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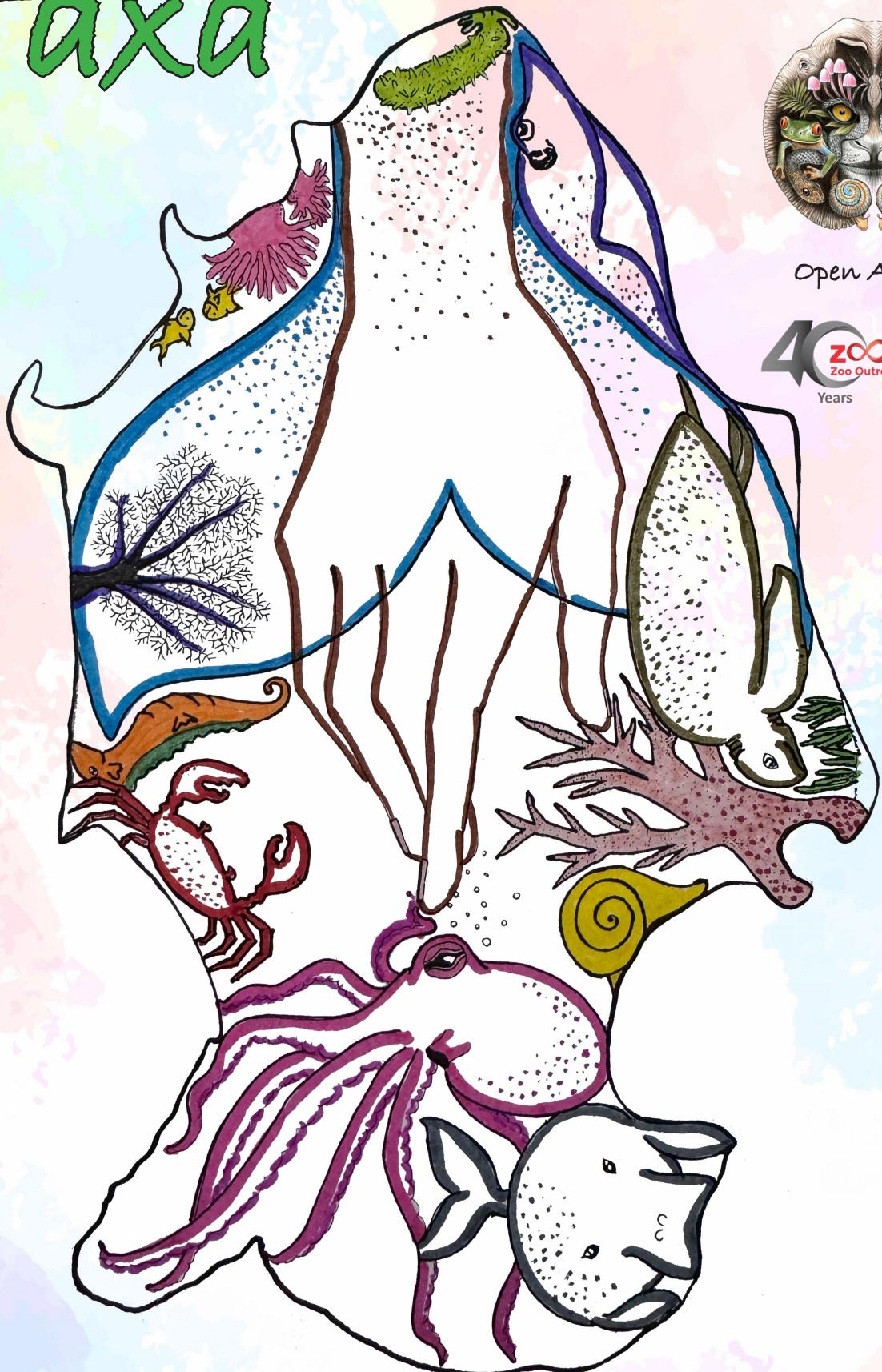
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continued on the back inside cover

Cover: Little Andaman is part of the island chain with incredible biodiversity, but these amazing species are threatened by development projects, and need our support.
Pen and ink artwork by Priyanka Iyer.



Taxonomic studies and breaking seed dormancy of *Hibiscus lobatus* (Murray) Kuntze, 1898 (Magnoliopsida: Malvales: Malvaceae) — a native plant of the central Western Ghats

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Abstract: *Hibiscus lobatus* (Murray) Kuntze is a medicinal plant of the Malvaceae family, very sparsely and seasonally distributed, particularly in the Western Ghats of Karnataka. This species, known for its ethnopharmacological uses, especially in wound healing, faces a declining population due to habitat loss, overexploitation, and poor seed germination. Seed dormancy has been identified as a major factor limiting its natural regeneration. In this study, the distribution, habitat, and taxonomic diagnostic features of *Hibiscus lobatus* were investigated across different floristic regions of the central Western Ghats. Seed viability and dormancy-breaking treatments were assessed both in the field and in vitro. Tetrazolium testing confirmed seed viability, but field germination rates were low (4–6%), indicating strong dormancy. Among the treatments tested, sulfuric acid scarification combined with GA₃ application proved most effective, substantially enhancing germination and reducing germination time. These findings establish an optimised protocol for overcoming seed dormancy in *Hibiscus lobatus*, which can be applied to conserve and propagate this important medicinal species, addressing its declining population.

Keywords Annual herb, ethnobotanical survey, Gibberellic acid (GA₃), native flora conservation, propagation techniques, scarification, seasonal germination, seed viability, tetrazolium test, Western Ghats biodiversity.

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Author contributions: KTD—conducted plant taxonomical study in the Central Western Ghats of Karnataka and studied the morphometric feature of *Hibiscus lobatus*, designed and performed seed dormancy-breaking experiments. KV—mentor, corresponding author, overseeing the study's conceptualization and coordination. SGBU—Conducted ethnobotanical survey and explored traditional medicine uses of *Hibiscus lobatus*. RK—assisted in evaluating the in vivo seed dormancy-breaking experiments of *Hibiscus lobatus*. SAS—Assisted in evaluating the in vitro seed dormancy-breaking experiments of *Hibiscus lobatus*.

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INTRODUCTION

Global ecological changes driven by human activity and climate shifts have significantly impacted plant biodiversity. Ecological degradation and its consequent biodiversity loss, pose a serious threat to the natural distribution of plant species. Intensive plant exploration studies conducted across various floristic regions have helped taxonomists recognise the vulnerable status of many native species, often impacted by habitat disturbance, and the spread of exotic species. In recent years, habitat loss, overexploitation, pollution, and illegal trade of plant resources have further contributed to biodiversity decline, pushing several species toward threatened status (Tali et al. 2015). These growing stresses are also linked to climate change (Urban 2015; Bachman et al. 2018; Hamid et al. 2020). Therefore, extensive plant surveys and identification of threat status are crucial for assessing extinction risks, formulating conservation strategies, and raising awareness to protect declining habitats. Continuous plant exploration and conservation assessments are essential for understanding species vulnerability, formulating protective strategies, and promoting sustainable use. This is particularly important for lesser-studied native species like *Hibiscus lobatus* (Murray) Kuntze, which faces seasonal growth constraints and germination barriers, making it a valuable candidate for conservation and regenerative studies.

Hibiscus lobatus (Murray) Kuntze (Synonyms: *Hibiscus solandra* L'Hér, *Solandra lobata* Murray, *Hibiscus torulosus* Salisb., *Hibiscus pumilus* Roxb., and *Laguna lobata* Willd.) (WFO 2025) is an annual herb of Malvaceae, primarily growing in the seasonally dry tropical biome of the world. This species was recorded in several monumental taxonomic publications, including flora of the Presidency of Madras (Gamble 1915), flora of Tamil Nadu Carnatic (Matthew 1983), flora of Karnataka (Saldahna 1984), flora of South Kanara (Bhat 2014), flora of Sri Venkateswara National Park and Andhra Pradesh (Benjamin & Murthy 2013). In addition to climatic changes, anthropogenic pressures such as road construction, resort development, mega power projects, deforestation, and agricultural activities in the core forest regions of the Central Western Ghats have severely disturbed natural habitats, pushing the native herbaceous species *Hibiscus lobatus* to the threshold of extinction (Noori et al. 2025). Intensive plant exploration studies in various floristic provinces of the central Western Ghats of Karnataka, such as, flora of Shimoga District (Ramaswamy et al. 2001), flora of

Davanagere District (Manjunatha et al. 2004), flora of British India (Hooker 1875), have not listed *Hibiscus lobatus*. Furthermore, detailed morphometric studies, and diagnostic characteristics of this species have not been thoroughly investigated. Hence, the present work is undertaken.

Seed dormancy is an adaptation that helps plants to survive unfavourable environmental conditions by coordinating germination and establishment with the surrounding environment (Donohue et al. 2010). Environmental factors such as soil temperature and humidity play a crucial role in controlling dormancy in mature seeds, serving as key determinants for dormancy cycling (Leubner 2006). Previous studies have investigated the seed viability of various *Hibiscus* species, including *Hibiscus acetosella* Welw. ex Fic., *H. calyphyllus* Cav., *H. surattensis* L., *H. lobatus* Kuntze, *H. radiatus* Cav., *H. vitifolius* L., and *H. panduriformis* Burm. F (Kak et al. 2015); as well as *Hibiscus waimeae* ssp. *hannae*, and *Hibiscus waimeae* ssp. *waimeae* (Wolkis et al. 2018).

In the present study, field surveys, and ethnobotanical investigations were conducted to explore the distribution, and traditional uses of *Hibiscus lobatus* (Murray) Kuntze in the central Western Ghats, particularly in the forest regions of Tirthahalli (Shivamogga District) and Narasimharajapura Taluk (Chikkamagaluru District). These surveys revealed valuable traditional knowledge, with local practitioners using whole-plant extracts for various skin-related treatments. Notably, these traditional uses have not been recorded in official pharmacopeia or documented in previous scientific literature. Although anti-aging properties have been reported in related species such as *Hibiscus syriacus* (Di Martino et al. 2017; Yang et al. 2019), *H. manihot* L., and *H. abelmoschus* L. (Luan et al. 2020), such properties in *H. lobatus* remain unexplored, and neglected in terms of scientific investigation. This study aims to document the morphological characteristics and distribution of *Hibiscus lobatus* in the central Western Ghats, assess its seed viability, and dormancy status, and develop effective *in vivo*, and *in vitro* dormancy-breaking protocols. These efforts are intended to overcome regeneration barriers and support the conservation of this native, and underutilised species.

MATERIALS AND METHODS

Study area

Western Ghats in Karnataka State, India, is a global biodiversity hotspot covering an area of approximately 20,668 km², popularly known as the Sahyadri Hills. This region encompasses the largest portion of the Western Ghats, accounting for about 37% of its total area, and is located between 13.769°–15.732° N and 74.124°–75.169° E. The mountain range runs parallel to the western coast of India. The climate is semi-arid and cooler, the mountain range runs parallel to the western coast of India. The climate is semi-arid to temperate, with higher elevations averaging around 15°C (60°F) annually, while lower elevations record mean annual temperatures varying from 20°C (68°F) in the south to 24°C (75°F) in the north (Ramachandra et al. 2019). The geographical habitat of *Hibiscus lobatus* in different study locations within the Sahyadri Hills includes both moist and dry forests.

Taxonomy

The standard herbarium method (Bridson & Forman 1992) was followed during the collection, processing, and preparation of the herbarium specimens. Voucher specimens have been deposited at Kuvempu University, DBT-BUILDER Herbarium (KUDBH- Mal 21-Hb). An ethnobotanical survey was conducted in the study area to document the traditional use of this plant species. The survey typically began with the interview of authorised traditional medicine practitioners residing in and around Sahyadri Hills.

Evaluation of seed viability

a) Tetrazolium Method: Tetrazolium method (Patil & Dadlani 2009) was followed to test the viability of seeds of *Hibiscus lobatus*. Three groups of seeds, aged 10 months, five months, and one month old, were prepared with 100 seeds per group, and were divided into four replicates of 25 seeds each. For hydration, seeds were placed on the moist paper towels, and were soaked directly in distilled water for 12 hours. Following pre-soaking, seed coats were removed, and a small puncture was made near the embryonic axis to facilitate better staining. The seeds were then treated in 1% tetrazolium chloride solution for 4 hours at diurnal room temperature, allowing the solution to react with viable seeds, which stained red or pink. After staining, seeds were rinsed with distilled water, and viability was assessed based on colour intensity in the embryo, with red or pink indicating viable cells. The viability of each

seed group was recorded by counting stained (viable) versus unstained (non-viable) seeds in each replicate. Viability percentage for each group was calculated using:

$$\text{Viability Percentage} = (\text{Number of Viable Seeds} / \text{Total Number of Seeds Tested}) * 100$$

b) Seed germination test: Seed germination test under field condition (Pace et al. 2016) was conducted to assess germination rates of 12 hr hydrated seeds of 10 months, 5 months, and 1 month old. Seeds were sown in manually prepared plots using humus-rich topsoil corresponding to the O horizon, and regular watering was provided to create conditions favourable for seed germination. In each plot, 25 seeds from each age group were sown, with four replicates per group, totalling 100 seeds per age group. Germination percentages were recorded based on seedling emergence over time under natural environmental conditions in the experimental garden.

Breaking of seed dormancy

To break the dormancy of *Hibiscus lobatus* seeds, experiments were conducted using two pretreatment methods: hot water stratification (Benedito et al. 2019) and acid stratification (Dilaver et al. 2017) were employed. Seeds were divided into triplicates of 30 seeds for each treatment group. For hot water stratification, seeds were immersed in hot water (60–70°C) for 10 min. Acid scarification involves treating the seeds with sulphuric acid (H₂SO₄) at concentrations ranging from 5% to 20% for 5 min. Following these treatments, seeds were sown *in vivo* in the field condition and cultured *in vitro* on Murashige and Skoog (MS) medium supplemented with gibberellic acid (GA₃) at concentrations of 0.75–1.5 mg/L (Zhang et al. 2020).

RESULTS AND DISCUSSION

Morphometric studies

Annual, erect, herbaceous plant attaining 50–70 cm in height. Stems fibrous, branched; branchlets hairy; scabrid or stellate trichomes; glabrescent on maturity. Leaves dimorphic, alternate, membranous; lower leaves ovate-cordate, 1.5–3 cm long; middle leaves trifoliolate, up to 9 cm; upper leaves either deeply lobed or trifoliolate, with roundly dentate margins. Lamina lanceolate, villous, up to 8 cm long; petiole equal to or slightly longer than the lamina. Flowers axillary, solitary or in sparse racemes, 1–1.5 cm across; pedicel 0.7–0.9 cm long; flower diameter 2.2–2.5

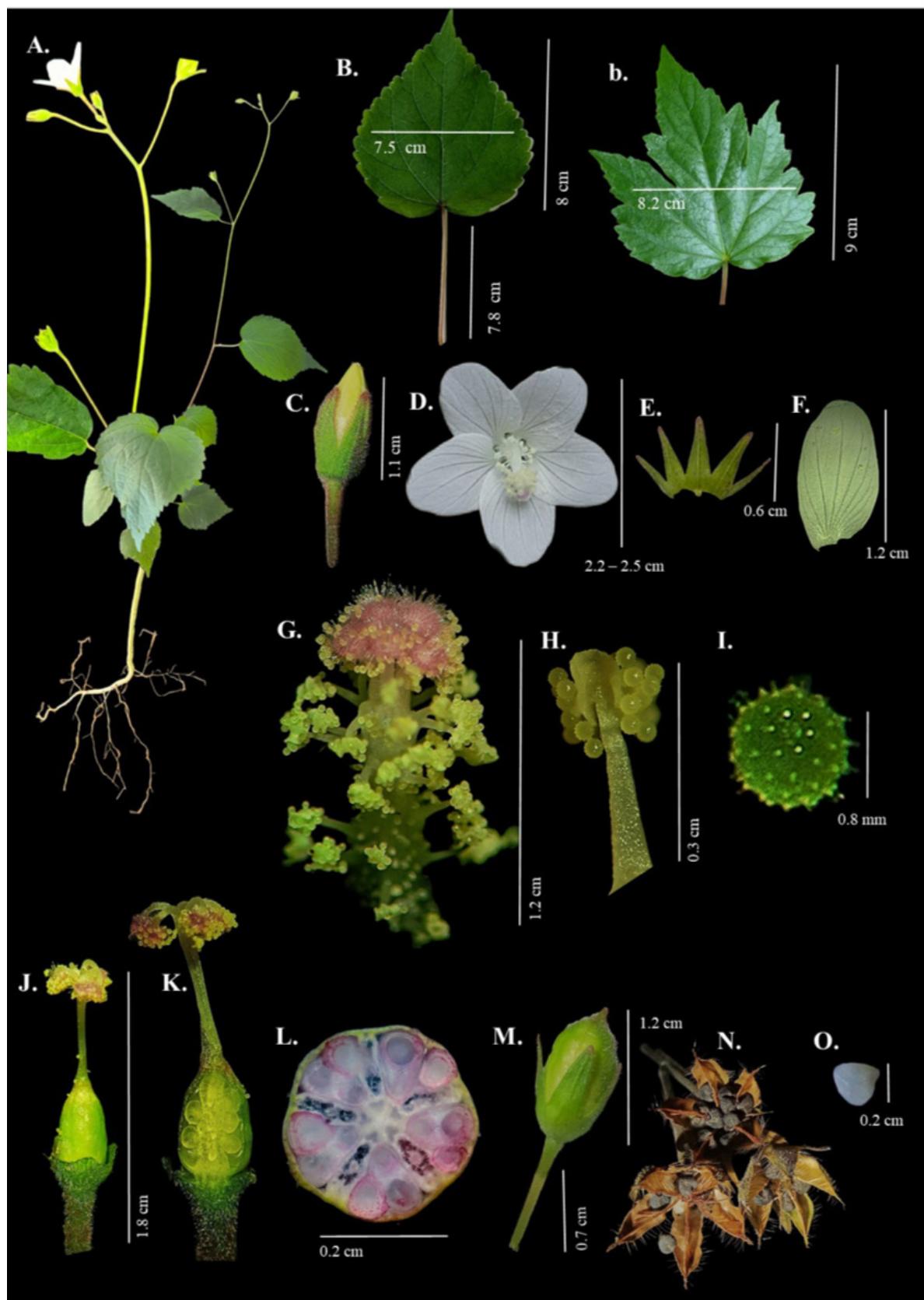


Image 1. Morphometric analysis and diagnostic feature of *Hibiscus lobatus*: A—*Hibiscus lobatus* habitat | B—Leaf | C—Flower bud | D—Blossomed flower | E—Sepals | F—Insect wing like petal | G—Staminal tube | H—Staminal branchlet | I—Pollen grain | J—Pistil | K—LS of ovary | L—TS of ovary | M—Capsule | N—Opened capsule | O—Seeds with hairs. © Karthik T.D.

cm. Calyx cup-shaped, 0.6 mm long, membranous, 5-lobed; lobes lanceolate, pilose, and strigose abaxially, persistent. Petals 5, white, 1.2–1.4 cm long, insect wing-like in appearance. Staminal tube 1.2 cm long; staminal branches up to 0.3 cm, staminal column bearing numerous monadelphous stamens with apical hairs. Pollen grains spheroidal, polycorporate, echinate, approximately 0.8 mm in diameter. Gynoecium with a superior ovary, ellipsoid, 1.3–1.8 cm long and 0.1–0.3 cm wide, 5-locular (occasionally up to 10), with axile placentation and multiple ovules per locule. Stigma 5, free, pinkish, arising from a single style column. Capsule broadly ovoid to cylindrical, 0.8 cm long, beaked at apex; fruit composed of five mericarps; endocarp thin, villous along the ventral side. Seeds minute, 0.2 mm, with scale-like hairs (Image 1).

Distribution

Hibiscus lobatus is distributed in the dry deciduous forests of India, tropical Africa, Madagascar, tropical and southeastern Asia, Sri Lanka, and Malaysia (Rao et al. 2019).

Distribution in India

Hibiscus lobatus is distributed in the forests of Andhra Pradesh, Bihar, Delhi, Gujarat, Himachal Pradesh, Jammu & Kashmir, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Sikkim, Tamil Nadu, Uttar Pradesh, Uttarakhand, West Bengal, and Assam (India Biodiversity Portal 2025).

The ethnobotanical survey in the central Western Ghats of Karnataka, India, revealed that *Hibiscus lobatus* is very sparsely distributed in the moist deciduous forests of Belagavi, Uttara Kannada, Shivamogga, Chikkamagaluru, Hassan, Dakshina Kannada, Kodagu, and Mysuru districts. The sites of herbarium specimen collection, along with their latitude and longitude, are shown in Image 2, and Table 1. This species is found only in two sites in the Shivamogga region, namely Kuruvalli Village, of Tirthahalli Taluk, and Thammadihalli Village, of Bhadravathi Taluk, in the form of small pockets during the spring season. In other localities, a sparse distribution was observed due to the spread of invasive species such as *Eupatorium odoratum*, *Lantana camara*, *Parthenium hysterophorus*, *Hyptis suaveolens*, *Senna siamea*, *Borreria stricta*, and *Amaranthus spinosa*.

Traditional medicinal value

The traditional medicine practitioners residing in the Tirthahalli Taluk of Shivamogga District and Narasimharajapura Taluk of Chikkamagaluru grind the

leaves of *Hibiscus lobatus* and *Terminalia arjuna* in a 3:1 ratio. The fine paste is then boiled with coconut water for 10 to 15 minutes. The oil content is filtered and used as a cosmetic for glowing skin. It is also used for epithelization and the cosmetic treatment of burnt wounds. The anti-aging property of *Hibiscus sabdariffa* L. (Li et al. 2020) and *H. rosa-sinensis* L. (Dos et al. 2021) has been investigated. The extracts and compounds from many species of *Hibiscus* are used in the cosmetic industry to produce various skin-glowing creams and lotions, such as plant science Hibiscus night cream and Saint Jane hydrating petal cream.

Seed viability

Seed viability of *Hibiscus lobatus* was evaluated using the tetrazolium method across three age groups: 1 month old, 5 month old, and 10 month old seeds. A gradual decline in viability was observed with increasing seed age. The 1 month old seeds exhibited the highest viability at $72.6 \pm 2.2\%$, followed by the 5 month old seeds at $69.8 \pm 1.8\%$, and the 10 month old seeds at $65.2 \pm 2.3\%$. Staining patterns revealed that 1 month old and 5 month old seeds were uniformly stained and showed minimal necrosis, reflecting healthy, and active embryonic tissues. In contrast, the 10 month old seeds displayed superficial staining in some seeds, particularly at the distal tip of the radicle, along with slightly higher necrosis. Despite these differences, the variation among seed groups was minor, highlighting that seeds of *Hibiscus lobatus* retain viability, and physiological integrity effectively over the time. This resilience is consistent with the plant's annual growth cycle, ensuring the seeds remain robust, and capable of germination in subsequent growing seasons.

Seed germination test in the field

Viable seeds of *H. lobatus*, confirmed through the tetrazolium test, were sown in fertile soil under optimal environmental conditions during the post-fruiting months of October to December, which align closely with the plant's natural growth cycle. Germination was monitored over 45 days, and the results showed that 1 month old seeds had a germination percentage of $25.8 \pm 2.6\%$, 5 month old seeds $18.6 \pm 2.4\%$, and 10 month old seeds $17.2 \pm 2.2\%$ as shown in Figure 1. Although the seeds were viable and in healthy condition, their germination potential under field conditions was low, confirming the presence of dormancy. The minimal variation in germination percentages between seed age groups indicates that seed age is not a major influencing factor in this context. These results emphasize the

Table 1. Distribution sites and geographical locations of *Hibiscus lobatus* in the central Western Ghats, Karnataka.

Observation Sites (S)	Location	Forest type	Latitude (Decimal)	Longitude (Decimal)
S1	Alavalli Village, Siddapur Taluk, Uttara Kannada	Semi Evergreen	14.308°N	74.764°E
S2	Chamundi Hill, Mysore	Deciduous	12.288°N	76.688°E
S3	Bhutaramahatti Village, Belgaum Taluka, Belgaum.	Deciduous	15.993°N	74.517°E
S4	Kuruvali Village, Tirthahalli Taluk, Shivamogga	Evergreen	13.684°N	75.249°E
S5	Thammadihalli Village, Bhadravathi Taluk, Shivamogga	Moist deciduous	13.741°N	75.624°E
S6	Monnageri Village, Madikeri Taluk, Kodagu	Evergreen	12.426°N	75.716°E
S7	Kodekkal, Beltangadi Taluk, Dakshina Kannada	Evergreen	13.013°N	75.323°E
S8	Thendihalli, Hassan Taluk, Hassan	Deciduous	12.999°N	76.173°E
S9	Balekoppa, Narasimharajapura Taluk, Chikkamagaluru	Moist deciduous	13.614°N	75.506°E

Table 2. Effect of seed pre-treatments on germination of *Hibiscus lobatus* under field conditions.

Treatments	Concentrations	Germination (%)			Number of days to germinate		
		1 month	5 months	10 months	1 month	5 months	10 months
Control (No pretreatment)		25.8±2.6	18.6±2.4	17.2±2.2	32–36	32–36	32–36
Hot water Treatment (°C)	20	26.5±1.4	18.8±1.2	18.6±1.4	28–31	28–31	28–31
	40	27.4±2.4	21.8±2.4	20.5±1.2	28–31	28–31	28–31
	60	32.6±2.2	30.6±1.5	29.4±1.2	24–28	24–28	24–28
	80	18.6±1.2	17.8±1.2	17.4±1.2	32–36	32–36	32–36
Sulphuric acid concentration (%)	5	25.4±1.4	19.4±1.2	19.2±1.2	28–31	28–31	28–31
	10	30.8±1.6	29.2±2.1	26.5±1.4	29–32	29–32	29–32
	15	38.5±1.4	35.6±1.2	32.8±1.5	22–26	22–26	22–26
	20	21.8±1.6	19.5±1.4	19.2±1.2	28–31	28–31	28–31

The value: mean of \pm SE four replicates of 25 seeds of each group.

dormancy mechanism in *H. lobatus*, which ensures the seeds remain synchronized with favourable environmental conditions, a crucial adaptation in its annual life cycle (Harel et al. 2011).

Reliable method for assessing seed germination, dormancy, and mortality of seeds is under field conditions. The result indicated that highest percentage of seed germination was noticed between 30–45 days (Figure 1). In this period, the average germination percentage of 1 month old, 5 month old, and 10 month old seeds was 13.3 ± 0.83 , 10.8 ± 0.83 , and 10.7 ± 0.86 , respectively, which were higher than those recorded during the other observation phases (0–15, 15–30, and 45–60 days). Several environmental factors control seed germination success under field conditions. Pradhan et

al. (2011) also evaluated the effects of microhabitat, light, and temperature on seed germination of a critically endangered Himalayan medicinal herb, *Swertia chirayita* (Roxb.) H. Karst. for conservation implications.

BREAKING OF SEED DORMANCY

In vivo method of breaking of seed dormancy

Experiments to break dormancy of seeds conducted *in vivo* under field condition following the method of Tiwari et al. (2018). The results revealed significant differences in germination percentages among seeds treated with hot water and sulphuric acid (Table 2). A decline in germination percentage was observed with increasing seed age. The control group, without any pretreatment, exhibited germination percentages of

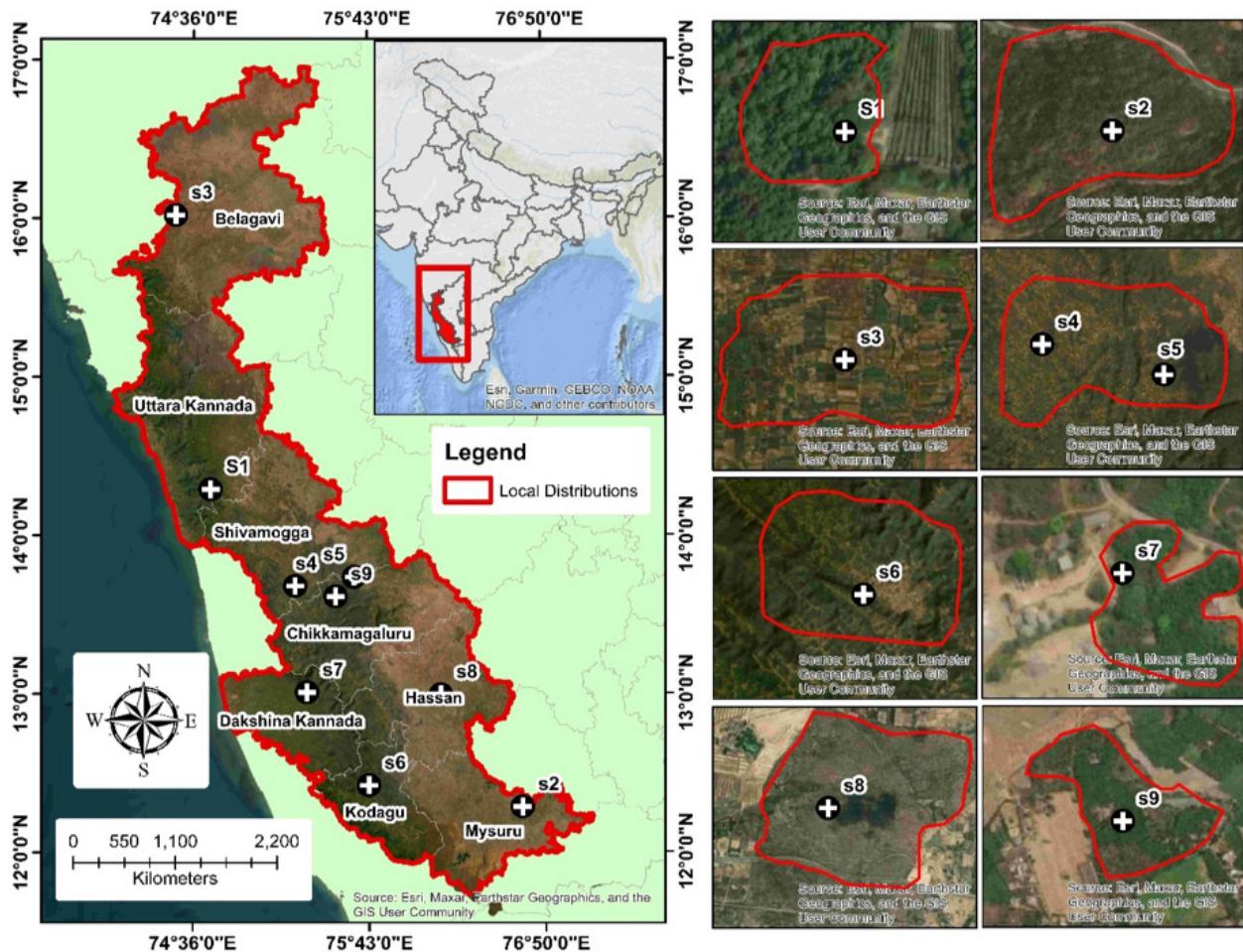
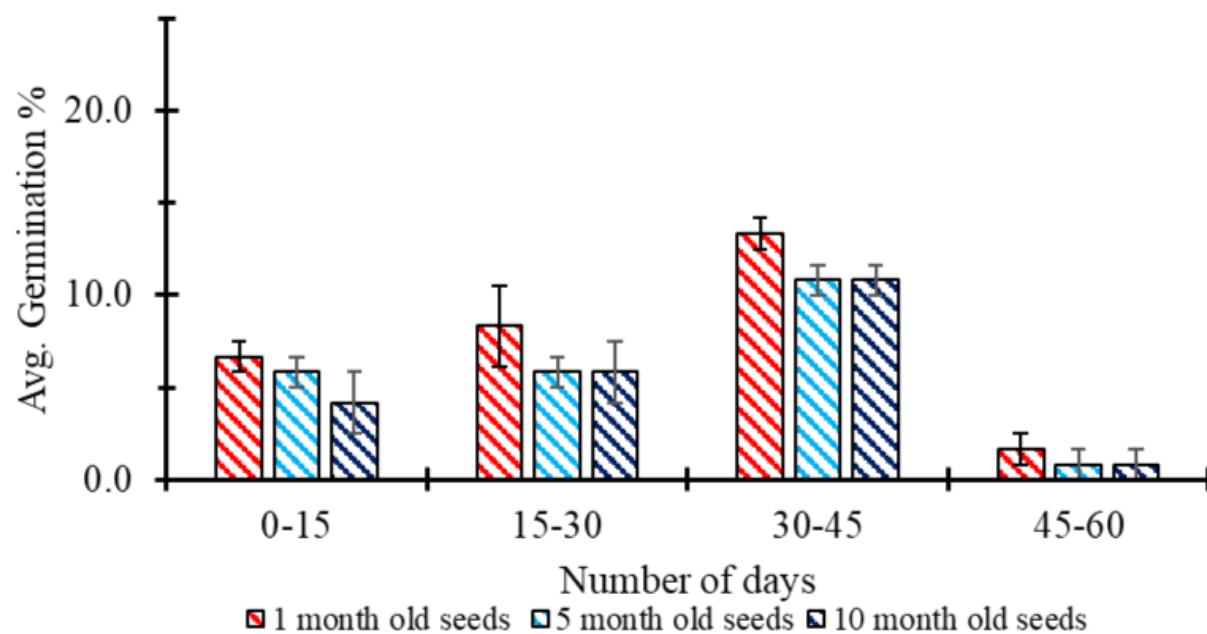
Image 2. Distribution of *Hibiscus lobatus* in the central Western Ghats of Karnataka.Figure 1. Percentage of *Hibiscus lobatus* seed germination under field condition.

Table 3. Effect of GA₃ treatment on breaking seed dormancy of *Hibiscus lobatus* under in vitro conditions.

	Concentrations	Germination (%)			Number of days to germinate		
		1 month	5 month	10 month	1 month	5 month	10 month
GA ₃ (mg/ml)	0.75	35.6±2.2	24.3±2.1	18.3±2.1	24–28	24–28	24–28
	1	58.8±3.6	56.6±3.2	55.5±3.2	16–20	16–20	16–20
	1.25	48.8±1.2	48.6±1.4	46.6±2.4	17–21	17–21	17–21
	1.5	40.6±2.4	38.6±2.2	36.8±2.2	28–31	29–32	29–32
Hot water Treatment (°C) + 1 mg/ml GA ₃	20	34.2±2.2	31.4±2.2	29.2±2.1	22–25	22–25	22–25
	40	68.8±4.6	65.8±3.6	59.8±3.4	15–18	15–18	15–18
	60	69.4±4.8	66.8±3.4	63.5±3.2	11–15	11–15	11–15
	80	28.6±2.2	23.8±1.8	16.4±1.2	18–21	19–21	19–21
Sulphuric acid (%) + 1 mg/ml GA ₃	5	38.8±2.4	34.8±1.2	34.6±1.3	21–25	21–25	21–25
	10	74.5±4.4	68.6±3.2	66.4±3.2	13–15	13–15	13–15
	15	76.3±4.2	72.5±5.3	71.5±5.3	10–13	10–13	10–13
	20	28.8±1.6	21.6±1.2	19.6±1.2	17–20	17–20	17–20

The value: mean of ± SE three replicates of 30 seeds of each group.

25.8±2.6% for 1 month old, 18.6±2.4% for 5 month old, and 17.2±2.2% for 10 month old seeds. Germination in the control group occurred between 32–36 days, reflecting the persistence of dormancy of seeds of *H. lobatus*.

Hot water scarification treatments of seeds moderately enhanced germination rates compared to the control group. The highest germination percentage of 32.6±2.2% was observed at 60°C, with germination times reduced to 24–36 days. Sulphuric acid scarification showed a more pronounced effect, particularly at a concentration of 15%, achieved percentages of germination of seeds was 38.5±1.4%, 35.6±1.2%, and 32.8±1.5% for 1 month old, 5 month old, and 10 month old seeds respectively. Germination of seeds was observed between 22–26 days, demonstrating its relative effectiveness in overcoming seed dormancy.

Despite these improvements, the overall germination rates remained low, indicating that these treatments partially alleviated seed dormancy, but they were insufficient to fully overcome it under field conditions. These results suggest that more targeted or refined dormancy-breaking methods may be necessary to achieve optimal germination. To address these limitations, in vitro approaches were undertaken. These methods aim to explore controlled environments and specific treatments to achieve higher germination success, and provide a more effective solution for

breaking dormancy in *Hibiscus lobatus* seeds.

In vitro method of breaking of seed dormancy

The in vitro methods of breaking of seed dormancy experiments were employed to know the conjugative effect of pretreated seeds cultured *in vitro* on MS medium (Murashige & Skoog 1962) supplemented with 0.75–1.25 mg/L of GA₃. The result of the experiment showed that pretreatment of seeds with either hot water or sulphuric acid and cultured on MS medium fortified with GA₃ showed improved seed germination in *Hibiscus lobatus* (Table 3).

In the culture of untreated seeds, GA₃ at the concentration of 1 mg/L was found to be effective to induce germination of 58.8±3.6% for 1 month old seeds, 56.6±3.2% for 5 month old seeds, and 55.5±3.2% for 10 month old seeds between 16–20 days of culture. Pretreatment of seeds with 15% sulphuric acid when cultured on 1 mg/L of GA₃ showed the highest germination percentages: 76.3±4.2% for 1 month old seeds, 72.5±5.3% for 5 month old seeds, and 71.5±5.3% for 10 month old seeds, respectively. These findings indicate the most effective in vitro approach, offering significantly higher percentage of germination, and shorter germination periods compared to other treatments. The combination of hot water treatment (60°C) and 1 mg/L of GA₃ also showed increased percentage of germination as compared to individual

treatments and the germination time was reduced to 11–15 days. Similar results were also observed in breaking of seed dormancy of *Hibiscus coddii* ssp. *barnardii* (du Plessis et al. 2019).

CONCLUSION

The present study highlights the taxonomic, ethnobotanical, and ecological significance of *Hibiscus lobatus* in the central Western Ghats. Traditional medicinal knowledge confirmed its therapeutic potential in skin healing and anti-aging applications, reinforcing its relevance in pharmaceutical, and cosmetic industries. Seed dormancy was identified as a critical factor limiting natural regeneration. Pretreatment with sulphuric acid followed by culture on MS medium fortified with GA₃ significantly improved seed germination, demonstrating an effective dormancy-breaking strategy. These findings provide a foundation for large-scale propagation.

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