International Journal of Ecology and Environmental Sciences 52: e0972, 2026
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2026.0972

© National Institute of Ecology, New Delhi

A Comparative Analysis of Early Seedling Growth in *Terminalia chebula* Retz. under Different Pre-sowing Treatments

SUSMITA SHIL[1*] AND R.K. PRAJAPATI[2]

[1]*Department of Silviculture & Agroforestry, College of Forestry, Kerala Agricultural University, Vellanikkara, 680656, Kerala, India*

[2]*Department of Forestry, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, 492012, India*

E-mail: susmitashilf@gmail.com, drprajapati@yahoo.in

***Author for correspondence**

ABSTRACT

Terminalia chebula, the king of medicines, is highly regarded in Ayurveda. The growing interest in its medicinal properties increased demand for its fruit, particularly with the shift from allopathic to Ayurvedic medicines. Nevertheless, the hindrance posed by its low germination rate, attributed to factors such as a hard endocarp, poor kernel development, and seed dormancy, remains a substantial obstacle, leading to slow and inadequate seedling growth. This issue significantly hampers nursery operations and plantation development. To address these challenges, presowing treatments have proven highly effective in enhancing germination and seedling vigour of pretreated seeds. In this study, a completely randomised design with 11 treatments and 3 replications was employed. Regular observations of various growth parameters were conducted over ninety days. Results revealed that among the diverse treatments, seedlings subjected to mechanical treatment exhibited the highest values for shoot length, number of leaves per seedling, root length, seedling height, shoot and root diameter, root:shoot ratio, shoot and root biomass, total biomass, seedling vigour index, and quality index. The subsequent treatment, in terms of performance, was acid (H_2SO_4). Importantly, all pre-sowing treatments outperformed the control group in seedling growth. Mechanical treatment emerged as a cost-effective and efficient method that requires minimal time and labour to promote high-quality seedling production. These methods hold promise for producing high-quality seedlings in a relatively short timeframe, overcoming the limitations of traditional methods, which are often devoid of pre-sowing treatments and often result in germination failures.

Key words: *Terminalia chebula*, Seed, Germination, Medicinal plant, Dormancy

INTRODUCTION

Plants have played a significant role in healthcare throughout history. Currently, over 10,000 plant species are used for medicinal purposes (Hossain et al. 2005). According to the World Health Organisation (WHO), approximately 80% of the world's population depends on traditional medicine, often utilising plant extracts or their active chemical components. *Terminalia chebula* holds a prominent position among medicinal plants and is widely used in Ayurveda, Siddha, Unani, and homoeopathic systems of medicine in India (Chandil et al. 2020, Bag et al. 2013). This recognition is evident in ancient texts such as the Charaka Samhita and the Sushruta Samhita, which document various medicinal plants. Belonging to the Combretaceae family, Terminalia is a sizable genus primarily comprising deciduous trees and a few climbers, with over 200 species, making it highly diverse in Southeast Asia (Fahmy et al. 2015). *T. chebula,* commonly referred to as black myrobalan, chebulic myrobalan, Harad (Hindi), Haritaki (Sanskrit and Bengali), Harada (Marathi and Gujarati), and Hardo (Gujarati) (Dodke and Pansare 2017, Chandil et al. 2020), is a medium to large-sized tree that originates from tropical and subtropical regions of Asia (Kannan 2009). This tree species is prevalent in deciduous forests throughout India, including regions such as Himachal Pradesh, Tamil Nadu, Kerala, Karnataka, Uttar Pradesh, Andhra Pradesh, and West Bengal, as well as in the neighbouring countries, including Sri Lanka, Pakistan, Bangladesh, and Myanmar (Gowda et al. 2011, Sumbali et al. 2012). Typically reaching heights of 25 to 30 meters, *T. chebula* trees have dark brown bark and hard, bulky wood. The fruit, ranging from 3 to 6 cm in length, matures between November and March, transitioning from green to a yellowish-brown hue upon ripening (Dodke and Pansare 2017). The fruit is a drupe, containing only one oval and hard seed (Hukkeri et al. 2010). Thriving in temperatures between 15 and 47.5!, and with an annual precipitation range of 900 to 4000 mm, *T. chebula* is well-adapted to diverse climatic conditions (Shekhar et al. 2022). *T. chebula* encompasses various phytoconstituents, including tannin, flavonoids, sterols, amino acids, fructose, resin, and fixed oil (Kumar 2006). Notably, it contains 33% hydrolyzable tannins, which are attributed to its pharmacological properties. The primary commercial product derived from this tree is its fruit, commonly referred to as 'myrobalans' (Benjamin et al. 2019).

The fruits of *T. chebula*, when combined with *Emblica officinalis* and *T. belerica*, form the composition known as "Triphala" (Naik et al. 2004). This formulation has proven effective in treating various ailments, including constipation, acidity, and even eye troubles (Ara et al. 1997). The unripe fruit, characterised by its astringent and aperient nature, is utilised in the treatment of dysentery and diarrhoea. On the other hand, ripe fruits exhibit purgative properties and are used in pharmaceuticals such as laxatives, stomachics, and tonics (Krishnan 1984). *T. chebula* is also used to treat piles, dropsy, headaches, dyspepsia, and ascites, and is sometimes used in conjunction with cholesterol-lowering medications (Usha et al. 2007).

Furthermore, the ripe fruit is recognised for enhancing blood circulation, treating issues with the spleen, piles, gums, paralysis, and a sore throat, and strengthening the nervous system (Jose and Jacob 1998). Beyond its medicinal uses, *T. chebula* serves as a fodder source for animals (Kumar and Bhatt 2006) and is rich in nutrients, including vitamin C, protein, amino acids, and minerals (Mahesh et al. 2007). The oil obtained from the seeds is highly esteemed for its use as a hair tonic. Notably, studies indicate that 70% of the methanol extract and phenolic compounds from *T. chebula* fruits exhibit the potential to decrease cancer cell viability, inhibit cell proliferation, and induce cell death in a dose-dependent manner (Saleem et al. 2002, Hossain et al. 2013). Despite its myriad benefits, *T. chebula* faces threats to its population, stemming from factors such as population pressure, poverty, the absence of suitable government policies, and unsustainable utilisation of forest resources. Additionally, the depredation of fruits by rats, squirrels, and rodents contributes to poor natural regeneration (Alam et al. 2021, Singh et al. 2003). In the field, the seeds of *T. chebula* exhibit low germination rates and slow seedling growth, attributed to factors such as a hard endocarp, a thick shell (endocarp), and inadequate kernel formation (Troup 1921). All these dormancy factors impede germination by restricting moisture and preventing gaseous exchange, which results in suboptimal natural regeneration of *T. chebula* in its native habitat (Singh et al. 2003).

The present study addresses these challenges by investigating the effects of different pre-sowing treatments on seed germination and seedling vigour. Recognising the significance of efficient nursery management for successful plantation programs, the study aims to overcome limitations associated with low germination percentages, extended germination times, and irregular seedling growth in *T. chebula* seeds.

MATERIAL AND METHODS

Study site and growing media

The current investigation was conducted under nursery conditions at Udaipur, Tripura, India. The study area is situated between longitudes 91°18' and 91°59'E and latitudes 22°56' and 23°45'N. Udaipur experiences a predominantly mild climate, characterised by humid summers and dry frigid winters, with regular showers occurring between July and October. Throughout the growth season, the experimental site receives approximately 34.44 cm of monthly rainfall, with temperatures averaging 25-32! (Fig. 1). For the experiment, the growing media were prepared by blending soil sourced from the nearby forest with FYM (3:1 ratio) and filling the mixture into polybags.

Experimental design and treatment details

The experimental setup for the study was laid out in a Complete Randomised Design (CRD) and comprised eleven treatments, each with three replications (Table 1). Seeds of *Terminalia chebula* were sourced from natural forests in Chhattisgarh and depulped before any treatment. For the examination of the impact of pre-sowing treatments on *Terminalia chebula* germination, twenty-five

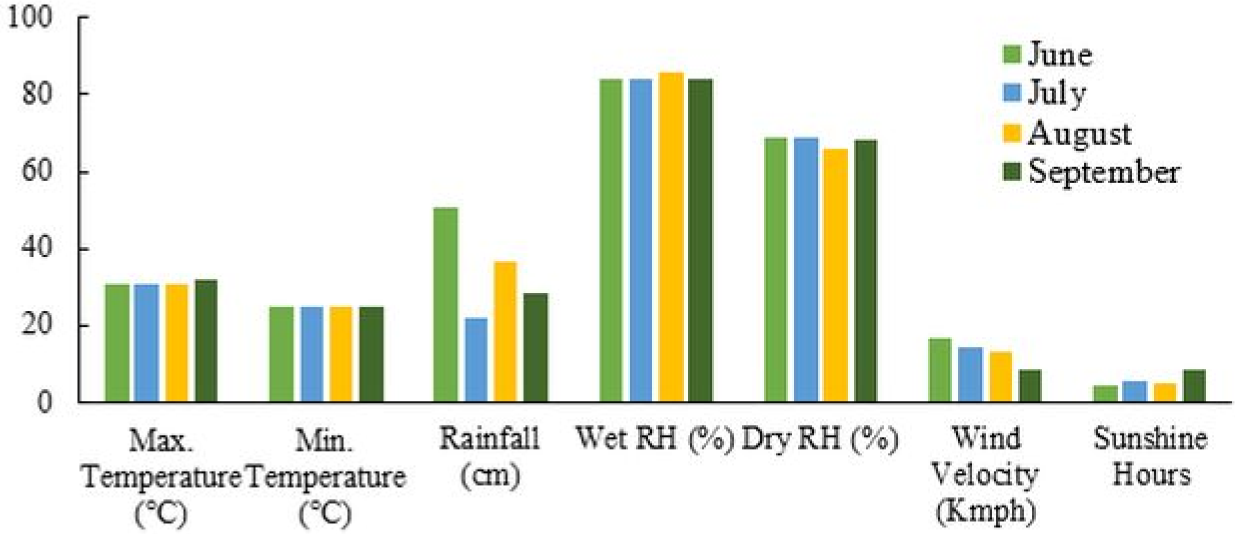

Figure 1. Monthly meteorological data during the conduct of the experiment

Table 1. Details of different pre-sowing treatments

T_1	Control
T_2	Soaked in cold water for 24 hours
T_3	Soaked in cold water for 48 hours
T_4	Soaked in cold water for 72 hours
T_5	Dipped in 50% H_2SO_4 for 20 minutes
T_6	Dipped in 50% H_2SO_4 for 25 minutes
T_7	Dipped in 50% H_2SO_4 for 30 minutes
T_8	Immersed in cow dung slurry for 15 days
T_9	Immersed in cow dung slurry for 30 days
T_{10}	Immersed in cow dung slurry for 45 days
T_{11}	Breaking of seed coat through stone (Mechanical)

seeds were sown under each replication, resulting in a total of seventy-five seeds (25×3) per treatment. Consequently, a total of 825 seeds (75 × 11) were randomly selected for the study, with one seed per polybag. Following the dibbling method, each seed was sown at a depth of 0.5 cm in the growing media. Subsequently, the seedlings were observed at regular intervals for various growth parameters.

Protection and maintenance of seedlings

Following seed sowing, comprehensive protective measures were implemented to safeguard seedlings against intense sunlight, heavy rainfall, avian threats, rodents, and pests. Initially, thorny bushes were used as a protective cover over the polybags to deter birds and rodents. Drenching with insecticide (Chlorpyriphos) and fungicide (Diathene M-45) was done to anticipate insect and fungal attacks. Additionally, temporary sheds were erected on the sides to shield the seedlings from excessive sunlight and raindrops. Optimum moisture was maintained in the growing media by applying water at 2-day intervals for up to 1.5 months, then at 5-day intervals for the remainder of the period, using a sprinkling can. Over the study period, diligent care was taken to ensure optimal seedling growth.

Growth attributes

Various growth parameters, including shoot length (cm), leaf number, and collar diameter (mm), were recorded at 30-day intervals over 90 days. Additionally, destructive sampling was carried out after 90 days for biomass measurements of both roots and shoots (g), measuring root length (cm), seedling height (cm), and root diameter (mm) and therefore computing total biomass (g), root: shoot ratio, seedling vigour index, and quality index. A digital calliper and scale were used to measure parameters, including root and collar diameters and shoot and taproot lengths. For root coiling, measurements were taken using a thread passed along the root, then recorded in centimetres. To determine dry matter content, shoots and roots from five typical seedlings per replication were oven-dried, their dry weight was measured, and the mean dry weight was computed. Total biomass and seedling height were calculated as Total biomass = Shoot dry biomass + Root dry biomass.

The seedling vigour index (SVI) was computed using the formulas outlined by Abdul-Baki and

Anderson (1973). The calculation used the germination percentages for all treatments, obtained from the study by Shil and Prajapati (2021).

SVI = Germination percent × (Shoot length + Root length)

The Quality Index (QI) was determined using the formula established by Dickson et al. (1960).

QI = Tdw (H/Dc + Sdw/Rdw)

where QI is the quality index, Tdw is the total dry weight (g), H is the seedling height (cm), Dc is the collar diameter, Sdw is the shoot dry weight (g), and Rdw is the root dry weight (g).

RESULTS

The shoot length, number of leaves, and collar diameter of *Terminalia chebula* seedlings during three time intervals (30, 60, and 90 DAS) varied significantly across different pre-sowing treatments (Fig. 2). Mechanically treated seedlings recorded a maximum shoot height of 3.78cm at 30 DAS, 13.27 cm at 60 DAS, and 20.97 cm at 90 DAS, while the minimum was observed in the control treatment at 60 DAS (3.74) and 90 DAS (11.20). A similar trend was observed for the maximum number of leaves per seedling at 30 DAS (3.42), 60 DAS (5.72), and 90 DAS (7.86) under mechanical treatment, compared with other treatments, with the control recording the lowest. Collar diameter ranged from 1.10 mm at 30 DAS to 1.98 mm at 90 DAS of mechanically treated seedlings, followed by acid, water, and cow dung slurry treatment. The other peculiar observation was that no germination was observed up to 30 days in the other treatments, except mechanical, cow dung slurry (45 days), and acid (25 minutes), resulting in no records of shoot length, collar diameter, and number of leaves.

The highest biomass production was observed with mechanical treatment (2.32), with a per cent contribution of 57.76% from shoot biomass and 42.24% from root biomass. It was preceded by the acid treatment for 20 min (2.20 g with 58.18 % shoot and 41.82 % root) and 25 min (2.03 g with 57.14 % shoot and 42.86 % root), cow dung slurry for 45 days (1.91 g with 59.16 % shoot and 40.84 % root) and water treatment for 72 hours (1.81 g with 59.12 % shoot and 40.88 % root) and the lowest biomass was produced under the control conditions (0.73 g with 79.45 % shoot and 20.55 % root) (Table 2). The root length and root diameter of *T. chebula* seedlings were measured under different pre-sowing treatments at 90 days after sowing (DAS). The highest root length (15.40 cm) was recorded in mechanical treatment, followed by acid treatment for 20 min (13.60 cm) and 25 min (13.14 cm), cow dung slurry for 45 days (12.92 cm), and water treatment for 72 hours (12.40 cm). Conversely, the control treatment exhibited the lowest root length (5.8 cm). Maximum root diameter was observed in mechanical (5.2 mm), followed by acid treatment for 20 min (4.94 mm) and 25 min (4.4

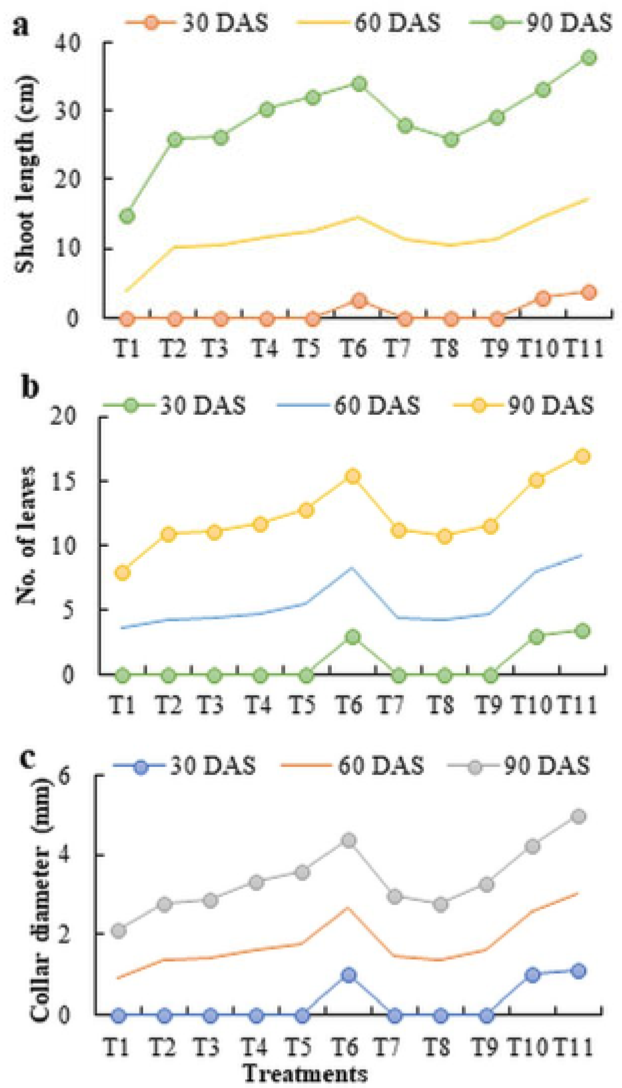

Figure 2. Effects of different pre-sowing treatments on shoot length (a), no. of leaves (b), and collar diameter (c) at 30, 60, and 90 DAS

Table 2. Effect of different pre-sowing treatments on root length, root diameter, shoot biomass, root biomass, and total biomass

Treatments	Root length (cm)	Root diameter (mm)	Shoot biomass (g)	Root biomass (g)	Total biomass = Shoot + Root (g)
T_1	5.80 ± 0.12^{i}	2.80 ± 0.12^{h}	0.58 ± 0.02^{j}	0.15 ± 0.01^{g}	0.73 ± 0.02^{j}
T_2	10.20 ± 0.12^{g}	3.56 ± 0.01^{fg}	0.73 ± 0.01^{h}	0.48 ± 0.02^{f}	1.21 ± 0.01^{i}
T_3	9.76 ± 0.01^{h}	3.80 ± 0.12^{e}	0.81 ± 0.02^{g}	0.56 ± 0.02^{e}	1.37 ± 0.04^{h}
T_4	12.40 ± 0.20^{d}	4.36 ± 0.01^{c}	1.07 ± 0.01^{d}	0.74 ± 0.03^{c}	1.81 ± 0.03^{e}
T_5	13.60 ± 0.12^{b}	4.94 ± 0.01^{b}	1.28 ± 0.02^{b}	0.92 ± 0.02^{b}	2.20 ± 0.02^{b}
T_6	13.14 ± 0.03^{c}	4.40 ± 0.06^{c}	1.16 ± 0.01^{c}	0.87 ± 0.02^{b}	2.03 ± 0.03^{c}
T_7	10.60 ± 0.12^{f}	3.72 ± 0.03^{ef}	0.86 ± 0.02^{f}	0.64 ± 0.02^{d}	1.50 ± 0.04^{g}
T_8	9.88 ± 0.01^{h}	3.40 ± 0.12^{g}	0.68 ± 0.03^{i}	0.52 ± 0.01^{ef}	1.20 ± 0.04^{i}
T_9	11.52 ± 0.01^{e}	3.92 ± 0.01^{de}	0.98 ± 0.01^{e}	0.68 ± 0.03^{d}	1.66 ± 0.03^{f}
T_{10}	12.92 ± 0.01^{c}	4.12 ± 0.01^{d}	1.13 ± 0.02^{c}	0.78 ± 0.01^{c}	1.91 ± 0.03^{d}
T_{11}	15.40 ± 0.12^{a}	5.20 ± 0.12^{a}	1.34 ± 0.03^{a}	0.98 ± 0.01^{a}	2.32 ± 0.02^{a}
P value	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

mm), water treatment for 72 hours (4.36 mm), and cow dung slurry for 45 days (4.12 mm). In contrast, the lowest root diameter (2.8 mm) was noted under the control treatment (Table 2). The highest root-to-shoot ratio (0.74) was observed in mechanical treatment, followed by cow dung slurry treatment for 45 days (0.69), acid treatment for 20 min (0.68), and 25 min (0.66) and water treatment for 72 hours (0.66). In contrast, the lowest root-to-shoot ratio (0.52) was recorded under the control treatment (Table 3).

The highest seedling vigour index of *T. chebula* was observed in mechanical treatment (2575.63), followed by acid treatment for 20 min (1295.87). In contrast, the lowest seedling vigour index (158.93) was observed under the control treatment. Significant differences in seedling height were also observed across treatments, with the highest seedling height recorded in the mechanical treatment (36.37 cm), followed by the acid treatments at 20 min (33.43 cm) and 25 min (32.94 cm). In contrast, the lowest height was observed in the control treatment (17 cm). The maximum quality index was observed in mechanical treatment (45.78), followed by acid treatment for 20

Table 3. Effect of different pre-sowing treatments on root: shoot ratio, seedling height, quality index, and seedling vigor index

Treatments	Root: shoot ratio	Seedling height	Quality index	Seedling vigor index
T_1	0.52 ± 0.01^{e}	17 ± 0.06^{g}	13.35 ± 1.17^{h}	158.93 ± 60.53^{d}
T_2	0.65 ± 0.02^{cd}	25.93 ± 0.54^{f}	24.32 ± 0.86^{g}	591.01 ± 135.39^{cd}
T_3	0.61 ± 0.01^{d}	25.70 ± 0.22^{f}	26.12 ± 0.92^{fg}	720.24 ± 104.93^{bcd}
T_4	0.66 ± 0.02^{bc}	31.12 ± 0.47^{c}	36.13 ± 0.14^{d}	950.77 ± 137.98^{bc}
T_5	0.68 ± 0.00^{b}	33.43 ± 0.23^{b}	43.52 ± 1.14^{ab}	1295.87 ± 244.80^{b}
T_6	0.66 ± 0.00^{bc}	32.94 ± 0.20^{b}	41.59 ± 0.50^{bc}	1185.63 ± 152.40^{bc}
T_7	0.64 ± 0.01^{cd}	27.07 ± 0.24^{e}	28.73 ± 0.62^{f}	934.13 ± 226.53^{bc}
T_8	0.63 ± 0.01^{cd}	25.48 ± 0.31^{f}	23.46 ± 0.89^{g}	608.80 ± 111.14^{cd}
T_9	0.65 ± 0.00^{cd}	29.23 ± 0.13^{d}	31.87 ± 1.94^{e}	858.53 ± 143.52^{bc}
T_{10}	0.69 ± 0.01^{b}	31.71 ± 0.21^{c}	39.72 ± 0.95^{c}	801.92 ± 149.59^{bc}
T_{11}	0.74 ± 0.01^{a}	36.37 ± 0.53^{a}	45.78 ± 0.32^{a}	2575.63 ± 371.74^{a}
P Value	< 0.05	< 0.05	< 0.05	< 0.05

min (43.52) and 25 min (41.59), cow dung slurry treatment for 45 days (39.72), and water treatment for 72 hours (36.13). In contrast, the minimum (13.35) was recorded in the control (Table 3).

The findings from the current study suggest that as the duration of sulfuric acid treatment increases, the seedling growth rate tends to decrease. The optimal acid treatment time is 20 minutes, as any further increase in treatment duration results in a notable reduction in seedling growth. In contrast, for water and cow dung slurry treatments, the opposite trend was observed: longer soaking under these treatments positively influenced various growth-related characteristics.

DISCUSSION

In general, many forest tree seeds display some form of dormancy. According to international seed certification standards (Anonymous 1985), 70% of the 178 species necessitate dormancy-breaking treatments. Seeds of numerous trees readily germinate under favourable conditions of moisture, substrate, light, and temperature. Dormancy in forest tree seeds can manifest as either exogenous (related to seed coat dormancy), endogenous (related to embryo dormancy), or a combination of both. Exogenous dormancy, specifically associated with seed coat dormancy, is notably prevalent in tropical tree seeds (Ramprasad 1999). Various investigations have shown that chemicals such as inorganic ions, organic acids, and growth regulators can eliminate dormancy, stimulate germination, and dissolve inhibitors in the seed coat, leaching them out (Shearer 1961). In the current investigation, different pre-sowing treatments significantly outperformed the control treatment across various seedling growth attributes. Mechanical treatment (T11) showed the highest values across all growth-related characteristics. Following seed coat-breaking treatment, acid treatment yielded promising results, ranking second for all growth-related attributes. Other treatments, such as water soaking and cow dung slurry treatment, also demonstrated improved results in various early growth parameters of *T. chebula* compared to the control. Shil and Prajapati (2021) observed that mechanical treatment, involving breaking the seed coat with stones, resulted in the earliest germination in *T. chebula*. The notable seedling growth observed under mechanical treatment in our study could be attributed to early germination, which allowed the resulting seedlings to grow further. In contrast, seeds under other treatments remained dormant.

Singh et al. (2021) reported that mechanical treatment resulted in the highest number of leaves per seedling (4.22) in *T. chebula*, while shoot length, root length, root-shoot ratio, and total dry biomass per seedling were not significantly affected by pre-sowing treatments. Likoswe et al. (2008) found that nicking and soaking in hot water for 12 hours improved germination and growth in *T. sericea.* H_2SO_4 (sulfuric acid) has commonly proven to be an effective scarifying agent for breaking physical dormancy (Bhatt et al. 2000). This effectiveness is attributed to the softening of the seed coat, facilitating water absorption and gaseous exchange, leading to the quick and early emergence of radicles (Hartmann et al. 1989). Our study found that H_2SO_4 treatment was the second most effective, which is inconsistent with other researchers' findings. The superior performance of H_2SO_4 treatment in these studies is attributed to its greater softening effect on the seed coat than cold water or cow dung slurry. *T. chebula* records the maximum shoot-to-root ratio (2.80) with a 50% concentration of H_2SO_4 for 5 minutes Shekhar et al. 2022). Immersing seeds in concentrated H_2SO_4 for a duration of 4 minutes, after which they are washed and soaked in cold water for 24 hours, led to the highest values in various growth parameters in *T. chebula,* including plant height, collar diameter, root diameter, number of leaves, shoot dry weight, root length, and vigour index. However, the root-to-shoot ratio was not significantly affected by pre-sowing treatments (Kamble et al. 2015). In our current study, we observed that among water treatments over different periods, 72 hours yielded the highest values for growth parameters. This finding aligns with similar trends reported by several researchers, such as Sumbali et al. (2012), Kamble et al. (2015), and Shekhar et al. (2022). However, Hossain et al. (2013) observed the opposite trend, and Alam et al. (2021) found that 96 hours of water treatment resulted in lower values than 48 hours of treatment. Our results suggest that 72 hours is the optimal duration for achieving the best seedling growth in *T. chebula*. Prolonged soaking beyond 72 hours may hurt seedling growth. Hossain et al. (2005) observed that shoot length, root length, number of leaves, vigour index, and biomass were maximised when the fruit was de-pulped and soaked in cold water for 48 hours, whereas the lowest values were observed in the control treatment. They also noted a positive correlation between increased water-soaking time and *T. chebula* seedling growth, consistent with our current investigation. Furthermore, Hossain et al. (2013) found that the overall growth of *T. chebula* seedlings derived from depulped seeds was notably higher compared to those originating from intact seeds. They observed varied optimal soaking times for different growth parameters, with the highest shoot length and seedling height observed in depulped seeds soaked in cold water for 72 and 48 hours, respectively. The maximum number of leaves, collar diameter, and root dry weight were found in the treatment of depulped seeds soaked in cold water for 24 hours, while mean root length and vigour index were significantly higher in depulped seeds soaked for 48 hours. In our study, cow dung slurry treatment emerged as a promising method, ranking second after mechanical and acid treatments. The enhanced seedling growth observed in the cow dung slurry treatment can be attributed to the presence of growth-promoting substances, such as auxins and nutrients (Shinde and Malshe 2015). Numerous researchers have noted significant effects of cow dung on seedling growth. For instance, Alam et al. (2021) observed that the treatment of cow dung slurry for six days resulted in the maximum shoot height (24.75 cm), number of leaves (51.38), leaf dry weight (2.04 g), shoot dry weight (3.37 g), root dry weight (1.13 g), root length (28.00 cm), and vigor index (4496.94) in *T. chebula*, while the minimum values were observed in the control. According to Kumar (2016), the maximum dry weight of the root and shoot of *Terminalia bellirica* was recorded when seeds were immersed in cow dung slurry for 72 hours. Sumbali et al. (2012) found that shoot length, root length, total length, collar diameter, and vigour index of *T. chebula* seedlings developed under different treatments were highest in the cow dung slurry treatment of depulped seeds for 24 hours, followed by alternately drying for 8 hours and then soaking for 24 hours.

A comparison of various pre-treatment methods for *T. chebula* across studies reveals diverse findings. While many researchers favour water soaking (Hossain et al. 2005, 2013), H_2SO_4 (Shekhar et al. 2022, Kamble et al. 2015), and cow dung (Alam et al. 2021, Sumbali et al. 2012) treatments as the most effective, our investigation identified mechanical treatment as the best method. This discrepancy in results could be attributed to researchers who obtained the best results with treatments other than mechanical ones and did not include mechanical treatment in their studies. However, studies such as those by Saleem et al. (2014) and Singh et al. (2021) reported results similar to ours, as they incorporated mechanical treatment alongside other treatments. This suggests that applying mechanical treatment may influence the study's outcome, and the variation in results could be linked to its inclusion or exclusion in the experimental design. Therefore, it's reasonable to assume that if other researchers had included mechanical treatment in their studies, their results might have differed and aligned more closely with our findings.

CONCLUSIONS

The high seed germination and robust seedling growth observed in mechanically treated seeds suggest that this method is optimal for preparing *T. chebula* seeds before sowing. Seed coat breaking is crucial for overcoming the physical dormancy of hard-coated seeds, which otherwise hinder water uptake and gaseous exchange. The cracks formed in the seed during mechanical treatment facilitate water entry and gas exchange, enabling enzymatic hydrolysis and the transformation of the embryo into a seedling. The rapid growth of seedlings from mechanically treated seeds can be attributed to their greater water-absorption efficiency and faster photosynthesis compared to other treatments. While seed coat breaking has proven highly effective for many species, it requires careful handling to avoid damaging the embryo. Nevertheless, the traditional method of seed coat breaking is labour-intensive and slow, making it applicable only to small seed samples. To address this limitation, seed scarifying drums with sandpaper lining are needed, allowing the physical scarification of large quantities of seeds at once rather than breaking individual seeds. This innovation could significantly improve the efficiency and scalability of the seed scarification process. However, it's acknowledged that using sulfuric acid and seed-coat-breaking techniques can be somewhat risky, time-consuming, and troublesome. In contrast, water and cow dung slurry treatments were identified as simpler and more cost-effective alternatives. Therefore, nursery practitioners and farmers have viable options beyond mechanical and acid treatments, including water and cow dung slurry treatments for seedling development. The valuable insights from the current study will enable and empower nursery practitioners to select and implement treatments that efficiently produce high-quality seedlings.

Authors' contributions: Both the authors contributed equally.

Conflict of interest: Authors declare no conflict of interest.

REFERENCES

Abdul Baki, A.A. and Anderson, J.D. 1973. Vigor determination in soybean seed by multiple criteria. Crop Science, 13(6), 630-633. https://doi.org/10.2135/cropsci1973.0011183X001300060013x

Alam, M.A., Rahman, M.H., Rahim, M.A., Hossain, M.M., Saifullah, M. and Jewel, K.N.A., 2021. Enhancing seed germination and seedling growth of chebulic myrobalan (*Terminalia chebula* Retz.) by appropriate soaking and sowing time after collection of fruits. Bangladesh Journal of Agriculture, 44-46, 45-54. https://doi.org/10.3329/bjagri.v46i1-6.59973

Anonymous. 1985. International rules for seed testing – Annexes 1985. Seed Science and Technology, 13, 356-513.

Ara, R., Merry, S.R. and Siddiqi, N.A. 1997. Cultivation and Uses of Twelve Medicinal Plants of Bangladesh. Minor Forest Products Series, Bangladesh Forest Research Institute, Chittagong, Bulletin, 7, 27-31.

Bag, A., Bhattacharyya, S.K. and Chattopadhyay, R.R. 2013. The development of *Terminalia chebula* Retz. (Combretaceae) in clinical research. Asia Pacific Journal of Tropical Biomedicine, 3(3), 244-252. https://doi.org/10.1016/S2221-1691(13)60059-3

Benjamin, A., Dilip, S., Ranibala, G. and Chanu, N.B. 2019. Effect of seed size, pre-sowing treatments and potting mixture on seedlings growth character and biomass production under nursery conditions of *Terminalia chebula* Retz. International Journal of Chemical Science, 7(4), 1502-1507. https://www.chemijournal.com/archives/2019/vol7issue4/PartAA/7-4-211-271.pdf

Bhatt, I.D., Rawal, R.S. and Dhar, U. 2000. Improvement in seed germination of *Myrica esculenta* Buch.-Ham. ex D. Don-a high value tree species of Kumaun Himalaya, India. Seed Science and Technology, 28(3), 597-605.

Chandil, S., Pansare, T.A. and Bamoriya, H., 2020. Medicinal importance of traditional herbal plant Haritaki (*Terminalia Chebula*): An overview. World Journal of Pharmaceutical Research, 9(10), 477-513. https://ijrpr.com/uploads/V5ISSUE12/IJRPR36461.pdf

Dickson, A., Leaf, A.L. and Hosner, J.F. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. The Forest Chronicles, 36(1), 10-13. https://doi.org/10.5558/tfc36010-1

Dodke, P.C. and Pansare, T.A. 2017. Ayurvedic and modern aspect of *Terminalia chebula* Retz. Haritaki an overview. International Journal of Ayurvedic Herbal Medicine, 7(2), 2508-2517. https://doi.org/10.47191/ijahm/v7i2.4

Fahmy, N.M., Al-Sayed, E. and Singab, A.N. 2015. Genus *Terminalia*: A phytochemical and biological review. Medicinal and Aromatic Plants, 4(5), 1-22. http://dx.doi.org/10.4172/2167-0412.1000218

Hartmann, H.T., Kester, D.E. and Davies, E.T. 1989. Plant Propagation: Principals and Practices, Fifth edition. Prentice Hall, USA.

Hossain, M.A., Arefin, M.K., Khan, B. and Rahman, M.A. 2005. Effects of seed treatments on germination and seedling growth attributes of horitaki (*Terminalia chebula* Retz.) in the nursery. Research Journal of Agriculture and Biological Sciences, 1(2), 135-141. https://www.aensiweb.net/AENSIWEB/rjabs/rjabs/135-141.pdf

Hossain, M.A., Uddin, M.S., Rahman, M. and Shukor, N.A.A. 2013. Enhancing seed germination and seedling growth attributes of a medicinal tree species *Terminalia chebula* through depulping of fruits and soaking the seeds in water. Journal of Food Agriculture Environment, 11(3&4), 2573-2578. https://doi.org/10.1234/4.2013.5091

Hukkeri, V.I., Joshi, M.P., Deshpande, M.N., Nagare, S.K. and Korgaonkar, A.M. 2010. Phyto-pharmacological review of *Terminalia chebula* Retz. Natural Products Indian Journal, 6, 24-28. https://www.tsijournals.com/articles/phytopharmacological-review-of-terminalia-chebula-retz.pdf

Jose, P.A. and Jacob, T. 1998. An account of vegetative propagation in *Terminalia chebula*. Indian Forester, 124(5), 357- 358. https://doi.org/10.36808/if/1998/v124i5/5219

Kamble, S.R., Bhingarde, M.T. and Nagawade, D.R. 2015. Influence of pre-sowing treatments on hirda seed (*Terminalia chebula* Retz.). BIOINFOLET-A Quarterly Journal of Life Sciences, 12(1b), 184-187. https://indianjournals.com/article/bil-12-1b-018

Kannan, P., Ramadevi, S.R. and Hopper, W. 2009. Antibacterial activity of *Terminalia chebula* fruit extract. African Journal of Microbiology Research, 3(4), 180-184. https://doi.org/10.5897/AJMR.9000052

Krishnan, B.M. and Kulasekaran, M. 1984. Studies on seed germination in wild ber (*Ziziphus rotundifolia*). South Indian Horticulture, 32(3), 153-154.

Kumar, K.J. 2006. Effect of geographical variation on contents of tannic acid, Gallic acid, chebulinic acid and ethyl gallate in *Terminalia chebula*. Natural Products, 2(3-4), 170-175. https://www.tsijournals.com/articles/effect-of-geographical-variation-on-contents-of-tannic-acid-gallic-acid-chebulinic-acid-and-ethyl-gallate-in-terminalia-.pdf

Kumar, M. and Bhatt, V.P. 2006. Plant biodiversity and conservation of forests in foot hills of Garhwal Himalaya. Lyonia, 11(2), 43-59. https://www.lyonia.org/articles/rbussmann/article_490/pdf/article.pdf

Kumar, V. 2016. Effect of Pre-sowing Seed Treatment on Germination and Seedling Growth of *Terminalia bellirica* (Gaertn.) Roxb. Indian Journal of Ecology, 43(1), 233-238. https://www.indianjecol.org/issues/6/download-combined

Likoswe, M.G., Njoloma, J.P., Mwase, W.F. and Chilima, C.Z. 2008. Effect of seed collection times and pretreatment methods on germination of *Terminalia sericea* Burch. ex DC. African Jorunal of Biotechnology, 7(16), 2840-2846. https://doi.org/10.5897/AJB08.373

Mahesh, R., Ramesh, T., Nagulendran, K.R., Velavan, S. and Begum, V.H. 2007. Effect of *Terminalia chebula* on monoamine oxidase and antioxidant enzyme activities in aged rat brain. Pharmacognosy Magazine, 3(12), 240. https://phcog.com/article/assets/v3/i12/PhcogMag-3-12-240.pdf

Naik, G.H., Priyadarsini, K.I., Naik, D.B., Gangabhagirathi, R. and Mohan, H. 2004. Studies on the aqueous extract of *Terminalia chebula* as a potent antioxidant and a probable radioprotector. Phytomedicine, 11(6), 530-538. https://doi.org/10.1016/j.phymed.2003.08.001

Ramprasad. 1999. Management of tropical forestry seeds for wastelands afforestation. In: Edwards, D.G.W. and Naithani, S.C. (Eds.), Seed and Nursery Technology of Forest Trees. New Age International (P) Ltd, New Delhi, India.

Saleem, A., Husheem, M., Harkonen, P. and Pihlaja, K. 2002. Inhibition of cancer cell growth by crude extract and the phenolics of *Terminalia chebula* retz. fruit. Journal of Ethnopharmacology, 81(3), 327-336. https://doi.org/10.1016/S0378-8741(02)00099-5

Shearer, R.C. 1961. A method of overcoming seed dormancy in sub-alpine larch. Journal of Forestry, 59, 513-514.

Shekhar, P.R., Rajendra, M.P., Chiranjeeva, M., Reddy, R.S., Bodiga, S., Ooha, M., Kale, I. and Bhargavi, C.H. 2022. Effect of pre-sowing treatments and growth hormones on germination and propagation of *Terminalia chebula* Retz. The Pharma Innovation Journal, 11(10), 1289-1293. https://www.thepharmajournal.com/archives/2022/vol11issue10/PartO/11-9-73-885.pdf

Shil, S. and Prajapati, R.K. 2021. Effect of pre-sowing treatments on seed germination of Harad (*Terminalia chebula* Retz.) in the nursery condition. The Pharma Innovation Journal, 10(10), 2344-2348. https://www.thepharmajournal.com/archives/2021/vol10issue10/PartAG/10-10-395-196.pdf

Shinde, V.V. and Malshe, K.V. 2015. Effect of cattle urine and cow dung slurry as seed treatment on germination and growth of Khirni (*Manilkara hexandra* L.). Journal of Eco-friendly Agriculture, 10(2), 128-30.

Singh, D.R.R., Dhir, K.K., Vij, S.P., Nayyar, H. and Singh, K. 2003. Study of genetic improvement technique of *Terminalia chebula* Retz. - An important multipurpose tree species of India. Indian Forester, 129(2), 154-168. https://doi.org/10.36808/if/2003/v129i2/2246

Singh, S., Sharma, K. and Bhatia, A.K. 2021. Effect of pre-sowing seed treatment, type of seed beds and time of sowing on *Terminalia chebula* in its natural forest. International Journal of Farm Science, 11(3), 76-82. http://dx.doi.org/10.5958/2250-0499.2021.00040.9

Sumbali, S., Gurav, M. and Santhosh, H. 2012. Effects of pre-sowing treatments on germination and seedling growth of *Terminalia chebula* Retz. International Journal of Life Sciences, 1(3), 68-73. https://www.crdeepjournal.org/wp-content/uploads/2012/08/Vol.-1-3-6-IJLS.doc.pdf

Usha, C., Satyanarayanan, R. and Velmurugan, A. 2007. Use of an aqueous extract of *Terminalia chebula* as an anticaries agent: A clinical study. Indian Journal of Dental Research, 18(4), 152-56. https://doi.org/10.4103/0970-9290.35823

Received: 27th March 2026
Accepted: 3rd July 2026