Study on the Effects of Various Pre-Sowing Treatments on Seed Germination and Growth of Chironji under Agroforestry Systems in Jabalpur (M.P.)

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Abstract

Buchanania cochinchinensis (Chironji) is a high-value wild fruit tree species increasingly threatened by unsustainable harvesting, poor seed germination due to its hard seed coat and ecological degradation. This study assessed the impact of various pre-sowing treatments on seed germination and early seedling growth, followed by evaluation under different agroforestry systems. The experiment was conducted from 2022 to 2025 at the ICFRE-Tropical Forest Research Institute, Jabalpur, using six pre-sowing treatments: T1 (Control), T2 (Cow dung), T3 (Cow urine), T4 (H_2SO_4 5%), T5 (GA_3 250 ppm) and T6 (Mechanical scarification), laid out in a CRD with three replications. Germination traits and post-emergence growth parameters were recorded. Seedlings from the best-performing treatment (T6) were transplanted into eight agroforestry models with varying spacings and intercrops (maize, cowpea, kalmegh) using a Randomized Block Design. Mechanical scarification (T6) significantly improved germination rate, uniformity and survival. Among agroforestry systems, wider spacing (AF8: Sole Chironji at 8×8 m) showed superior growth performance, followed by AF7 and AF6. The findings highlight mechanical scarification as an effective low-cost technique to improve Chironji propagation and suggest that wider spacing in agroforestry enhances long-term growth and establishment.

Introduction

Chironji (*Buchanania cochinchinensis* Lour.) is an important tree native to the dry deciduous forests of India. It is an underutilized nut-yielding plant and a member of the Anacardiaceae family (Avani et al., 2015). It holds both economic and ecological value (Rajput et al., 2018). Known by names like Achar, Char, Chawar, Charoli and Priyal among tribal communities (Vijay et al., 2022), it is also called the Almondette tree (Chauhan et al., 2012). This tree is especially known for its production of fruit and nuts and is commonly found in tropical forests across Asia (Agrawal and Quraishi, 2024). It predominantly grows in Indian tropical forest regions, especially in Madhya Pradesh, Jharkhand and Chhattisgarh (Srivastava et al., 2021; Vijay et al., 2022; Bhanu et al., 2024). These areas contribute to nearly half of the national chironji production, amounting to around 5,120 tons annually (Pradhan & Pradhan, 2020). It has significant potential to mitigate nutrient deficiencies in vulnerable tribal and rural people, since it fulfils their dietary and medicinal needs (Tomar et al., 2024).

Economically, chironji holds considerable value, sold at about 10 USD per kilogram in local markets and serving as a critical livelihood source for rural populations (Pradhan and Pradhan, 2020). As per the Tribal Co-operative Marketing Development Federation of India Limited, chironji has a market potential of around 30.04 million USD per year in India. The most prized part of the fruit is the kernel, which is sold at 7 to 10 USD per kilogram (Rajput et al., 2018). These seeds are nutritionally rich—high in proteins, essential fatty acids and antioxidants—making them useful in cooking, healthcare and beauty products (Kumar et al., 2023; Singh et al., 2023). The tree's leaves, bark and gum are also used medicinally, further adding to its value in traditional healing practices (Sharma et al., 2022). The kernels are typically small, brownish and nut-flavored, consumed either raw or roasted (Pradhan & Pradhan, 2020).

Chironji is not grown like typical crops. It tends to grow naturally in forested areas without deliberate planting. Rather than cultivating it in farmland, local populations gather it from the wild for trade and use (Vijay *et al.*, 2002). People often cut branches for collection, but overuse and unsustainable harvesting methods, including lopping and cutting, threaten its survival—thus demanding urgent conservation efforts (Prasad, S., 2020; Malakar et al., 2024). Although chironji has great economic and environmental potential, its farming is limited due to its long fruiting duration (Chauhan et al., 2020). It has been categorized as Near Threatened (NT) by the IUCN because of habitat destruction, over-harvesting and limited natural regeneration (IUCN, 2023; Malakar et al., 2023). While it reproduces via seeds in the wild, seed harvesting for consumption slows natural propagation.

Seed dormancy and irregular germination patterns hinder its natural reproduction (Gupta et al., 2023), which restricts its integration into agroforestry systems. The seeds are covered with a tough outer layer (Singh et al., 2010) that significantly blocks germination. This outer seed coat impedes the absorption of water and oxygen, disrupting essential metabolic processes (Bewley & Black, 1982; Copeland & McDonald, 2012). Even under favourable conditions, germination rates remain low due to dormancy. Factors contributing to this may include tough physical seed structures, improper storage, or poor handling (Joshi et al., 2017; Vijay et al., 2022). Freshly harvested seeds are also difficult to germinate because of the hard seed covering (Sharma, 2012). The main hurdle in artificially regenerating chironji is low germination, often caused by fungal contamination during seed storage (Sanjay Singh, 2007; Narayan et al., 2018). Warm and humid conditions promote fungal growth (Agrawal and Quraishi, 2024). High humidity, along with intense sunlight, reduces seed viability and hinders germination (Shende and Rai, 2005).

To achieve optimal propagation, Singh et al. (2019) suggest collecting seeds from ripened fruits in April-May and sowing them in June-July in polybags or nursery beds. Applicaproper pre-sowing treatments may improve germination (Koirala et al., 2000), leading to strong and healthy seedling growth (Azad et al., 2006). Choosing the right seed treatment method should balance practicality and efficiency, considering the environmental context and seed characteristics (Falemara et al., 2014). One effective method is mechanical scarification, which is known to enhance germination in hard-coated seeds and has recently been used as a standard technique in experiments (Jansen et al., 2021).

The tree is suitable for agroforestry and social forestry systems because it is hardy and suitable for arid land and degraded soil restoration (Hiwale & Hiwale, 2015). Including chironji in agroforestry practices could support its conservation, improve production sustainability and benefit farmers economically (Verma & Yadav, 2024). Agroforestry plantations of chironji help improve soil quality, enhance biodiversity and support local livelihoods, especially in semi-arid regions (Patel et al., 2023; Meena et al., 2023). In Central India, these systems have high potential for income and job creation. One of the key components in such systems is managing planting distances to maximize output and efficient use of natural resources. Wider spacing reduces competition for essentials like light, water and nutrients, supporting better tree growth. On the other hand, denser planting may lead to more competition and lower yields (Tiwari et al., 2023; Roy et al., 2023).

"The present study focuses on improving seed germination techniques and assessing the impact of various spacing treatments on the growth performance of chironji. This research is driven by the increasing market demand for chironji kernels and the need for sustainable agroforestry systems that emphasize species conservation. The findings aim to facilitate successful regeneration of chironji, promote environmentally friendly cultivation practices, contribute to biodiversity conservation and enhance livelihood opportunities for farmers."

Materials and Methods

Study Area

The study was conducted for three years i.e. 2022 and 2025 at the ICFRE-Tropical Forest Research Institute (TFRI), Jabalpur, Madhya Pradesh, India, within the agroforestry demonstration plot. The site is geographically located at 23°6'0.32" N latitude and 79°59'17.72" E longitude, depicted in Fig. 1. The TFRI campus is situated in a semi-arid climate with an average annual precipitation of 1350 mm. It is encircled by agricultural regions and shares a boundary with the River Gour. The area is classified under the Kymore Plateau and Satpura Hills Agro-Climatic Zone (Zone VII), noted for its medium to high soil fertility. The sandy loam-textured soil at the research site has a pH between 6.0 and 7.0, which signifies it is mildly acidic to moderately alkaline. The temperature fluctuates significantly, with a low of 7.5°C in winter and a high of 42.5°C in summer.

Experimental details

The research was systematically carried out over a three-year period (2022–2025) in three distinct phases to examine how different pre-sowing treatments influence the germination, seedling development and field performance of Chironji under agroforestry systems. In the first phase, seeds freshly collected from local Chironji trees were subjected to six pre-sowing treatments: T_1 – untreated control, T_2 – cow dung, T_3 – cow urine, T_4 – sulfuric acid (5% for 10 minutes), T_5 – gibberellic acid (GA_3 at 250 ppm for 24 hours) and T_6 – mechanical scarification using a hammer. The root trainers have been used for the germination of seeds after pre- sowing seed treatments. The medium used for the study was coco-peat, soil and farmyard manure at a ratio of 2:1:1. No additional nutrients were added to the medium. The watering of the root trainers was done after the sowing of seeds. The germination trial followed a Completely Randomized Design (CRD) with three replications and observations were recorded on germination-related parameters such as *viz.*, days taken to germination, germination percentage (%), mean daily germination (%), peak value, germination value and survival percentage (%).

Observations

Observations of different germination parameters were recorded throughout the growing period at specific intervals.

Days taken to Germination

The seeds were observed daily, for seedling emergence. The days on which the first seedling emerged was expressed as days to initial germination.

Survival percentage

This is the percentage of seedlings that survived after a certain period post-germination or transplantation.

$$Survival\, percentage\ (\%) = \frac{Number\ of\ Surviving\ Seedlings}{Total\ Number\ of\ transplanted\ seedlings} \times\ 100$$

Germination percentage

The germination percentage was calculated using the following formula proposed by (Tiwari et al., 2020):

$$Germination\, percentage\ (\%) = \frac{Number\ of\ seeds\ germinated}{Number\ of\ seeds\ sown} \times\ 100$$

Mean daily Germination

The mean daily germination was calculated according to the methods of (Czabator, 1962).

$$Mean\ daily\, Germination = \frac{Total\, number\ of\ seeds\ germinated}{Total\, number\ of\ days}$$

Peak Value

The peak value is the maximum mean daily germination reached at any stage of the germination period, which is calculated by the following formula proposed by (Tiwari et al., 2020):

$$Peak\ value = \frac{Highest\ germinated\ seeds}{Number\ of\ days}$$

Germination Value

The germination value is an index of the combination of the speed and completeness of seed germination. GV was calculated as per Czabator (1962).

$$GV = PV\ \times\ MDG$$

The second phase of experiment was conducted in Completely Randomized Design (CRD) involved transplanting the germinated seedlings into polybags containing a soil and farmyard manure mixture in a 2:1 ratio. All treatment were undertaken for observation for initial growth traits. Data were collected on Shoot Height, shoot collar diameter, No. of leaves per plant, Leaf area index, shoot length, Root length and Shoot: Root ratio were recorded.

In the third and final phase, Seedlings from the best-performing treatment (T_6 – mechanical scarification) were further assessed under nursery conditions. Healthy seedlings from the (T_6) treatment were transplanted to the field to study their performance under various agroforestry combinations. The field experiment adopted a Randomized Block Design (RBD) with three replications and eight treatment setups: AF_1 – Chironji (6 × 6 m spacing) + maize, AF_2 – Chironji (6 × 6 m) + cowpea, AF_3 – Chironji (6 × 6 m) + kalmegh, AF_4 – Chironji (8 × 8 m) + maize, AF_5 – Chironji (8 × 8 m) + cowpea, AF_6 – Chironji (8 × 8 m) + kalmegh, AF_7 – Sole Chironji (6 × 6 m) and AF_8 – Sole Chironji (8 × 8 m). Growth performance was evaluated through key parameters such as plant height, collar diameter and number of branches, aiming to determine the impact of spacing and intercrop combinations on Chironji growth within agroforestry systems.

Statistical Analysis

The experimental data were analyzed using Analysis of Variance (ANOVA) (Rangaswamy, R. 1995) in Microsoft Excel to determine whether there were statistically significant differences among the treatment means. The F-test was employed to evaluate the overall significance at a 5% level of probability ($p < 0.05$). Upon finding significant variation through ANOVA, a post-hoc comparison was carried out using the Critical Difference (CD) method. The CD was computed using the standard error of the mean and the relevant t-value based on the degrees of freedom. Treatment means that exceeded this calculated CD value were interpreted as significantly different from one another. This test facilitated the detection of statistically meaningful differences under the assumption of equal variances.

All graphical representations, including bar charts, box plots and line graphs, were created using R software version 4.2.2, employing various packages for data visualization and formatting.

Results

Germination parameters

This experiment examined the variance in several germination characteristics of chironji. Notable disparities among the examined parameters were detected as a result of the various physical and chemical treatments administered to the seedlings. Table 1. presents the ANOVA analysis, which reveals significant differences among the germination parameters across treatments, as further depicted in Figs. 2 and 3. Among the treatments, mechanical scarification (T_6) emerged as the most effective in enhancing germination and early seedling performance compared to the untreated control (T_1). The number of days required for germination decreased markedly from 39.78 days in the control to 21.84 days in (T_6), reflecting nearly a 45% reduction. The germination percentage also improved considerably from 31.65% (T_1) to 51.88% (T_6). Other germination parameters, including mean daily germination (1.81), peak value (3.89) and germination value (7.05), were significantly higher under (T_6) in comparison to the control (0.51, 2.14 and 1.09 respectively). Additionally, seedling survival improved notably, with survival percentage increasing from 40.58% (T_1) to 64.77% (T_6). These findings clearly indicate that mechanical scarification effectively overcomes the physical dormancy imposed by the hard seed coat of chironji, likely by enhancing water absorption and gaseous exchange. This, in turn, stimulates metabolic activities essential for seed germination and seedling emergence. The significant improvement in both germination and survival under (T_6) demonstrates the potential of this treatment to improve nursery-stage establishment and regeneration success in agroforestry systems.

Table 1
Evaluation of Initial Germination Parameters of Chironji Seeds under Various Pre-Sowing Treatments

Treatments	Days taken to Germination	Germination percentage (%)	Mean daily Germination (%)	Peak Value	Germination Value	Survival percentage (%)
T_1 (Control)	39.78 ± 0.973	31.65 ± 0.035	0.51 ± 0.000	2.14 ± 0.006	1.09 ± 0.006	40.58 ± 0.101
T_2 (Cow dung)	35.42 ± 0.092	33.89 ± 2.465	0.75 ± 0.006	2.27 ± 0.015	1.70 ± 0.024	44.21 ± 0.321
T_3 (Cow urine)	31.06 ± 0.131	36.55 ± 0.445	0.98 ± 0.015	2.49 ± 0.036	2.44 ± 0.068	48.97 ± 0.687
T_4 (H2SO4)	28.17 ± 0.396	44.80 ± 0.300	1.22 ± 0.006	3.01 ± 0.012	3.67 ± 0.033	52.36 ± 0.217
T_5 (GA3)	25.39 ± 0.187	47.52 ± 4.510	1.46 ± 0.006	3.37 ± 0.009	4.92 ± 0.026	59.88 ± 0.155
T_6 (Mechanical Scarification)	21.84 ± 0.054	51.88 ± 0.365	1.81 ± 0.045	3.89 ± 0.095	7.05 ± 0.348	64.77 ± 1.582
C.D.	1.374	7.461	0.062	0.133	0.456	2.261
SE(m)	0.441	2.115	0.02	0.043	0.146	0.726

Seedling growth parameters

Significant variation in Seedling growth parameters across treatments, as revealed by statistical analysis, is summarized in Table 2 and graphically represented in Fig. 4. The growth characteristics of chironji seedlings were significantly improved by mechanical scarification (T_6) compared to the untreated control (T_1). The shoot height increased from 10.42 cm (T_1) to 13.89 cm (T_6) and the shoot collar diameter improved from 0.24 cm to 0.33 cm. The number of leaves per plant nearly doubled, rising from 6.73 in the control to 13.88 in T6. A notable increase was also observed in the leaf area index, from 18.45 in T_1 to 22.94 in (T_6). Furthermore, both shoot length and root length were substantially higher under (T_6)

(22.81 cm and 27.63 cm, respectively) compared to T_1 (12.37 cm and 16.18 cm, respectively). The shoot-to-root ratio remained fairly balanced, increasing slightly from 0.77 to 0.83 under (T_6). The superior performance of mechanically scarified seeds can be attributed to enhanced water and oxygen uptake, resulting from the physical alteration of the impermeable seed coat. This likely contributed to a more uniform and rapid metabolic activation post-sowing, translating into robust seedling growth. In contrast, the untreated control (T_1) exhibited reduced growth across all parameters, reaffirming the inherent dormancy constraints in untreated Chironji seeds. Enhanced root and shoot development contribute to better nutrient uptake, photosynthetic capacity and survival in early growth stages.

Table 2

Assessment of Pre-Sowing Treatment on growth characteristics of chironji seedling

Treatments	Shoot Height	Shoot collar diameter	No. of leaves per plant	Leaf area index	Shoot length	Root length	Shoot: Root ratio
T_1 (Control)	10.42 ± .027	0.24 ± 0.000	6.73 ± 0.015	18.45 ± .048	12.37 ± 0.029	16.18 ± 0.042	0.77 ± 0.015
T_2 (Cow dung)	10.95 ± 0.078	0.26 ± 0.000	7.58 ± 0.057	19.12 ± 0.141	14.01 ± 0.104	18.25 ± 0.134	0.77 ± 0.000
T_3 (Cow urine)	11.63 ± 0.163	0.28 ± 0.006	9.04 ± 0.125	20.37 ± 0.286	16.45 ± 0.229	20.42 ± 0.286	0.81 ± 0.018
T_4 (H2SO4)	12.07 ± 0.050	0.30 ± 0.000	10.91 ± 0.047	21.08 ± 0.089	18.23 ± 0.078	22.79 ± 0.095	0.80 ± 0.012
T_5 (GA3)	13.27 ± 0.036	0.31 ± 0.000	12.36 ± 0.033	22.16 ± 0.057	20.57 ± 0.054	25.11 ± 0.066	0.82 ± 0.012
T_6 (Mechanical Scarification)	13.89 ± 0.339	0.33 ± 0.009	13.88 ± 0.339	22.94 ± 0.562	22.81 ± 0.556	27.63 ± 0.675	0.83 ± 0.003
C.D.	0.496	0.013	0.471	0.835	0.787	0.96	0.036
SE(m)	0.159	0.004	0.151	0.268	0.253	0.308	0.012

After transplantation

The treatment-wise variation in morphological traits such as collar diameter, number of branches and plant height is presented in Table 3 and illustrated in Figs. 5 and 6, highlighting distinct groupings and performance differences among treatments. The growth performance of Chironji under agroforestry and sole plantation systems at 18 months after planting (540 DAP) showed notable variation across treatments. The plant height was observed to be slightly higher in the sole plantation at 189.88 cm (AF8) compared to 182.12 cm (AF_1) in the agroforestry system with maize. The collar diameter also followed a similar trend, being significantly greater under sole plantation (54.92 mm) than in the agroforestry setup (48.13 mm). Additionally, the number of branches per plant was higher in the sole Chironji treatment (4.12) than in the maize-based agroforestry treatment (2.08). These findings suggest that wider spacing and the absence of intercrop competition in the sole plantation system promoted better vegetative growth and branching in chironji. In contrast, the presence of intercrops like maize may have imposed competitive stress for light, water and nutrients, thus slightly reducing growth parameters. However, agroforestry systems still support considerable tree growth while offering the added benefits of intercropping.

Table 3

Assessment of plant height, Number of Branches and collar diameter of chironji plant in agroforestry system growth observation under agroforestry / field condition (18 month after planting/540DAP)

Treatment	Plant Height	Collar diameter	Number of Branches
AF_1 **(Chironji 6x6m + Maize)**	182.12 ± 0.454	48.13 ± 0.119	2.08 ± 0.006
AF_2 **(Chironji 6x6m + Cowpea)**	182.98 ± 1.332	48.97 ± 0.357	2.31 ± 0.015
AF_3 **(Chironji 6x6m + Kalmegh)**	184.05 ± 2.587	49.82 ± 0.702	2.44 ± 0.036
AF_4 **(Chironji 8x8m + Maize)**	185.24 ± 0.771	51.04 ± 0.214	2.73 ± 0.012
AF_5 **(Chironji 8x8m + Cowpea)**	186.53 ± 0.482	52.37 ± 0.136	3.13 ± 0.009
AF_6 **(Chironji 8x8m + Kalmegh)**	187.81 ± 4.595	53.65 ± 1.311	3.85 ± 0.095
AF_7 **(Sole Chironji 6x6 m)**	189.06 ± 1.671	54.11 ± 0.479	4.09 ± 0.036
AF_8 **(Sole Chironji 8x8 m)**	189.88 ± 3.063	54.92 ± 0.886	4.12 ± 0.068
C.D.	N/A	2.007	0.136
SE(m)	2.325	0.655	0.044

Discussion

The findings indicate that pre-sowing treatments significantly influenced the germination and early growth of chironji seedlings. The enhanced germination observed in T_6 (Mechanical Scarification) aligns with previous studies, also significantly improved germination compared to the control, supporting earlier research that emphasizes the effectiveness of physical treatments in breaking dormancy by creating micro-cracks in the seed coat (Sharma & Patel, 2018). The lowest germination percentage in T_1 (Control) suggests that the natural dormancy of chironji seeds impedes germination, which aligns with findings by Ramesh et al., (2017), who noted that untreated seeds exhibit delayed germination due to the presence of impermeable seed coats. Seed treatment has been an established technique to accelerate up and render uniform the process of emergence and crop establishment for quite a while (Ray and Berry, 2023). Mechanical scarification immediately compromises the water-impermeable seed coverings, illustrating the biological impact of mastication, the preliminary phase of endozoochory (Razanamandranto *et al.*, 2004). Mechanical or manual scarification involves the removal of a small portion of the seed coat ('nicking' or 'filing') or the complete cracking of the seed coat ('cracking') utilizing tools such as secateurs, files, sandpaper, or a hammer (Danthu, 1995; Razanameharizaka et al., 2006; Saied et al., 2008; Kempe et al., 2018; Hansohm et al., 2020; Lautenschläger et al., 2020). advocate for mechanical scarification in a hard seed coat germination to assist rural farmers, noting that any rough surface may serve to scarify the seed in the lack of appropriate instruments. Gibberellic acid (T_5) also performed good across measured in all other parameters suggests its potential as an effective pre-sowing treatment for chironji seedlings, which likely contributed to the increased shoot height and diameter (Singh et al., 2019).The positive impact of T_5 (GA_3) and T_4 H_2SO_4 on germination can be attributed to its ability to weaken the hard seed coat, thereby improving permeability and facilitating faster imbibition, as reported by (Sharma & Patel, 2018; Ramesh et al., 2017; Kumar et al., 2020).

The consistent underperformance of the control group across all parameters highlights the potential benefits of pre-sowing treatments in improving seedling vigor and growth characteristics. These findings suggest that implementing appropriate pre-sowing treatments, particularly Mechanical scarification, could significantly enhance the early growth and establishment of chironji seedlings, supporting previous studies on (Sharma, D. K. 2016).

The study highlights that wider spacing (8x8 m) in sole Chironji plantations resulted in better plant height (189.88 cm), number of branches (4.12) and collar diameter (54.92 mm), likely due to reduced competition for light, nutrients and water. In contrast, intercropping with maize (6 x 6 m) led to the lowest growth performance, indicating strong competition effects (Roy et al., 2023). These results align with previous findings that higher tree density and competitive crops limit tree growth (Sharma et al., 2022). Future research should explore less competitive intercrops, such as legumes, to improve soil fertility while minimizing competition (Gupta et al., 2023).

Conclusion

This study establishes the critical role of pre-sowing treatments in enhancing the germination and early growth performance of *Buchanania cochinchinensis*. Among the evaluated treatments, mechanical scarification (T_6) demonstrated the most significant improvement in germination percentage, reduced emergence time and promoted superior seedling vigour. While GA_3 (250 ppm for 24 h) and H_2SO_4 (5% for 10 min) also improved germination traits, their effects were comparatively moderate. Furthermore, post-transplantation assessment revealed that wider spacing (8 × 8 m) facilitated better seedling growth, likely due to reduced intra-specific competition. These findings underscore the efficacy of mechanical scarification and optimal spacing configuration as vital considerations for the successful propagation and agroforestry integration of chironji.

Declarations

Conflict of interest

The authors declare no competing interests.

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Author Contribution

Mukul Anand Ray: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Nanita Berry: Writing – review & editing, Validation, Supervision, Resources, Methodology. Swati Priya: Writing – review & editing, Writing – original draft, Visualization, Resources, Formal analysis, Data curation. Komal Bhatt: Writing review & editing, Visualization, Validation, Investigation.

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References

1. Agrawal, T., & Quraishi, A. (2024). Assessing the genetic diversity of *Buchanania lanzan* Spreng. (Chironji) using inter simple sequence repeat markers. *Genetic Resources and Crop Evolution, 71*(6), 2935–2947.
2. Avani, P., Bauri, F. K., & Sarkar, S. K. (2015, August). Chironji: A golden nut fruit of Indian tribes. In *III International Symposium on Underutilized Plant Species* (Vol. 1241, pp. 37–42).
3. Azad, M. S., Islam, M. W., Matin, M. A., & Bari, M. A. (2006). Effect of pre-sowing treatment on seed germination of *Albizia lebbeck* (L.) Benth. *South Asian Journal of Agriculture, 1*(2), 32–34.
4. Bewley, J. D., & Black, M. B. (1982). *Physiology and biochemistry of seed germination. Part II*. Springer-Verlag.
5. Bhanu, L., Goudar, G., Gogoi, P., Mahajan, A., Subhash, K., Chandragiri, A. K., Sreedhar, M., Dutta, H., Roy, A., Hmar, B. Z., & Sharma, P. (2024). Effect of roasting on nutritional composition, polyphenols and antioxidant properties of chironji (*Buchanania lanzan* Spreng.) kernels. *Journal of Food Measurement and Characterization, 18*(8), 7003–7018.

6. Chauhan, P. S., Jitendra Singh, J. S., & Kavita, A. (2012). Chironjee: A promising tree fruit of dry subtropics. *HortFlora Research Spectrum, 1*(3), 375–379.
7. Chauhan, P. S., Sharma, M., Pandey, S. B. S., Bhatnagar, P., Sharma, M. K., & Nagar, B. (2020). Effect of seed treatments on plus trees of *Buchanania lanzan* in South-Eastern Rajasthan. *Journal of Pharmacognosy and Phytochemistry, 9*(4), 301–303.
8. Copeland, L. O., & McDonald, M. F. (2012). *Principles of seed science and technology*. Springer Science & Business Media.
9. Czabator, F. J. (1962). Germination value: An index combining speed and completeness of pine seed germination. *Forest Science, 8*(4), 386–395.
10. Danthu, P., Roussel, J., Gaye, A., & El Mazzoudi, E. H. (1995). Baobab (*Adansonia digitata* L.) seed pretreatments for germination improvement. *Seed Science and Technology, 23*, 469–475.
11. Falemara, B. C., Chomini, M. S., Thlama, D. M., & Uden-Kwere, M. (2014). Pre-germination and dormancy response of *Adansonia digitata* L. seeds to pre-treatment techniques and growth media. *European Journal of Agriculture and Forestry Research, 2*, 31–41.
12. Gupta, N., Sharma, R., & Das, A. (2023). Overcoming seed dormancy in tropical agroforestry tree species: A review. *Journal of Tree Sciences, 42*(1), 55–70.
13. Gupta, P., Sharma, A., & Mehta, R. (2023). Influence of leguminous intercrops on tree growth and soil fertility in agroforestry systems. *Agroforestry Systems, 97*(2), 235–248.
14. Hansohm, N., Jansen, L., Mandala, K., Kandiado, P., Meinhold, K., Darr, D., Wichern, F., & Gebauer, J. (2020). *Instruction manual for Baobab cultivation – Based on experiences in Mangochi, Malawi* (pp. 1–21). OPUS Publication Server of the Rhine-Waal University of Applied Sciences. https://nbn-resolving.org/urn:nbn:de:hbz:1383-opus4-5859
15. Hiwale, S., & Hiwale, S. (2015). Chironji (*Buchanania lanzan* Spreng.). In *Sustainable horticulture in semiarid dry lands* (pp. 247–253).
16. International Union for Conservation of Nature (IUCN). (2023). *Buchanania cochinchinensis*: The IUCN Red List of Threatened Species. https://www.iucnredlist.org
17. Jansen, L., Wichern, F., & Gebauer, J. (2021). Effect of different mechanical seed scarification methods on germination and emergence dynamics of baobab (*Adansonia digitata* L.). *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS), 122*(2), 183–192.
18. Joshi, C. J., Sharma, D. K., Gotur, M., & Rajan, R. (2017). Effect of different chemicals on seedling growth and biomass of Chironji (*Buchanania lanzan* Spreng.). *International Journal of Current Microbiology and Applied Sciences, 6*(9), 1819–1823.
19. Kempe, A., Neinhuis, C., & Lautenschläger, T. (2018). Adansonia digitata and Adansonia gregorii fruit shells serve as a protection against high temperatures experienced during wildfires. *Botanical studies*, *59*(1), 7.
20. Koirala, B., Hossain, M. K., & Hossain, M. S. (2000). Effect of presowing treatments on *Adenanthera pavonina* L. seeds and initial seedling development in the nursery. *Malaysian Forester, 63*(2), 82–91.

21. Kumar, A., Sharma, R., & Verma, P. (2020). Effect of sulfuric acid treatment on seed germination and seedling growth in tropical tree species. *Indian Journal of Agroforestry, 22*(1), 56–62.
22. Kumar, R., Sharma, P., & Meena, S. (2023). Seed dormancy and germination enhancement in agroforestry tree species: A review. *Agroforestry Systems, 97*(2), 215–230.
23. Lautenschläger, T., Teutloff, N., Gunther, M., & Neinhuis, C. (2020). *Adansonia digitata* germination tests: Elephants or heat—What causes scarification of seed to facilitate germination? *Botanical Studies, 61*, Article 19. https://doi.org/10.1186/s40529-020-00288-z
24. Malakar, A., Kumar, R., Mishra, Y., & Sinha, A. (2024). Evaluation of seed germination of Chironji (*Buchanania cochinchinensis* (Lour.) M.R. Almeida) under nursery conditions. *International Journal of Economic Plants, 11*(4), 531–538.
25. Malakar, A., Sahoo, H., Sinha, A., & Kumar, A. (2023). Necessity of genetic diversity study and conservation practices in chironji (*Buchanania cochinchinensis* (Lour.) M.R. Almeida). *Environment Conservation Journal, 24*(1), 253–260.
26. Meena, V., Singh, K., & Yadav, R. (2023). Effect of tree spacing on growth and productivity in agroforestry systems. *Indian Journal of Agroforestry, 25*(3), 101–115.
27. Narayan, K., Shankar, D., Yadaw, K. N., & Sahu, N. (2018). Effect of seed sowing and scarification methods on germination and growth of chironji (*Buchanania lanzan* Spreng). *International Journal of Current Microbiology and Applied Sciences, 7*(6), 1291–1296.
28. Patel, D., Verma, S., & Singh, K. (2023). Spacing and growth performance of tree species in agroforestry systems. *Silvicultural Research Journal, 19*(4), 312–328.
29. Pradhan, D., & Pradhan, R. C. (2020). Optimization of process parameters using a hybrid intelligent system model and evaluation of physicochemical properties of microwave roasted Chironji (*Buchanania lanzan*) kernels. *Journal of Food Measurement and Characterization, 14*(6), 2956–2969.
30. Prasad, S. (2020). Chironji (*Buchanania lanzan*): A retreating valuable resource of central India. *International Journal of Bioresource Science, 7*(1), 1–4.
31. Rajput, B. S., Gupta, D., Kumar, S., Singh, K., & Tiwari, C. (2018). *Buchanania lanzan* Spreng. (Chironji): A vulnerable multipurpose tree species in Vindhyan region. *Journal of Pharmacognosy and Phytochemistry, 7*(5), 833–836.
32. Ramesh, M., Yadav, D., & Choudhary, S. (2017). Influence of seed dormancy-breaking treatments on germination of agroforestry species. *Journal of Forest Science, 63*(3), 145–152.
33. Rangaswamy, R. (1995). *A text book of agricultural statistics*. new age international. pp 269-309.
34. Ray, M. A., & Berry, N. (2023). Effect of Seed Treatments on Germination and Growth of Seedlings in *Aegle Marmelos*. *Journal of Tropical Forestry*, *39*(1-4). pp 15-20.
35. Razanameharizaka, J., Grouzis, M., Ravelomanana, D., & Danthu, P. (2006). Seed storage behaviour and seed germination in African and Malagasy baobabs (*Adansonia* species). *Seed Science Research, 16*, 83–88.

36. Roy, B., Tiwari, M., & Srivastava, A. (2023). Impact of spacing on tree growth and soil properties in agroforestry plantations. *Journal of Agroforestry Research, 18*(2), 89–104.
37. Roy, S., Kumar, R., & Mishra, V. (2023). Competition effects of maize on tree growth in silvi-agricultural systems. *Indian Journal of Agroforestry, 25*(1), 102–110.
38. Saied, A. S., Gebauer, J., & Buerkert, A. (2008). Effect of different scarification methods on germination of *Ziziphus spina-christi* seeds. *Seed Science and Technology, 36*, 201–205.
39. Sharma, A. (2012). Scientific harvesting for quality seed collection of *Buchanania lanzan* Spreng. for its conservation and sustainable management – Case study of Chhindwara, Madhya Pradesh, India. *International Journal of Bio-Science and Bio-Technology, 4*(1), 65–74.
40. Sharma, D. K. (2016). Effect of plant growth regulators and scarification on germination and seedling growth of Chironji (*Buchanania lanzan* Spreng.). *Advances in Life Sciences, 5*(8), 3237–3241.
41. Sharma, M., Patel, R., & Roy, B. (2022). Tree-crop interactions and sustainable agroforestry models. *Journal of Sustainable Forestry, 40*(3), 567–582.
42. Sharma, P., & Patel, V. (2018). Mechanical and chemical scarification techniques for enhancing germination in hard-coated seeds. *Seed Science Research, 28*(4), 98–105.
43. Sharma, P., Verma, R., & Patel, V. (2022). Impact of tree density and intercropping on growth performance in agroforestry. *Journal of Sustainable Forestry, 41*(3), 345–360.
44. Shende, S., & Rai, M. (2005). Multiple shoot formation and plant regeneration of a commercially-useful tropical plant, *Buchanania lanzan* (Spreng). *Plant Biotechnology, 22*(1), 59–61.
45. Singh, A., Gupta, N., & Das, A. (2023). Advances in seed treatment methods for enhancing germination in dryland species. *Journal of Forestry Research, 35*(1), 45-62.
46. Singh, N., Tiwari, R., & Kumar, S. (2019). Role of gibberellic acid in seed dormancy breaking and seedling vigor. *Journal of Plant Physiology, 184*, 120–128.
47. Singh, S. (2007). Chironji. In *Underutilized and Underexploited Horticultural Crops* (Vol. 2, pp. 295–303).
48. Singh, S., Singh, A. K., Bagle, B. G., & More, T. A. (2010). *Chironji: A potential dry fruit for dry lands* (Technical Bulletin No. 33). Central Horticultural Experiment Station.
49. Srivastava, A. K., Gupta, D., Tiwari, C., Kumar, S., & Rajput, B. S. (2021). *Buchanania lanzan* Spreng. (Chironji): A potential wild fruit tree of peninsular India – A review. *Journal of Progressive Agriculture, 12*(1), 1–8.
50. Tiwari, P., Kumar, R., & Lavania, P. (2020). Response of presowing treatment on seed germination and seedlings growth characteristics of *Albizia lebbeck*. *Journal of Pharmacognosy and Phytochemistry, 9*(6), 138–141.
51. Tiwari, P., Mishra, D., & Jha, P. (2023). Productivity and economic benefits of integrating high-value trees in agroforestry systems. *Agroforestry Review, 14*(1), 31–48.

52. Tomar, A., Priya, S., Singh, B. K., & Singh, S. (2024). Promotion of Multipurpose Tree Species Cultivation for Improving Livelihood Security in Drought-Vulnerable Ecosystems. In *Sustainable Land Management in India* (pp. 93-115). Springer, Singapore.
53. TRIFED. (n.d.). *Importance of MFPs*. https://trifed.tribal.gov.in/non/timber/msp-mfp.
54. Vijay, M. K., Sharma, R. S., Maloo, S. R., Jain, V., & Sharma, A. (2022). *Buchanania lanzan* Spreng. (Chironji): An endangered socioeconomic forest tree species of Central India. *The Pharma Innovation Journal, 11*(6), 336–342.

Figures

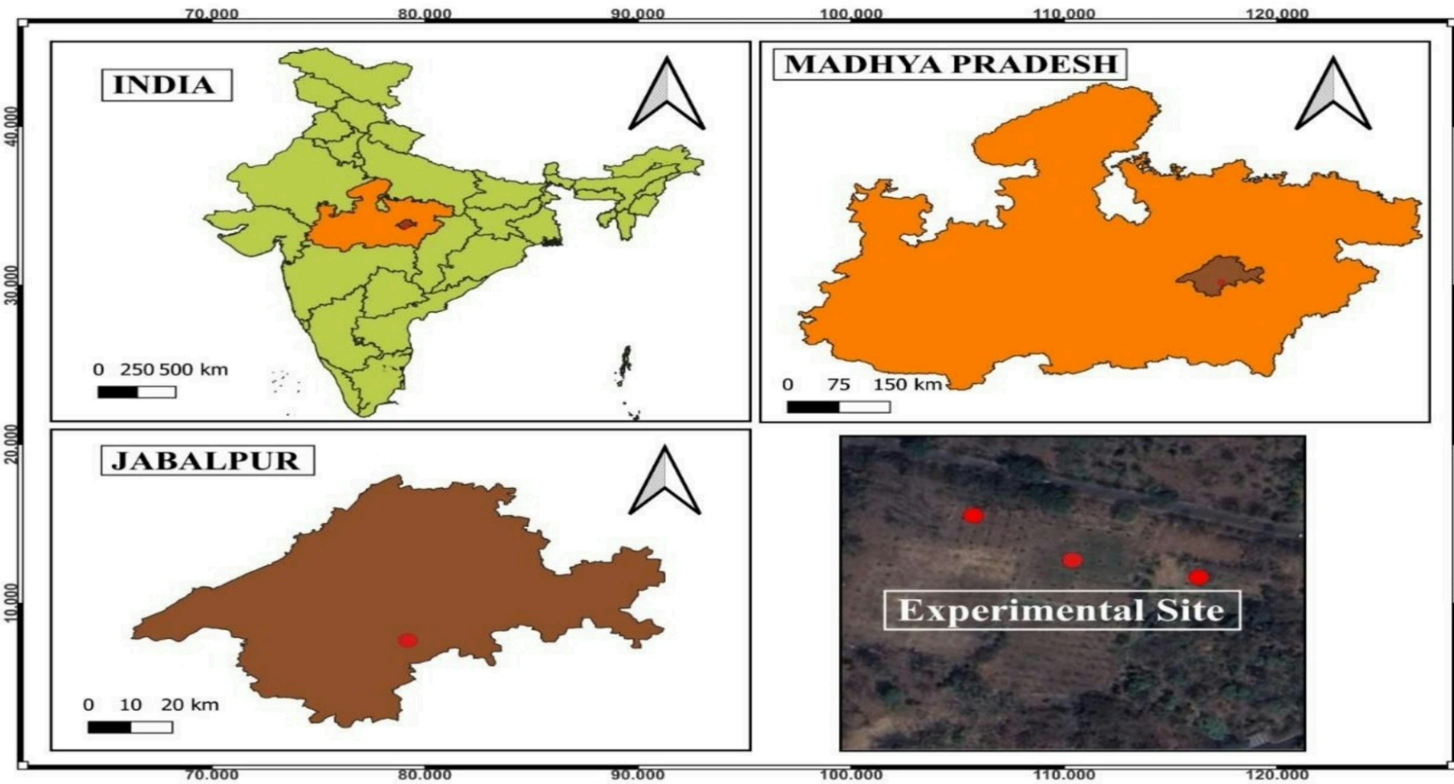

Figure 1

Study area map showing the agroforestry nursery site at TFRI, Jabalpur, M.P, India.

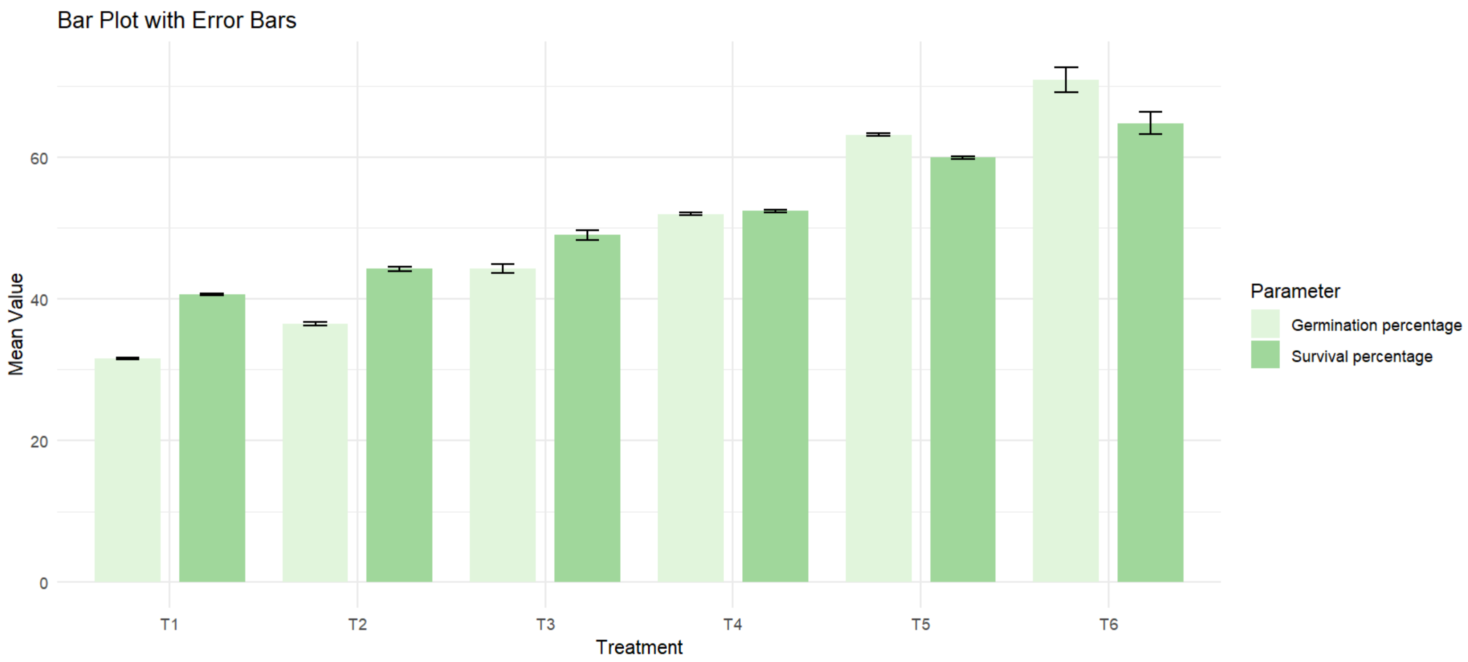

Figure 2

Distribution of germination metrics (Mean Daily Germination, Peak Value and Germination Value) under different treatments.

(*The dot plot visualizes individual germination-related parameters across treatments, showing the variation in each metric type under different seed treatment conditions.*)

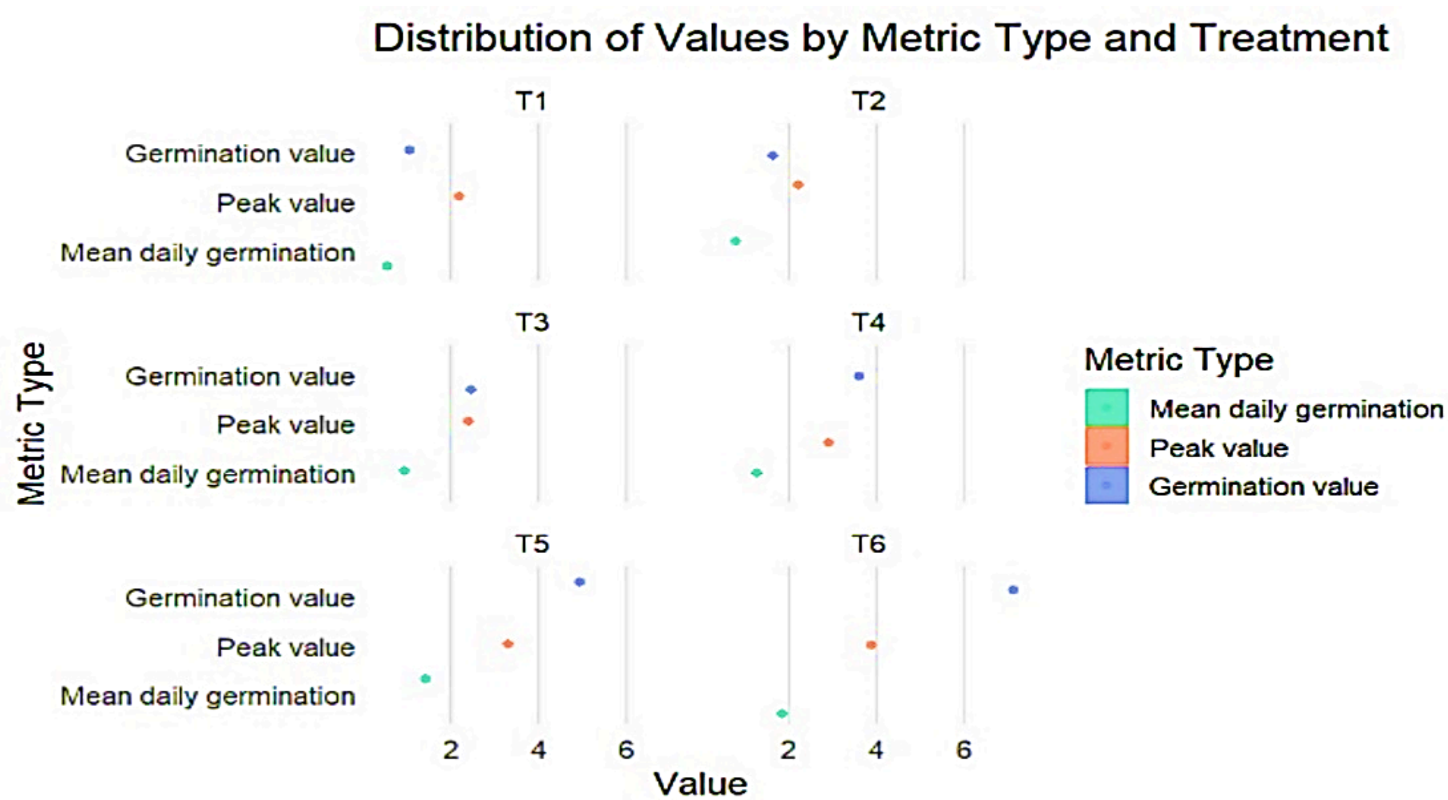

Figure 3

Bar plot showing Germination Percentage and Survival Percentage with error bars across treatments.

(This figure compares the mean values of germination and survival percentages with standard error bars, highlighting the effectiveness of different pre-sowing treatments on germination success and seedling survival of Chironji)

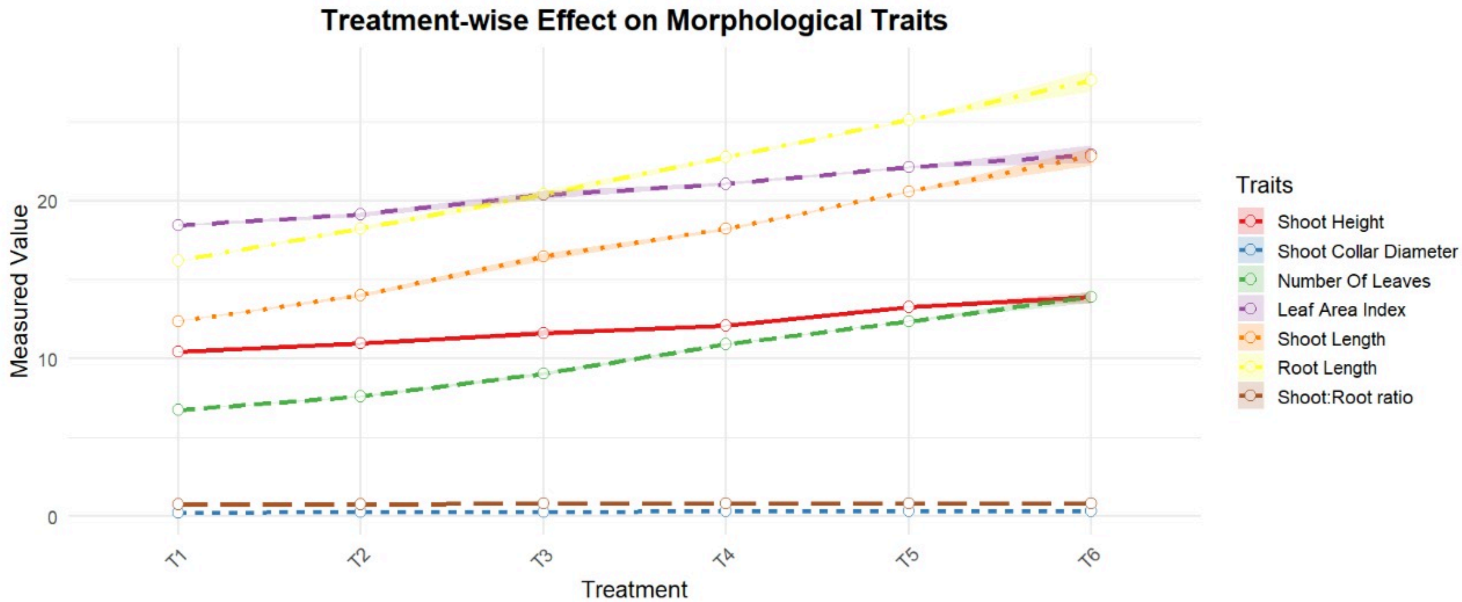

Figure 4

Effect of pre-sowing treatments on morphological traits of chironji seedlings.

(The line plots represent the mean ± standard error of morphological parameters including shoot height, shoot collar diameter, number of leaves, leaf area index, shoot length, root length and shoot: root ratio across six treatment groups (T1–T6). (T6) treatment consistently showed higher values across most traits, indicating its positive influence on seedling vigour.)

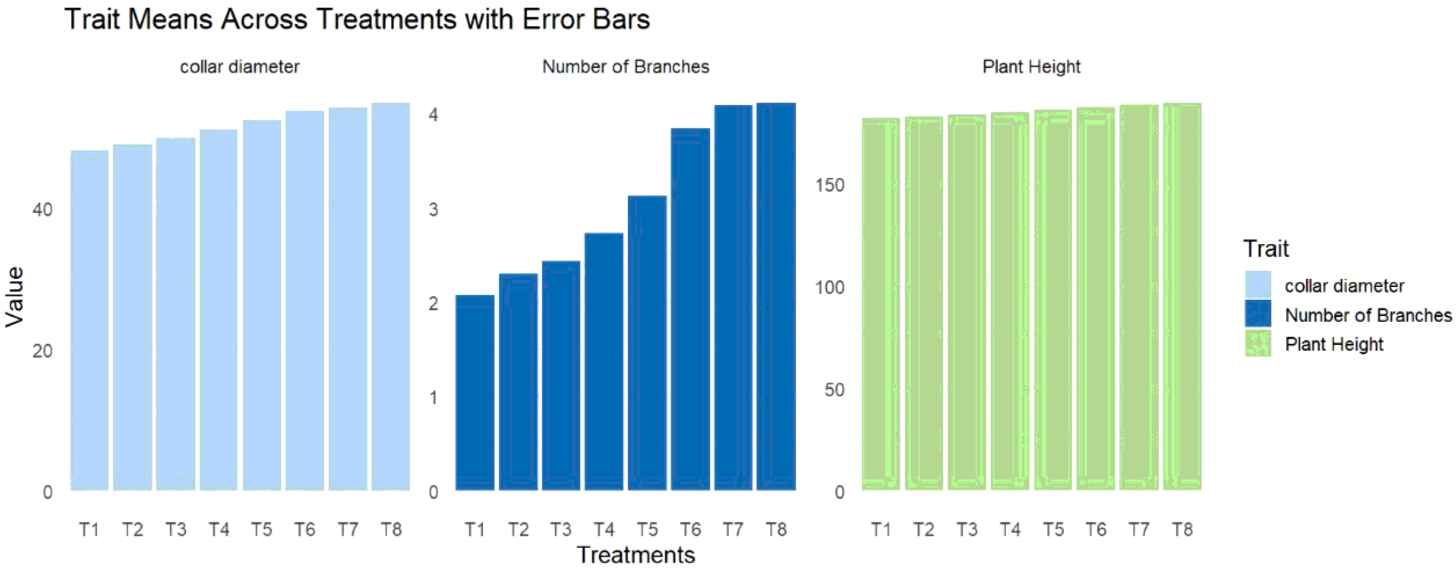

Figure 5

Trait means for collar diameter, number of branches and plant height across treatments

(Bar plots illustrate the mean values of key morphological traits under different agroforestry treatment combinations of Chironji with associated crops. The results show a consistent increasing trend from AF1 to AF8, with T8 showing the highest values for all three traits, indicating a favourable combination of spacing and intercrop.)

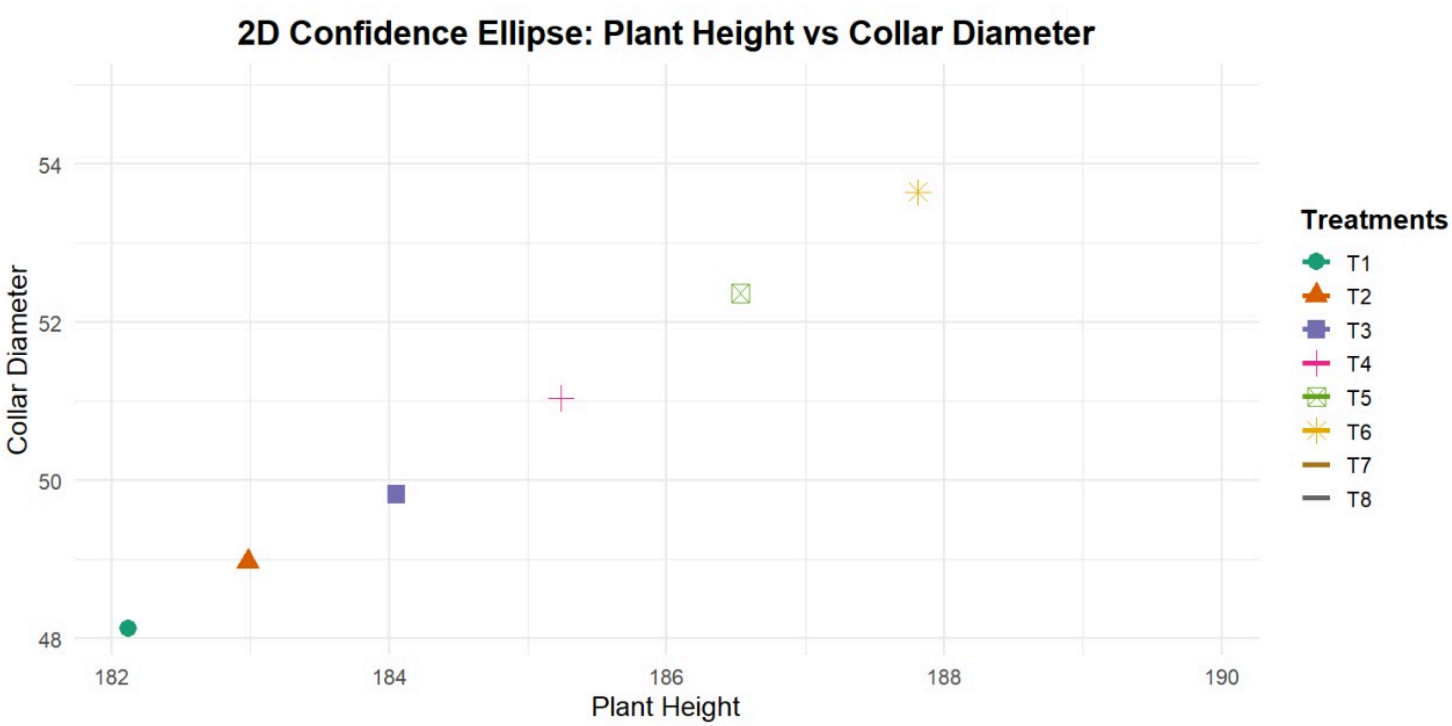

Figure 6

2D confidence ellipse depicting the relationship between plant height and collar diameter across treatments (T_1 –T8).

(Scatter plot with treatment-wise symbols shows the interaction between plant height and collar diameter. Treatments T6, T7 and T8 cluster in the upper right quadrant, suggesting better overall growth performance, while T_1–T_3 appear in the lower range, indicating comparatively less growth.)