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Seed morphology and germination dynamics of *Garcinia gummigutta* (L.) from western Ghats of Kerala: Implications for propagation and conservation

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Abstract
The present study explores the seed biology of *Garcinia gummigutta* (L.) N. Robson, an economically and ecologically important tree species of the Western Ghats, Kerala. The seeds are ovoid, non-endospermic and exhibit the characteristic "Garcinia-type" pattern of hypogeal germination. Morphological observations revealed distinct variation in seed size and weight across ecosites, while anatomical analysis showed a central hypocotyl core and parenchymatous storage tissue without cotyledons. Seed viability studies indicated a strong positive relationship between moisture content and germination success, as revealed by linear regression. Viability remained above 90% at 48% moisture content but declined drastically with desiccation below 25%, confirming the recalcitrant nature of the seeds. Germination experiments demonstrated that removal of the seed coat and chemical treatment with gibberellic acid and Dithane M-45 significantly accelerated germination and enhanced seedling vigor compared to untreated controls. These results highlight the moisture sensitivity and short-term storability of *G. gummigutta* seeds, emphasizing the importance of immediate propagation and moisture management for maintaining viability. The findings provide valuable insights for improving nursery practices, promoting large-scale propagation and ensuring effective conservation of this high-value species in the Western Ghats.

Keywords: *Garcinia gummigutta*, recalcitrant seeds, germination behaviour, seed viability, Western Ghats

1. Introduction

The berry-producing tree *Garcinia gummigutta* (L.) N. Robson under Clusiaceae family, is widely distributed in the Western Ghats and coastal regions of India particularly Kerala, and holds considerable socio-economic value for its fruit rind and seed derivatives used in food, medicine and agroforestry systems [10]. Despite its utility, cultivation and restoration programmes of *G. gummigutta* remain limited by insufficient understanding of its reproductive biology, particularly seed structure, dispersal dynamics and germination behaviour. In this context, elucidating these seed-related traits is crucial not only for nursery propagation and plantation establishment but also for in-situ conservation of wild populations.

A critical facet of *G. gummigutta* propagation is its seed physiology, like many tropical tree species, Garcinia seeds display recalcitrant storage behaviour, meaning they are shed with high moisture contents, are intolerant of desiccation and low-temperature storage and consequently cannot be stored long-term under conventional seed-bank conditions [16,1]. Such seeds typically lose viability rapidly when moisture falls below a threshold (often 20-40%) and are also vulnerable to chilling and fungal attack [12, 4]. For Garcinia spp., limited viability, rapid ageing and storage constraints present major hurdles for ex-situ conservation and large-scale propagation efforts.

In natural stands, seed fate of *G. gummigutta* is further shaped by dispersal ecology and microsite conditions: fleshy fruits attract frugivorous mammals and bats which facilitate endozoochorous dispersal, and subsequent hypogeal germination occurs under moist, shaded forest-floor conditions [8, 9]. Field and experimental work in Garcinia indicates that mechanical removal of aril or seed coat, hormonal priming (e.g., GA_3) and mitigation of pathogen load markedly enhance germination rates and reduce germination rate [7, 11]. Therefore, an integrated investigation of seed morphology, dispersal mechanism and germination behaviour is imperative to develop effective nursery and restoration protocols for *G. gummigutta*, especially under changing climatic conditions and fragmented habitats.

2. Methodology

Mature fruits of *Garcinia gummigutta* were collected during the fruiting season (June-July) from naturally occurring populations across three ecological zones of Kerala-coastal (Edathua-Mavelikara-Kayamkulam), midland (Pathanamthitta-Konni), and highland (Vithura-Kulathupuzha-Thenmala). Ripe fruits, golden yellow to brownish yellow in colour, were handpicked and transported to the laboratory for analysis. Seeds were separated from the fleshy rind, cleaned using muslin cloth, and air-dried at room temperature for 4-5 hours. Morphometric parameters such as seed length, breadth, and fresh and dry weights were recorded using a digital caliper and precision balance. Seed coat and internal structures were examined under a stereomicroscope, and thin longitudinal sections were prepared to observe tissue organization and embryonic development following the "Garcinia-type" germination pattern [15]. Field observations on fruit fall, dispersal, and natural germination were conducted in the Bonacaud and Kulathupuzha ecosites, with frugivore interactions documented visually and photographically.

Experimental germination studies were conducted under controlled laboratory and nursery conditions. Three treatments were applied: (i) intact seeds with aril, (ii) seeds without aril and testa, and (iii) seed segments containing the central meristematic strand. Additionally, a subset of seed coat-removed samples was treated with Gibberellic acid (GA_3) at 250 ppm for 5-6 hours and Dithane M-45 (4 g/L) for 2 hours to promote early germination. Treated seeds were sown in moist peat moss and maintained under 70-80% humidity in glasshouse conditions, with daily watering. Germination percentage, time to sprouting, and seedling vigor were recorded over 60 days. For viability studies, freshly harvested and desiccated seeds were analyzed for moisture content (oven-dry method) and germination potential at storage temperatures of 15 °C, 28 °C, and-20 °C following the protocols of Malik *et al.* [8]. Data obtained were analyzed descriptively to determine the relationship between seed moisture, viability, and longevity, aiding in the characterization of *G. gummigutta* as a recalcitrant-seeded species.

A simple linear regression and an independent-samples t-test were performed using Python (version 3.11) with statistical and visualization libraries including NumPy [5], SciPy [14], and Matplotlib [6] to analyse the relationship between seed moisture content and viability, and to compare germination rates between control and chemically treated seeds, respectively. The regression model $(y = \beta_0 + \beta_1 x)$ was used to determine the rate of viability loss per unit decrease in moisture content, while the t-test assessed whether the treatment significantly improved germination percentage. All data were tested for normality and variance homogeneity prior to analysis, and statistical significance was determined at $p<0.05$. Graphical outputs were generated to visualize both the regression trend and treatment effects, supporting the interpretation of *Garcinia gummigutta* seed physiological responses.

3. Results and Discussion

3.1 Seed Morphology and Structure

The seeds of *Garcinia gummigutta* exhibited significant morphological uniformity across the sampled ecosites, with minor size variations related to fruit dimensions (Table 1). The fruit bears an average of 5-8 seeds, indicating a high reproductive potential of the species (Fig. 1). The seeds are ovoid to elliptical, measuring 0.5-1.7 × 1.5-3.6 cm, and possess a dry weight of 1-1.5 g, while the fresh weight with aril is 6.5-6.75 g. The testa is thick, brownish to brownish-black, with a thin membranous integument fused to the outer coat. The absence of endosperm and cotyledons was evident from longitudinal sections, which instead revealed a central core of hypocotyl tissue and a single-layered epidermis enclosing undifferentiated parenchymatous cells rich in storage materials. A longitudinal meristematic strand connects the two poles, showing no clear differentiation into radicle and plumule. Root initiation from one pole followed by its abortion and subsequent development of the plumule from the opposite pole confirms the "Garcinia-type" germination [15].

Table 1: Morphological characteristics of *Garcinia gummigutta* seeds collected from different ecosites

Ecosite Region	Seed Length (cm)	Seed Breadth (cm)	Fresh Weight (g)	Dry Weight (g)	Shape	Colour
Coastal	1.5-3.5	0.7-1.5	6.2-6.8	1.0-1.3	Ovoid	Pale brown
Midland	1.6-3.2	0.8-1.6	6.5-6.7	1.1-1.4	Elliptical	Brown
Highland	1.7-3.6	1.0-1.7	6.7-6.9	1.3-1.5	Elliptical	Brownish black

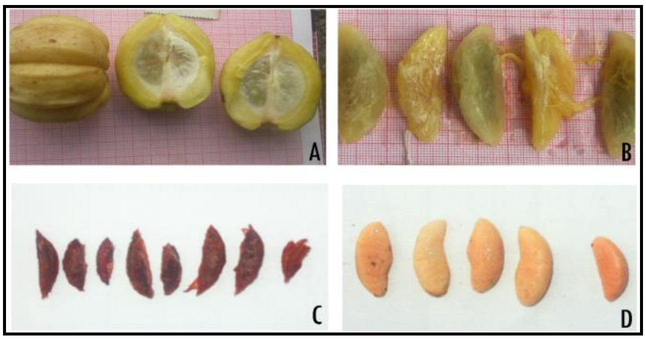

Fig 1: A. Mature fruits; B. Fresh seeds with aril; C. Dry seeds with aril; D. Dry seeds without aril.

3.2 Seed Dispersal Mechanisms

Ripened, fleshy fruits of *G. gummigutta* are consumed by several frugivorous mammals such as *Ratufa indica*, *Macaca radiata*, *Pardoxurus hermaphroditus*, and large fruit bats like *Pteropus giganteus* and *Rousettus leschenaultii*, which aid in endozoochorous dispersal. The deposition of seeds beneath parent trees during the monsoon season, when soil moisture is high, facilitates natural germination within 2-3 months. This animal-assisted dispersal strategy ensures wide genetic dispersal and ecological recruitment, as observed in other Garcinia species [8, 13].

3.3 Seed Germination and Viability Studies

In situ germination on forest floors begins by October-November and continues through December, with hypogeal germination observed. Under controlled laboratory conditions, marked differences in germination success were noted depending on seed treatment (Table 2).

Table 2: Germination response of *Garcinia gummigutta* seeds under different treatments

Treatment Type	Germination Period (days)	Germination%	Findings
Seeds with aril intact	120	40	Slow germination, delayed onset
Seeds without aril	35-50	90	Early, uniform germination
Seeds after 5 months of storage	45-50	50	Reduced viability
Chemically treated seeds	15-20	95	Rapid germination under mist chamber

The seed coat-removed seeds are treated with Gibberelic acid at 250 ppm for 5 to 6 hours and soaked in Dithane M-45 at 4 g/L for two hours. This accelerated the germination to within 15-20 days, indicating that hormonal priming helps overcome dormancy barriers. Similar GA_3-induced improvements have been reported in *Garcinia indica* and *G. xanthochymus* [3, 8].

The independent sample t-test comparing control (untreated) and chemically treated (GA_3 + Dithane M-45) seeds showed a significant difference in germination percentage between the two groups ($t = 50.34$, $p<0.001$). The bar graph (Fig. 2) clearly depicts that chemically treated seeds achieved a mean germination rate of about 90%, compared to only 40% in untreated seeds. This statistically significant improvement demonstrates that hormonal priming and antifungal treatment effectively enhance seed germination and Vigor in *Garcinia gummigutta*.

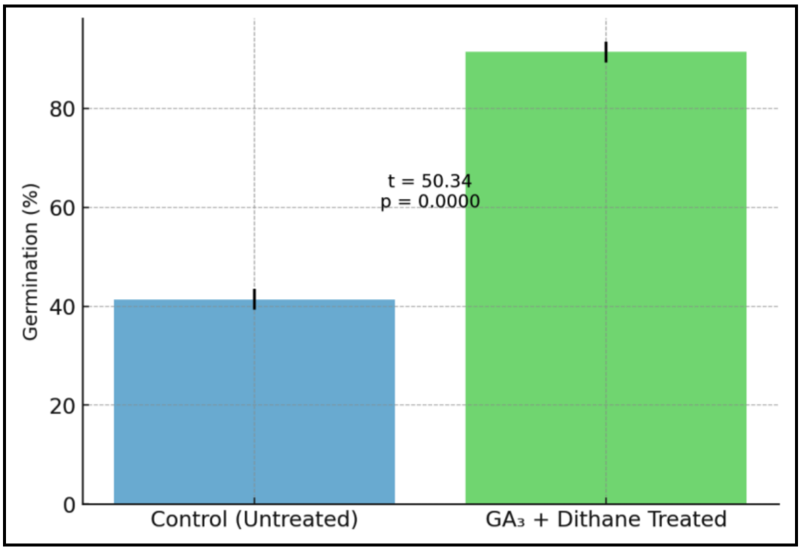

Fig 2: Comparison of Germination Percentage between Control and Chemically Treated Seeds

3.4 Seed Viability, Longevity and Storage

Fresh seeds of *G. gummigutta* recorded 48.2% moisture content and 92.5% viability at harvest. Upon desiccation, moisture levels dropped to 22.4% within 24 hours, resulting in 57.5% viability, and viability was completely lost below 17.6% moisture content [2]. The critical moisture limit for viability is thus around 21%, below which germination ceases. Viability retention was only 23% after 30 days at 28 °C, and 17% after 45 days at 15 °C, shows desiccation sensitivity.

Table 3: Effect of desiccation and storage on seed viability of *Garcinia gummigutta*

Moisture Content (%)	Viability (%)	Storage Duration and Desiccation	Temperature	Observations
48.2	92.5	Fresh	Ambient	Normal germination
22.4	57.5	24 hrs	Ambient	Reduced viability
17.6	0	48 hrs	Ambient	Viability lost
Ex-situ	23	30 days	28 °C	Recalcitrant nature evident
Ex-situ	17	45 days	15 °C	Short-lived seeds

The inability of Garcinia seeds to withstand desiccation or freezing (-20 °C) highlights the physiological sensitivity typical of tropical recalcitrant seeds [8]. This poses significant challenges for ex situ conservation, emphasizing the need for cryopreservation alternatives or clonal propagation techniques. Interestingly, germination of seed fragments retaining the central meristematic strand produced normal seedlings, suggesting potential for clonal multiplication through seed segmentation, which is a rare phenomenon linked to the agamospermic nature of the species.

A simple linear regression analysis was performed to examine the relationship between seed moisture content and viability in *Garcinia gummigutta*. The regression model $(\text{Viability} = 1.91x - 10.81)$ showed a strong positive correlation between moisture content and seed viability, indicating that viability declines sharply with decreasing seed moisture. The graph (Fig. 3) illustrates that freshly harvested seeds with high moisture content (> 45%) maintained more than 90% germinability, whereas viability dropped drastically when moisture content fell below 25%, and was completely lost below 18%. This trend confirms the recalcitrant nature of *G. gummigutta* seeds, which are highly sensitive to desiccation and require moisture retention for maintaining viability during storage.

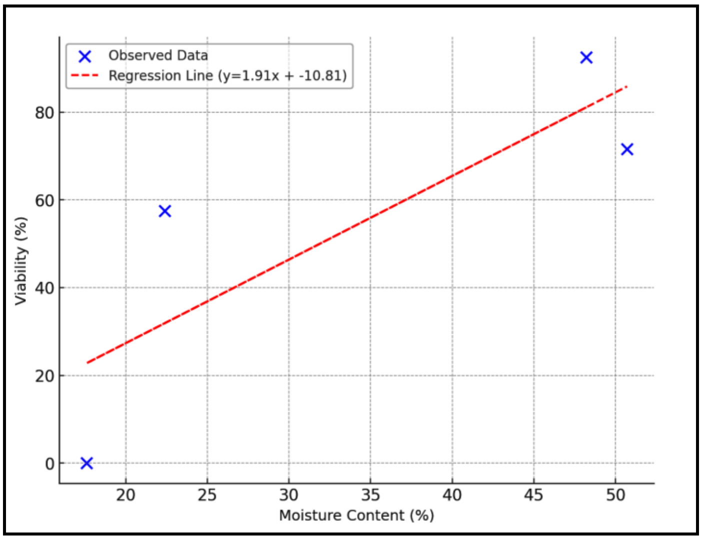

Fig 3: Graph showing relationship between seed moisture content and viability for *Garcinia gummigutta*.

3.5 Ecological and Propagation Implications

The natural regeneration of *Garcinia gummigutta* in forest habitats is highly dependent on sustained soil moisture, animal dispersal, and absence of desiccation stress. The species' recalcitrant seed physiology, though evolutionarily adaptive in humid environments, limits its storage and large-scale propagation potential. The successful germination of cut seed segments suggests a promising pathway for vegetative clonal propagation to ensure genetic uniformity in plantation programs [8].

Seedlings raised through the GA_3 treatment achieved healthy growth (15 cm in 6 months) and were suitable for transplantation after 12-18 months, with saplings reaching bearing maturity within 10-12 years (Fig. 4). In comparison, grafted saplings bear fruit within three years, underlining the advantage of vegetative propagation for commercial cultivation.

Fig 4: A. Stages of development of seeds; B. Seedlings after 4 months; C. Seedlings after 6 months

The present study demonstrates that *Garcinia gummigutta* exhibits a distinct combination of morphological adaptation, physiological recalcitrance and germination sensitivity typical of many humid tropical species. The strong dependency of seed viability on moisture retention confirms its desiccation-intolerant nature, a hallmark of recalcitrant seeds as reported in other *Garcinia* species and tropical taxa [4, 12]. The observed enhancement of germination following GA_3 and Dithane treatments aligns with previous findings that hormonal priming and antifungal protection can effectively overcome dormancy and promote early seedling establishment in *G. indica* and *G. xanthochymus* [8,11]. The results collectively indicate that successful regeneration of *G. gummigutta* depends on maintaining optimal seed moisture and immediate post-harvest propagation under shaded, humid conditions.

4. Conclusion

The present study provides a comprehensive understanding of the seed biology of *Garcinia gummigutta*, encompassing its morphology, dispersal, germination behaviour, and physiological characteristics. Morphological and anatomical observations revealed the absence of cotyledons and endosperm, with germination following the characteristic "Garcinia-type" pattern. The species relies primarily on zoochorous dispersal, with frugivorous mammals and bats facilitating effective endozoochory. However, the natural regeneration potential remains limited by its recalcitrant seed physiology, the fresh seeds with high moisture content (>45%) maintained over 90% viability, while viability declined drastically with desiccation below 25%. The linear regression analysis demonstrated a strong positive relationship between moisture content and viability, confirming that seed desiccation directly governs longevity and germination success.

Experimental germination trials further established that both mechanical and chemical treatments significantly enhance germination performance. The independent-samples t-test revealed a statistically significant difference between untreated and GA_3 + Dithane-treated seeds, confirming the efficacy of hormonal priming in overcoming dormancy and improving seedling vigor. These findings collectively demonstrate that *G. gummigutta* seeds are short-lived, moisture-sensitive, and require immediate propagation under controlled conditions to maintain viability. The integration of morphological, ecological, and statistical analyses provides valuable insights for developing improved nursery techniques, ex situ conservation strategies, and large-scale propagation protocols. Overall, the study underscores the need for rapid post-harvest handling, moisture management, and the potential adoption of clonal multiplication to ensure sustainable utilization and conservation of this economically and ecologically significant species in the Western Ghats.

Author's Contributions: Dr. Alexander T solely conceived and designed the study, conducted field sampling and analyses, performed data interpretation and statistical analysis, and prepared the manuscript.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request. As the sole author, I affirm that all datasets used and analysed during the current study were generated by me and are securely archived.

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