



Germination and Growth Response of *Prosopis Glandulosa* as Affected by Moisture and Thickness of Seed Palletization

Muhammad Haseeb Saleem¹, Muhammad Asif ^{*1}, Muhammad Haroon U Rashid¹, Irfan Ahmad¹, Umar Aftab Abbasi¹, Akhtar Munir¹, Muhammad Atiq² and Muhammad Hassan Khalid¹ and Abdul Jabbar³

1. Department of Forestry and Range Management, University of Agriculture, Faisalabad, Pakistan
2. Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan
3. Department of Agronomy, University of Agriculture, Faisalabad, Pakistan

*Corresponding author e-mail: asif.chohan@yahoo.com

SUMMARY

Converting arid lands into woodlots with seeds can be tough due to several obstacles, including insufficient precipitation, long-term water shortages, seed scavenging, and nutrient-deficient soil. Several plant species, including trees, shrubs, and herbs, face germination problems and growth-related issues due to the aforementioned limiting factors. Seed pellets, a combination of soil, seeds, clay, and water, protect seeds from severe ecological factors like strong winds, animal damage, and water scarcity while also providing a minor boost of nutrients during the early growth stage. This coating technique has shown promising results regarding seed germination and overall seedling vigor. *Prosopis glandulosa*, also known as Khejri, is a unique tree species that is well-known for its extraordinary capacity to adapt to arid and semi-arid climatic conditions. The hardy legume *P. glandulosa* (which is native to arid regions in Pakistan) is an essential species for ecological restoration and sustainable land management. Its establishment, however, may be more difficult under challenging environmental conditions. This study has explored the germination potential and growth response as affected by pellet thickness and different moisture levels. The pot trials were conducted at the research area of the Forestry Department, using a completely randomized design (with five treatments, including a control). A total of five treatments (along with a control) with three irrigation levels were evaluated. Among all combinations, treatment (T₃) with a 2 cm pellet size and 10 ml irrigation produced the highest germination rate. This study suggests that adopting this combination can be an effective strategy for farmers to enhance the germination rate and ensure optimal seedling establishment and overall growth response.

Keyword: Seed Ball, Germination, Arid regions, Restoration, Stem diameter, Moisture Stress, Plant growth, Biomass distribution

INTRODUCTION

Arid lands are ecosystems characterized by extremely low precipitation (typically <250 mm annually), high evapotranspiration, and scarce vegetation cover, which collectively result in water scarcity and fragile soil structures. Such areas originate primarily due to persistent climatic conditions such as high temperatures, low rainfall, and strong solar radiation, and are augmented by human-induced pressures like overgrazing, deforestation, and poor farming practices (Cherlet et al., 2018). Arid lands are increasingly significant in global climate change discussions as they are highly vulnerable to desertification and land degradation, which directly threaten the

food security and livelihoods of millions of people (IPCC, 2019). Converting arid lands into woodlots with seeds can be tough due to several obstacles, including insufficient precipitation, long-term water shortages, seed scavenging, and nutrient-deficient soil. Seed pellets (also called seed balls and seed bombs) have emerged as an encouraging solution to overcome these hurdles and facilitate successful tree planting in hot areas (Madsen et al., 2016).

Seed pellets, made from soil, clay, water, and seeds, are a seed enhancement technology designed to protect seeds from predation, wind, water erosion, and moisture stress while supplying initial nutrients to improve seedling establishment. Direct seeding methods often face challenges such as poor root penetration, animal consumption, and low survival rates, making pelletization a cost-effective alternative (Farlee, 2013). By forming protective agglomerates, pellets improve germination by disintegrating after adequate rainfall and minimizing seed loss to predators (Shackelford et al., 2021). Advances in production techniques, such as hand rolling and rotary coating, have reduced mechanical injury to seeds, while new formulations allow pellets to adapt to restoration goals across arid and semi-arid ecosystems. Seed balls can be spherical, conical, cube-shaped, or disc-shaped, depending on species and site requirements, and have proven effective in ecological reforestation in various projects (Ortolani, 2015; Stock et al., 2020). Despite their potential, further quantitative research is required to link laboratory, greenhouse, and field studies for optimizing pellet size, shape, and formulation (Wise et al., 2012; Berto et al., 2024).

Seed ball technology enhances water use efficiency and helps prevent seed predation by insects and birds (Shackleton et al., 2014). However, direct seeding has its drawbacks, including the risk of seeds being consumed by insects and birds (Jawahar and Umarani, 2019) and the challenges posed by harsh environmental conditions that can hinder seed germination and survival, particularly on steep and inaccessible slopes (Schmidt, 2008). While seed balls can be easily produced by hand in small quantities and are popular among schools and community groups, large-scale manufacturing typically requires mechanization, which often involves compression, rolling, or extrusion (Jawahar and Umarani, 2019). To help local communities reduce manufacturing costs, some researchers recommend incorporating sieved local soil into the seed ball mixture along with other components (Nwankwo et al., 2018).

As compared to single-seed coating methods, seed ball technology has the benefit of managing several seeds into a single pellet, and this might serve as a modern seed treatment method at a local level (Afzal et al., 2020). The use of seed bombs and their different forms, such as seed shells, coins, and pellets, can help in environmental restoration (Bado et al., 2018). Researchers have started to explore the impact of various seed-ball ingredients, soil types, seedling establishment and their ultimate growth response under different climatic conditions (Madsen et al., 2012). To ensure effective seed pellet use in degraded arid land restoration, it is essential to develop and clarify basic principles that improve seed-ball value (Davies, 2018).

Arid lands hinder vegetation establishment due to scarce rainfall, nutrient-deficient soils, and seed predation, thus making direct seeding primarily ineffective. Seed pellet technology has emerged as a promising solution by improving germination, reducing predation, and enhancing water efficiency in the restoration of degraded arid regions. However, limited evidence exists on how pellet thickness and

irrigation levels interact to influence germination and seedling growth of xerophytic flora (Pedrini et al., 2020; Shackelford et al., 2021; Berto et al., 2024).

Prosopis glandulosa, commonly known as Khejri, is a hardy evergreen legume well-adapted to arid and semi-arid regions, particularly in Pakistan. It is a small to medium-sized thorny tree with bluish-green foliage and conical thorns, widely valued for its ecological and economic importance. Beyond its role in ecological restoration and sustainable land management, it provides multiple resources such as firewood, charcoal, fodder, construction materials, tools, shade, and traditional medicines (Pasiiecznik et al., 2001; Saucedo et al., 2014). Its wood is prized for premium charcoal, while in India, it supplies fuel to more than 70% of the inhabitants of the arid regions (Pasiiecznik et al., 2001). Medicinally, the bark and extracts show antibacterial, antioxidant, anti-inflammatory, analgesic, and wound-healing properties (Nagori and Solanki, 2011; Kumar et al., 2011), and despite its significant worth, indefensible harvesting threatens its survival in some areas (Shukla et al., 2019).

Keeping in view the significance of the species, the current study was designed to explore the germination and growth response of *P. glandulosa* under varying pellet thickness and moisture levels, aiming to identify optimal seed ball size and irrigation practices for maximizing germination and seedling vigor.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the research area of the Department of Forestry and Range Management, University of Agriculture, Faisalabad, Pakistan. The region lies in the subtropical and semi-arid plains of Punjab, located at 605 feet above sea level between 74° East and 31° North.

Preparation of Seed Pellets

Sandy soil was collected from the nursery site, air-dried, and sieved through a 2-mm mesh to remove coarse particles (pot filling). Seed pellets were prepared by mixing three parts of water, one part of potting soil, and five parts of clay, along with Sodium alginate (1.5%) as a binder. After thoroughly mixing the medium, 230-250 ml of water per kilogram of medium was added to achieve proper consistency. Two *Prosopis glandulosa* seeds were embedded in each pellet, and hand-crafted seed-balls of four sizes (1.0 cm, 1.5 cm, 2.0 cm, and 2.5 cm in diameter) were formed. These seed balls were allowed to dry in the shade for 24-36 hours, depending on ambient temperature and humidity.

Experimental Design

The experiment was conducted under a Completely Randomized Design (CRD) with factorial arrangements to evaluate the effect of pellet thickness and irrigation levels on the germination and growth of *Prosopis glandulosa* (as the experiment was conducted under controlled conditions). Five treatments of seed pellet thickness were used: T₀ (control), T₁ (1.0 cm), T₂ (1.5 cm), T₃ (2.0 cm), and T₄ (2.5 cm). Each treatment was replicated ten times with three irrigation levels (5 ml, 10 ml, and 15 ml) to ensure the reliability of the results. This factorial arrangement enabled the

study of the interaction between pellet thickness and moisture availability on seedling establishment and early growth performance.

Irrigation and Maintenance

Manual irrigation was applied after every three days using three volumes (5 ml, 10 ml, and 15 ml) to study the effect of moisture level on germination and growth. Weeding was carried out as and when required to prevent nutrient and water competition. Special care was taken during the weeding to avoid disturbing the seedlings.

Data Collection Parameters

Shoot length (cm), root length (cm), and stem diameter (cm) were measured for each seedling using a measuring scale and digital calliper. The root-to-shoot ratio was calculated by dividing root length by shoot length. Shoot fresh weight (g), root fresh weight (g), and total fresh weight (g) were recorded immediately after harvesting the seedlings using an electronic weighing balance (JJ3000B). For dry biomass determination, shoots and roots were separately packed in labelled paper bags and sun-dried until reaching a constant weight. The samples were then oven-dried at 75 °C for 24 hours in a thermal electric drying oven (DGH-9202 DGH-9202 Series Thermal Electric Thermostat Drying Oven) to a constant weight. After drying, shoot dry weight (g), root dry weight (g), and total dry biomass (g) were measured with an electronic weighing balance. All measurements were taken at regular intervals, and data were recorded accordingly.

Statistical Analysis

The collected data were analyzed using Two-Way ANOVA to assess the significance of treatment effects ($P < 0.05$). All statistical analyses were performed using R software.

RESULTS

Shoot Length, Root Length and Root-Shoot Ratio

Seed ball thickness and irrigation levels showed a significant effect on shoot length of *Prosopis glandulosa* seedlings ($p < 0.05$). The shoot length was maximum (11.4cm) at the treatment T₃ with 10ml of irrigation, while it decreased to a minimum (6.9 cm) at the treatment T₄ with 15ml of irrigation (Figure 1-a). Root length was also significantly influenced by seed ball thickness and irrigation levels (at $p < 0.05$) as root length was maximum (24.1cm) at treatment T₃ with the irrigation of 10ml, while minimum (15.250cm) root length was recorded at the treatment T₀ with 5ml irrigation (Figure 1-b). Similarly, the root-to-shoot ratio was also found to be significantly influenced by different treatments and irrigation levels (at $p < 0.05$), and the highest root-to-shoot ratio (approximately 2.42 cm) was observed in treatment T₃ with 10 ml irrigation, and the lowest root-to-shoot ratio (around 1.94 cm) was recorded in T₃ under 15 ml irrigation (Figure 1-c).

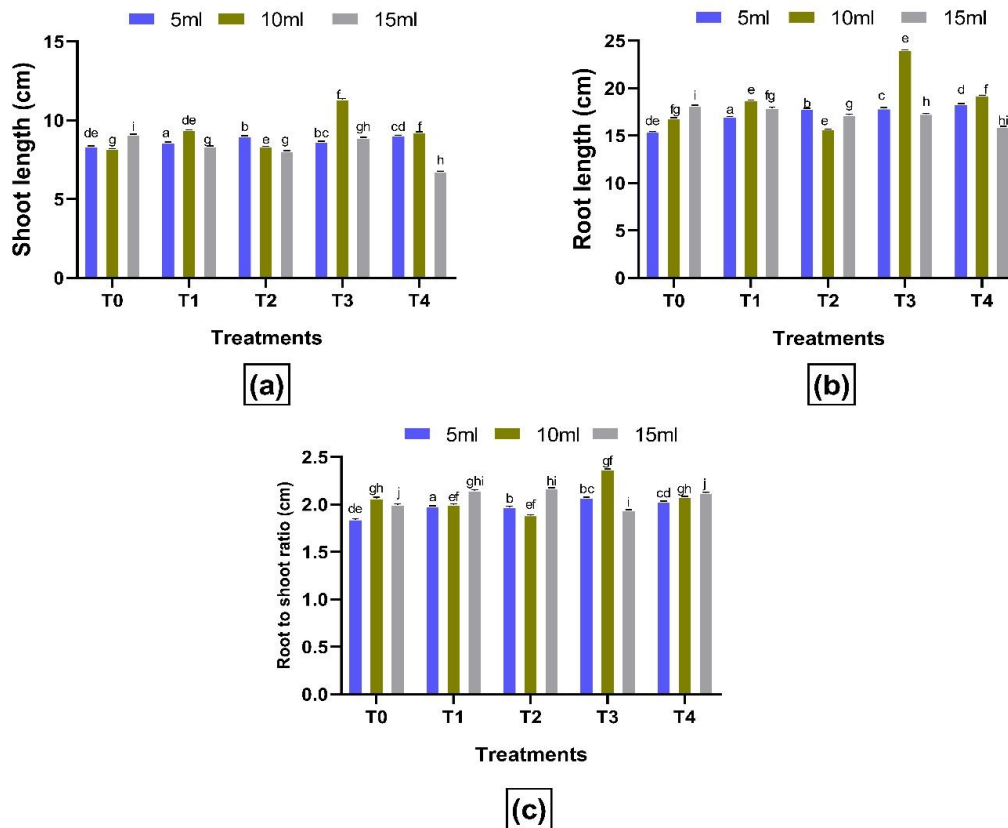


Figure 1: Effect of different levels of irrigation and size of seed ball on (a) root length (cm), (b) shoot length (cm) (c) root to shoot ratio (cm).

Stem Diameter

Stem diameter exhibited significant variation with varying levels of seed balls and moisture levels (at $P < 0.05$), as maximum stem diameter (0.127 cm) was recorded in the treatment T₃ under 10 ml irrigation. In contrast, the lowest stem diameter (about 0.085 cm) was noted in treatment T₁ with 5 ml irrigation (Figure 2-a).

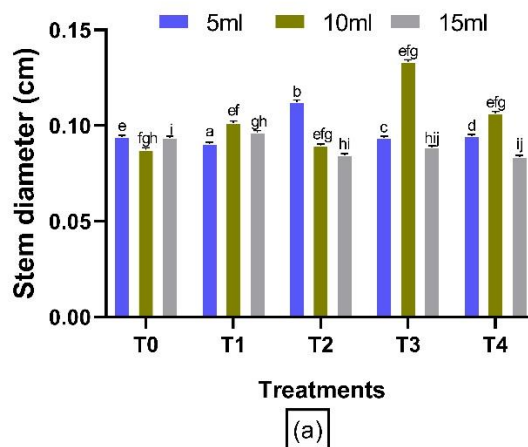


Figure 2: Effect of different levels of irrigation and size of seed ball on (a) stem diameter (cm).

Biomass distribution pattern

Fresh/dry weight of the shoot was also affected by seed ball size and moisture level (at $p < 0.05$). The highest shoot fresh weight (approximately 0.33 g) and shoot dry weight (0.11 g) were recorded in the T₃ treatment with 10 ml irrigation (Figure 3-a). Whereas, the lowest shoot fresh weight (approximately 0.19 g) and the lowest shoot dry weight (0.06 g) were observed in T₄ with 15 ml irrigation (Figure 3-b).

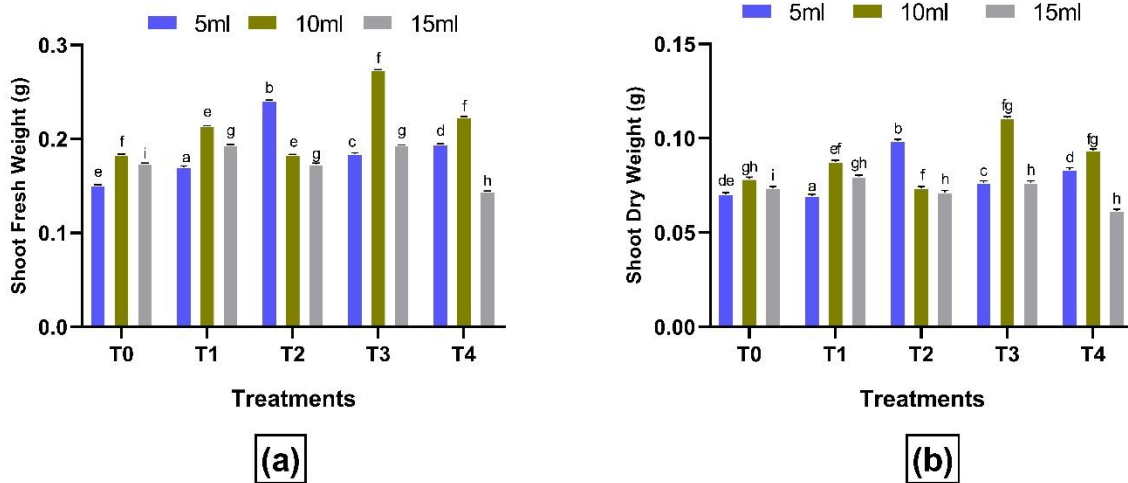


Figure 3: Effect of different levels of irrigation and size of seed ball on (a) shoot fresh weight (g), (b) shoot dry weight (g).

The Root fresh and dry weight showed significant variation with varying levels of seed balls and irrigation (at $p < 0.05$). The highest root fresh weight (0.56 g) and root dry weight (0.22 g) were recorded in T₃ with 10 ml irrigation (Figure 4-a and b), whereas the lowest root fresh weight (0.33 g) and dry weight (0.12 g) were observed in T₄ with 15 ml irrigation. Overall, moderate irrigation levels (10 ml) generally resulted in higher root fresh weight and dry weight across treatments, particularly in Treatment T₃.

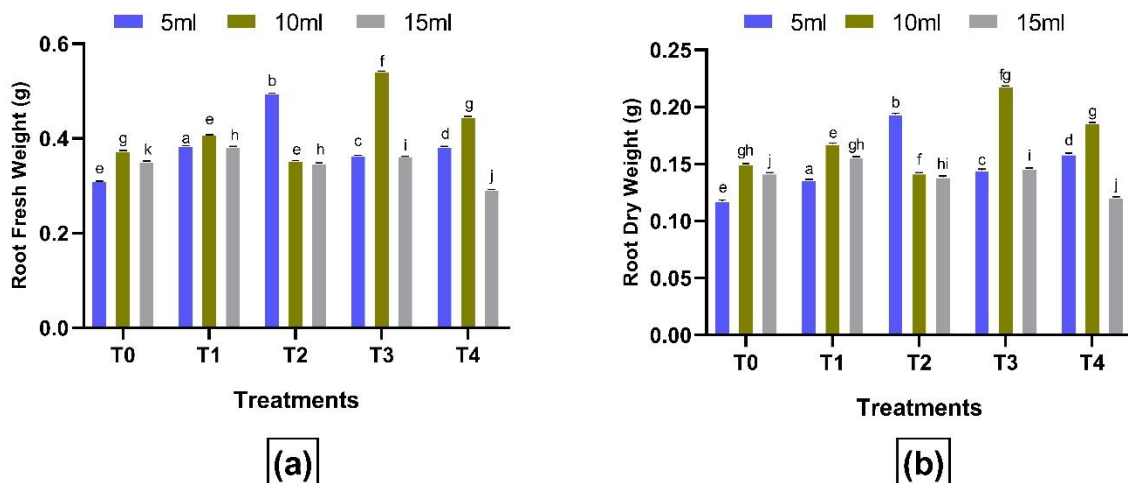


Figure 4: Effect of different levels of irrigation and size of seed ball on (a) root fresh weight (g), (b) root dry weight (g).

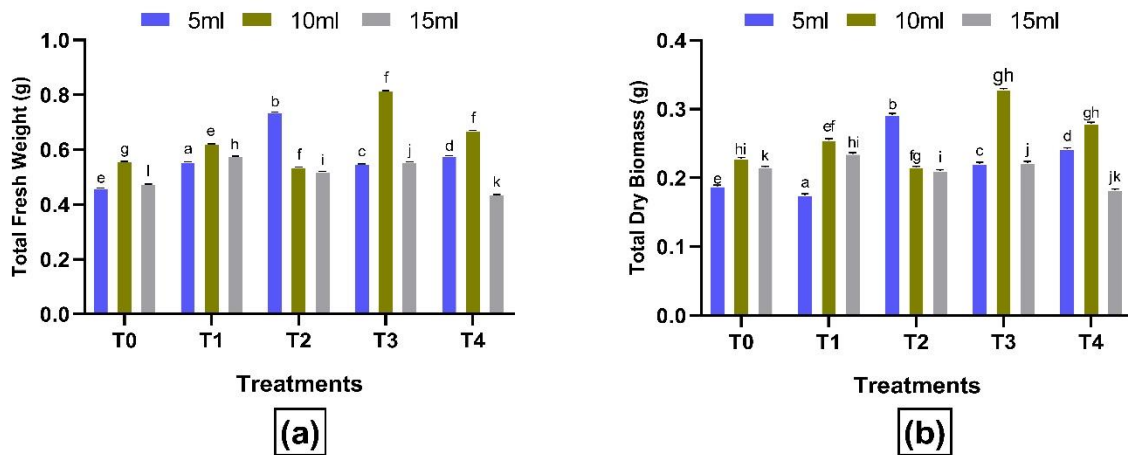


Figure 5: Effect of different levels of irrigation and size of seed ball on (a) total fresh weight (g), (b) total dry biomass (g).

Total fresh and dry biomass was also impacted by seed ball size and irrigation levels (at $p < 0.05$). The highest total fresh weight (0.82 g) and dry weight (0.33 g) were recorded in treatment T₃ under the 10 ml irrigation level (Figure 5-a and b). On the other hand, the lowest total fresh weight (0.49 g) and the lowest total dry biomass (0.17 g) were observed in T₄ under the 15 ml irrigation level. Overall, seed ball size and irrigation levels had a notable interactive effect on the total fresh biomass and total dry biomass production of the seedlings.

DISCUSSION

Arid lands have attracted researchers in global climate change discussions as they are highly vulnerable to desertification and land degradation, which directly threaten food security and the livelihoods of millions of people (IPCC, 2019). Converting arid lands into woodlots with seeds can be tough due to several reasons, including insufficient precipitation, long-term water shortages, seed scavenging, and nutrient-deficient soil, among others. Seed pelleting (also called seed balls and seed bombs) has emerged as an encouraging solution to overcome these hurdles and facilitate successful tree planting in hot areas for different xerophytes (Madsen et al., 2016).

Seed balls play an important role in enhancing productivity in arid regions. Their use has been shown to improve shoot and root growth in crops such as pearl millet (Nwankwo et al., 2018; Romuli et al., 2023). The positive effects on root and shoot development contribute to overall early seedling growth (Zhang *et al.*, 2022). Consistent with these findings, the results of the present study suggest that an appropriate combination of seed ball size and irrigation level can significantly enhance early shoot and root growth of *Prosopis glandulosa*.

Pelleted seeds need to exhibit strong mechanical properties to endure handling, with weight loss (Sarker et al., 2023). Seed balls contribute to enhanced root development by maintaining consistent moisture and improving the soil seed interface (Bainbridge, 2007; Mwase et al., 2015). The present study aligns with these findings, suggesting that an appropriate seed ball treatment can improve the root-to-shoot ratio. A higher root-to-shoot ratio generally indicates more developed roots

relative to shoots, which supports seedling establishment, particularly under water-limited or nutrient-poor conditions.

Seed coatings can alter the size, shape, and surface characteristics of seeds, thereby improving their handling and ease of planting (Sohail et al., 2022). Seed treatments combined with adequate irrigation can significantly influence stem development by enhancing water uptake and nutrient availability (Yadeta et al., 2019). Seed balls help retain moisture and nutrients for the seed to germinate, providing a stable growth environment that supports greater stem elongation and thickness (Abd El-Wahab, 2006; Yadeta et al., 2019). Consistent with these observations, the present study suggests that an optimal combination of seed ball size and irrigation level can enhance stem thickness, which reflects improved seedling health, mechanical strength, and efficient transport of water and nutrients.

Seed balls have been shown to increase shoot fresh and dry weights in seedlings, likely due to enhanced nutrient availability and moisture retention that create a favourable microenvironment for growth (Nwankwo et al., 2018; Jarrar et al., 2023). Optimal irrigation level also contributes positively to overall seedling development (Jarrar et al., 2023). These findings are consistent with studies on pelleted *Amaranthus* seeds, which reported significant increases in seed length and width following the application of coating materials (Kangsopa et al., 2018). Similarly, the present study suggests that optimizing seed ball size and irrigation volume can effectively enhance shoot fresh and dry biomass, promoting overall plant development.

Numerical simulation technology for seed pelletizing can be used to model the pelletizing process for various small or irregularly shaped seeds, facilitating the identification of optimal operating parameters for each seed type and promoting improved plant growth (Zheng et al., 2024). Seed balls have been shown to enhance root biomass, with increases in root fresh and dry weights, as compared to control treatments, likely due to improved soil seed contact and a favourable microenvironment for root elongation and nutrient uptake (Nwankwo et al., 2019; Abhishek et al., 2024). Consistent with these observations, the present study suggests that an appropriate combination of moisture level with appropriate seed ball size can promote superior root development and greater below-ground biomass by ensuring effective moisture retention and nutrient availability at the root zone.

The observed increases in fresh and dry weights reflect enhanced seedling biomass, likely resulting from improved nutrient absorption and utilization (Rocha et al., 2019). Studies on pearl millet have shown that seedlings grown from seed balls exhibited greater total fresh and dry biomass, which has been attributed to improved seed soil contact, moisture retention, and localized nutrient availability within the seed ball, leading to enhanced root and shoot development (Nwankwo et al., 2018; Rawat et al., 2023). These findings support the results of the present study, indicating that an optimal combination of seed ball size and irrigation volume can substantially improve total seedling biomass during the early growth stages.

CONCLUSION

Seedball technology has been shown to effectively enhance germination and early seedling growth, especially in arid and semi-arid regions. The study found that

optimizing seed ball thickness and implementing moderate irrigation can significantly improve root development, biomass, and overall seedling vigor. These characteristics are vital for plant establishment and survival in water-limited environments. Due to its low cost and high effectiveness, this technique presents a practical solution for ecological restoration in degraded drylands. Therefore, adopting seedball technology can greatly support reforestation and land rehabilitation efforts in harsh arid to extremely arid climates.

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