Ethanolic leaf extract	At 500 µg/disc, the extract inhibited the growth of *Sa. Paratyphi* and *Pi. ovale* significantly more than ciprofloxacin (30µg/disc).	Anti-microbial activity (Tania *et al.* 2013)

The analysis of the methanol extract and its ethyl acetate fraction of *S. villosa* was performed using the DPPH free radical scavenging method, and the scavenging activity was compared with that of the standard antioxidant ascorbic acid (Vitamin C). Activity was found to be dosage dependent not only for ascorbic acid but also for *S. villosa* extracts (Uddin *et al.* 2015). The research found that the concentration of 800 µg/ml resulted in the highest percentage of scavenging activity out of the eight different concentrations that were utilised in the experiment (20, 40, 60, 80, 100, 200, 400, and 800 µg/ml) (Uddin *et al.* 2015). At this concentration, the scavenging activity of the methanol extract was found to be 72.56 %, the scavenging activity of the ethyl acetate fraction was found to be 91.34 %, and the scavenging activity of the ascorbic acid was found to be 95.95 %. It was determined that the IC_{50} values for methanol extract, ethyl acetate fraction, and ascorbic acid were respectively 23.99, 60.25, and 16.1 micrograms per millilitre (Uddin *et al.* 2015).

Anti-inflammatory activity

The ethanolic extract of *S. villosa* bark administered in a dose-dependent (100, 200 and 400 mg/kg) way in albino wistar rats compared to control group was found to be significantly effective in reducing both acute and chronic inflammatory reactions evaluated by two models carrageenan induced paw edema and cotton pellet granuloma (Hossain *et al.* 2012). In an in-vitro anti-inflammatory test, the crude ethanol extracts at the dose of 500 µg/ml showed a 48 percent inhibition of protein denaturation, whereas the standard acetyl salicylic acid (ASA) exhibited a 52.35 percent inhibition of protein denaturation. It was discovered that the efficacy of ethanol extract to suppress heat-induced protein denaturation was significant (Tania *et al.* 2013).

The carrageenan-induced inflammation in rat paws served as a model for examining the efficacy of the crude methanolic extract as an anti-inflammatory agent. Carrageenan injected subcutaneously into the plantar region of the animals led to the development of localised edema. Before the administration of carrageenan, there was no discernible difference in the paw volume among the groups (0.73±0.038 ml, 0.69±0.035 ml, 0.68±0.036 ml, and 0.75±0.047 ml for the control, diclofenac, 250 mg/kg, and 500 mg/kg crude methanolic extracts group, respectively). In contrast, the volume of paw edema was found to be considerably reduced at each of the time periods assessed in the animals that were pretreated with crude methanolic extract and diclofenac, in comparison to the volume found in the control group. The most significant inhibition (p<0.001) was seen at 9 hours in the 250 mg/kg methanolic extract and 500 mg/kg methanolic extract groups, respectively (Ullah *et al.* 2015). This inhibition was 52.7 percent in the 250 mg/kg methanolic extract group and 48.7 percent in the 500 mg/kg methanolic extract group. In the current investigation, methanolic extracts were effective across all three phases in preventing the edema that was brought on by the injection of carrageenan. At both study's doses of methanolic extracts, the proportion of edema that was inhibited was shown to be at its maximum at 9 hours (Ullah *et al.* 2015).

Analgesic activity

The methanolic extract of *S. villosa* bark, as well as its petroleum ether fraction, at a dosage of 400 mg/kg demonstrated significant analgesic effect in animals. The crude methanolic extract and petroleum ether fraction showed promising peripheral anti-nociceptive behaviour in acetic acid induced writhing as well as in central anti-nociception by radiant heat tail flick method in Swiss-albino mice (Hossain *et al.* 2013).

In the hot-plate test, the basal reaction latencies of the groups treated with distilled water (10 ml/kg body weight), diclofenac (10 mg/kg body weight), seed methanolic extract (250 mg/kg body weight), and seed methanolic extract (500 mg/kg body weight) were 8.30±0.63 s, 7.42±0.29 s, 7.68±0.21 s, and 7.40±0.38 s, respectively. Comparing the animals treated with methanolic extract (250 mg/kg and 500 mg/kg) and diclofenac to the control group, the animals treated with methanolic extract and diclofenac had significant inhibitory effects on heat stimuli as early as 1 hr. At 3 hours, the 250 mg/kg (14.64±0.214) and 500 mg/kg (14.64±0.294) methanolic extract-treated groups had the greatest effects. In the hot-plate test, the methanolic extract-treated group had a longer latency period than the control group. This shows that the methanolic extract has intriguing analgesic qualities, which are likely mediated by a central inhibitory mechanism and may have potential benefits for the management of pain (Ullah *et al.* 2015).

Analgesic activity test by acetic acid-induced abdominal writhing test were done at doses of 250 mg/kg and 500 mg/kg of methanolic seed extracts, the percentage inhibition values were 40.2% and 59.8%, respectively ($p<0.01$ and $p<0.001$ compared to the control group, respectively), with the percentage of inhibition increasing with the dose. Inhibition of acetic acid-induced writhing was seen in the presence of methanolic extracts. Diclofenac (10 mg/kg) had a percentage inhibition value of 67.8% ($p<0.001$ when compared to the control group). There was a decrease in the number of writhings, which suggests that at dosages of 250 and 500 mg/kg, the crude methanolic seed extracts might show analgesic efficacy by decreasing the synthesis or action of prostaglandins (Ullah *et al.* 2015).

In the early phase (0-5 minutes) of the formalin test for analgesic effectiveness, the methanolic extract considerably suppressed the pain response: 62.1% at 250 mg/kg ($p<0.001$) and 66.7% at 500 mg/kg ($p<0.001$). During the late phase (15-30 minutes), the inhibition responses were 64.4% ($p<0.01$) and 70.3% ($p<0.01$) at 250 mg/kg and 500 mg/kg, respectively. Also, diclofenac, at a dose of 10 mg/kg, was found to considerably shorten the duration of the reaction in both the early and the late phase. Pain was reduced in both phases (early and late) as a result of the methanolic extracts, but the benefits of the extracts were more noticeable in the second phase (Ullah *et al.* 2015).

Antidiabetic activity

Hossain *et al.* (2012) used alloxan-induced diabetic albino rats and anti-diabetic drug glibenclamide (5 mg/kg) as a positive control to measure the anti-diabetic efficacy of *S. villosa* barks methanolic extract at doses of 250 mg/kg, 500 mg/kg, and 1000 mg/kg. The methanolic bark extracts doses and anti-diabetic drug glibenclamide significantly lowered blood glucose level at hourly intervals when compared with alloxan-induced diabetic control rats. Most probably bark extracts enhanced insulin secretion from existing β-cells of islets of Langerhans and/or boosting glucose consumption in peripheral tissues, furthermore, author suggested detailed study is needed to explore the exact molecular mechanism responsible for anti-diabetic activity of *S. villosa* barks extracts (Hossain *et al.* 2012).

Anti-atherothrombosis activity

Streptokinase (a positive control) revealed a clot lysis of 81.53 %. Clots treated with 100 µl ethanol (negative control), on the other hand, showed barely minor lysis (2.49 percent). Clots were also treated with 100 µl of crude ethanol extract of *S. villosa* leaves resulted in 19.62 % clot lysis (Tania *et al.* 2013). In another experiment, 100 µl Streptokinase (30,000 I.U.) was administered to the clots and incubated for 90 minutes at 37 °C, resulting in 65.56 % clot lysis. Clot lysis was only 11.75 percent when clots were treated with 100 µl sterile distilled water (negative control). Between the positive and negative control groups, the mean difference in clot lysis percentage was extremely significant. When 100 µl ethyl acetate fraction of *S. villosa* bark was applied to 20 distinct clots, 47.88 percent clot lysis was obtained, and the mean clot lysis percentage differences were significant ($p < 0.05$) when compared to the negative control (water). Methanolic extract of bark had a fibrinolytic activity of 32.34 percent, which was not statistically significant ($p =1.339$) (Uddin *et al.* 2015).

Diuretic activity
Ethanolic bark extract of *S. villosa* was administered in healthy Wistar rats and rabbits doses at the rate of 100, 200, and 400 mg/kg, showed significant potent diuretic efficacy in a dose-dependent manner, with results equivalent to those of the reference drug furosemide (20 mg/kg) (Alam *et al.* 2012). The diuretic effect is caused by increased urine production combined with an increase in sodium and potassium salt excretion, which may help lower pulmonary congestion, cardiac overload, and blood pressure (Alam *et al.* 2012).

Sedative activity
The methanolic leaves extract of *S. villosa* generated a significant decrease in the number of holes crossed in the hole cross test. This inhibitory effect began at 30 minutes (11.33 ± 2.51) and lasted for a total of 120 minutes (8.67 ± 1.53). In the same manner, the plant also provides a sedative effect (decrease spontaneous locomotion) when tested in open field test. The sedative effect started to take effect around 30 minutes (69.33 ± 16.92), and it lasted for 120 minutes (34.66 ± 5.13). The findings of both tests revealed that the extract from the leaves had an effect on the mice's locomotor activity, which is indicative of the sedative property (Hossain *et al.* 2016).

In the Elevated plus-maze (EPM) test, diazepam was found to have a considerable percentage of open arm entry at a very low dose (1 mg/kg of body weight), with a value of 29.40 ± 3.286 %. At a dose of 400 mg/kg, the methanol leaves extract likewise showed a significant increase in the percentage of open arm entry with a value of 42 ± 9.970 %. The findings of the EPM test make it abundantly evident that the methanolic extract of *S. villosa* has anxiolytic potential (Hossain *et al.* 2016).
The sedative effect of the *S. villosa* leaves extract was confirmed in a Thiopental sodium induced sleeping time test by showing that pretreatment of Swiss albino mice with the plant extract increased the amount of time spent sleeping and decreased the amount of time it took for the mice to fall asleep. The effect of *S. villosa* methanol leaves extract on sleep latency and sleeping time is more intense when administered at a dose of 400 mg/kg compared to the effect of the conventional sedative drug diazepam when administered at a dosage of 1 mg/kg. When combined with thiopental sodium, the extract has an enhanced sedative and hypnotic effect (Hossain *et al.* 2016).

Anti-microbial activity
The antimicrobial activity of *S. villosa* bark and leaf extracts was determined by measuring the diameter of the inhibition zone in the presence of Gram-positive and Gram-negative bacteria and fungi. Using the disc-diffusion process, the ethanolic leaf extract demonstrated mild to moderate antimicrobial activity, with inhibition zones varying from 7 to 13 mm and 11 to 14 mm for the fungi and bacteria examined, respectively. *Bacillus subtilis* Cohn, *Bacillus cereus* Frankland & Frankland, *Bacillus megaterium* de Bary, and *Staphylococcus aureus* Rosenbach were used as Gram-positive bacteria, while *Escherichia coli* Castellani & Chalmers, *Shigella dysenteriae* Castellani & Chalmers, *Pseudomonas aeruginosa* Migula, *Salmonella typhi*, *Salmonella paratyphi*, Shigella sonnei Weldin, and *Vibrio cholerae* Pacini were used as Gram-negative bacteria. *Aspergillus niger* van Tieghem, *Blastomyces dermatitidis* Gilchrist & W.R. Stokes, *Candida albicans* Berkhout, *Candida neoformans*, *Microsporum sp.*, *Pityrosporum ovale*, and *Trichophyton sp.* were among the fungi examined. At 500 µg/disc, the extract inhibited the growth of *Salmonella paratyphi* and *Pityrosporum ovale* significantly more than ciprofloxacin (30 µg/disc) (Tania *et al.* 2013). It was found that the bark crude methanolic extract (400 µg /disc) was equally effective against a variety of bacteria, including Gram-positive and Gram-negative strains, but the authors used a different set of fungi, including *C. albicans*, *A. niger*, and *Saccharomyces cerevisiae* Meyen ex E.C. Hansen. All of the microorganisms examined showed sensitivity against the bark crude methanolic extract (Haque *et al.* 2014).

Anthelmintic activity
The ethanolic extract of *S. villosa* barks was put through an anthelmintic test, and the results showed that it both paralysed and killed the worms (*Pheretima posthuma*). The ethanolic extract displayed anthelmintic activity in a dose-dependent manner, yielding the shortest period of paralysis and death with a concentration of 200 mg/ml. A higher quantity of bark extract generated a paralytic effect much earlier, and the length of time it took for all worms to die was significantly less. The Albendazole (10 mg/ml) reference standard drug was used for the evaluation of anthelmintic activity. When compared to the conventional medicine albendazole, the ethanolic extract of *S. villosa* bark was discovered to be superior in its ability to cause earthworms to become paralysed and eventually die. It is possible to draw the conclusion that the bark extracts include the active elements that are responsible for the anthelmintic activity (Alam *et al.* 2012).

Antileishmanial activity
S. villosa bark extracts exhibited significant anti-leishmanial activity against *Leishmania donovani* Ross, a protozoan that causes visceral leishmaniasis (kala-azar), a serious disease with a high mortality rate. The extract's IC_{50} value was 17.5 µg/ml,

which was equivalent to amphotericin B. Antileishmanial activity is mainly due to increase in reactive oxygen species (ROS) production and an increase in superoxide levels, causing oxidative stress and DNA damage in protozoans (Das *et al.* 2017).

Cytotoxic activity

The brine shrimp lethality bioassay was performed on the methanolic crude extract as well as the various fractions of the bark of *S. villosa*, including the ethyl acetate fraction, crude methanolic extract, petroleum ether extract, carbon tetrachloride extract, and dichloromethane extract. The maximum value of LC_{50} was seen in Ethyl acetate fraction (LC_{50} 55.98 µg/ml), Dichloromethane extract crude (35.33 µg/ml), Carbon tetrachloride extract (3.76 µg/ml), Petroleum ether extract (2.95 µg/ml), Crude Methanolic extract (0.3 µg/ml) in comparison with Vincristine Sulfate (0.544 µg/ml) (Haque *et al.* 2014).

Fibrinolytic activity

Streptokinase, a positive control (30,000 I.U.), was added to the clots and incubated for 90 minutes at 37 °C, which resulted in 65.56 percent clot lysis. In contrast, only 11.75 percent of clot lysis was seen when clots were treated with 100 µl of sterile distilled water (the negative control). The difference in the mean percentage of clot lysis between the positive control and the negative control was highly significant. On the other hand, when 100 µl of the ethyl acetate fraction of *S. villosa* was applied to 20 distinct clots, 47.88 percent of the clots were lysed, and when compared with the negative control (water), the mean clot lysis percentage differences were significant ($P < 0.05$). Again, methanol extract demonstrated 32.34 percent fibrinolytic activity, which was not statistically significant ($P = 1.339$) (Uddin *et al.* 2015).

Conclusions and future prospects

Socio-culturally, *S. villosa* is utilized by local people across its geographically growing regions and ethnicity for its ethno-medicinal uses, fibre, fodder, food, firewood, gums, traditional musical instruments and handicrafts items etc. Especially natural fibre can be utilized to make diversified eco-friendly handicrafts and bags. The tree species mainly found in wild and up to some extent being integrated in traditional agro-forestry systems (shifting cultivation) in the Meghalaya, NE region of the India and largely remains commercially an underutilized species. The species is a valuable component of natural forest ecosystems that supports ecological services such as carbon sequestration, biodiversity conservation and ecosystem restoration.

S. villosa has huge ethnomedicinal uses across ethnicities. Many of its uses are similar across the cross cultures in the South Asian regions, reflecting its high medicinal value. Scientifically, highly diversified biological and pharmacologically activities have been reported from the extracts of different parts. But compared its biological activities only few active principles such as flavonoids (Diosmetin, Chrysoeriol and its derivative) and triterpenoid (Lupeol) were chemically analyzed from the tree species. Only in few cases molecular mechanisms of action was studied, henceforth the medicinal tree species warrants detailed phytochemical investigations for their biological activities with exact molecular mechanism (s) for its further medical applications for human welfare, especially search for new safer green compounds for antimicrobial resistance and emerging diseases management.

There is a crucial need to develop commercial silvicultural and plantation techniques for *S. villosa* in order to integrate the species in the prevailing shifting cultivation fields to enhance its potential for local livelihood support and degraded forest area for ecosystem restoration and moreover, achieving sustainable development goals. There is no work reported in respect of plant-soil-microbial interaction for the species especially, rhizospheric microbial associations and their role in water and nutrient acquisitions, seedling and sapling establishments, plant and soil health, and its dynamics. Detailed agro-forestry studies such as tree-crop-soil interactions such as allelopathy, productivity, soil fertility and quality need to be assessed before integration and scale-up in a farmer's fields.

The tree species reproductive biology studies such as phenology, floral biology, pollen production, pollen/ovule ratio, mating systems and incompatibility and plant-pollinator interactions are lacking which could be valuable for devising conservation and utilization strategies with respect to climatic conditions. Since the tree species distributed across the varied agro-climatic zones in the regions, there is a need to study its geographical variations (seed source and provenance), genetic variation and its population differentiation for its genetic conservation and appropriate seed and germplasm (genetic) source utilization for better adaptability, commercial growth and performance.

Declarations

List of abbreviations: NE- North-east; NaOH- Sodium hydroxide; M- Molarity; EDTA- Ethylene-diamine-tetraacetic acid; IC_{50}- Half maximal inhibitory concentration; I.U.- International Unit; L- Litre; µl- Microlitre; kg- Kilogram; mg- Milligram; µg- Microgram; DPPH- 2,2-diphenyl-1-picryl-hydrazyl-hydrate; HBr- Hydrogen bromide; g- Gram; ml- Millilitre; %- Percent; hrs- Hours; min- Minute; s- Second; ph- Potential of hydrogen; °C- Degree celsius; mm- Millimetre; cm- Centimetre; masl- Mean average sea level; m- Metre; mEq- Milliequivalents; CNS- Central nervous system; BHT- Tert-butyl-1-hydroxytoluene; PE- Petroleum ether; CT- Carbon tetrachloride; DCM- Dichloromethane; EA- Ethyl acetate; MIC- Minimum inhibitory concentration; MTT- 3-(4,5dimethylthiazol-2-yl)- 2,5-diphenyltetrazolium bromide; ASA- Acetyl salicylic acid.

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