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Research Article

Effect of Seed Rates on Growth and Yield of BAU Chia-1 (*Salvia hispanica* L.)

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ABSTRACT

BAU Chia-1, registered in 2019 in Bangladesh for countrywide cultivation, is considered a superfood due to its high amount of ω-3 fatty acids. A field experiment was conducted from November 2024 to February 2025 to evaluate the effect of different seed rates on the growth, reproductive traits, and yield performance. Four seed rate treatments (T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}) were assessed with three replications and a Randomized Complete Block Design (RCBD). T_3 produced the tallest plant (145.067 cm), the highest fresh weight (28.67 g), and dry weight (8.1 g). The efficiency of photosynthetically active radiation and the number of leaves per plant were the highest in the T_4 treatment. On the other hand, canopy spread (44.67 cm) and inflorescence number plant^{-1} (8) were the highest in T_1. However, spikelet spike^{-1} was almost similar (7) in T_1 and T_2 seed rates. Despite that, the highest seed yield (1116.67 kg ha^{-1}) was recorded in T_2, followed by T_3 (1083 kg ha^{-1}), T_4(933 kg ha^{-1}), and T_1(883 kg ha^{-1}). In contrast, a lower population may be influenced by a lower seed rate in T_1, whereas reduced growth and yield parameters from higher seed rates (T_4) may be associated with increased intraspecific competition. Taken all together, the seed rate of 250 g ha^{-1}, designated as T_2, showed the most effective crop performance and productivity at the BAU research field in Mymensingh. However, further multi-location trials are required to validate these findings before making any recommendations.

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Introduction

Chia (*Salvia hispanica* L.), a member of the Lamiaceae family, is globally recognized as a superfood for its multiple health benefits and diverse applications. This ancient crop originates from Mexico and Guatemala, contains approximately 30-34% oil, with a high proportion of alpha-linolenic acid (ALA), and essential omega-3 fatty acids that contribute to cardiovascular health (Hossain *et al.,* 2016; Biswas *et al.,* 2023). The seeds are also rich in dietary fiber (34-40%), which aids digestion and helps in weight management (Nadem *et al.,* 2024). Additionally, chia contains essential minerals such as calcium, phosphorus, magnesium, and potassium, making it a highly nutritious food source (Ikumi *et al.,* 2023). Apart from its nutritional significance, chia is well known as a climate-resilient crop. Being drought-tolerant, this short-duration crop can be grown without irrigation or with minimal irrigation using a reduced amount of fertilizer, making it suitable for sustainable and climate-smart agriculture (Hossain, 2023; Harisha et al., 2023; Shorna *et al.,* 2024). Its adaptability to different soil types and minimal input requirements make it an attractive crop to the farmers. This crop needs no pesticides at all (Njoka *et al.,* 2024). Thus, the rising concerns about food security and environmental sustainability, promoting chia cultivation through improved agronomic practices, can contribute to global and national food systems' resilience.

Several field trials have been done in Bangladesh based on agronomic practices of Chia cultivation (Karim *et al.,* 2015; Biswas *et al.,* 2020; Rahman *et al.,* 2023). Recently, it was reported that a plant density of 66 plants m^{-2} of BAU Chia performed well (Sumi *et al.,* 2023). However, very few works are available focused on seed rates, though it is a fundamental agronomic factor that affects plant establishment, intra-crop competition, yield, and farmers' income. Understanding the relationship between seed rate and plant growth is

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essential for developing precise recommendations to enhance productivity while minimizing input costs (McDonald and Copeland, 2012). A lower seed rate results in fewer plants per unit area, reducing competition for water, nutrients, and light. This promotes better vegetative growth, increased branching, and higher seed production per plant. However, lower seed rates can encourage weed growth, increase production cost, and reduce overall yield per hectare. Conversely, a higher seed rate leads to more plants per unit area, intensifying competition for essential resources and potentially limiting individual plant growth and biomass accumulation (Xiao *et al.,* 2025). Optimizing the seed rate is essential for achieving a balanced plant density, enhancing growth efficiency, and maximizing yield. Nowadays, the Market demand for BAU chia-1 is increasing, which leads farmers to cultivate this crop on their lands. However, the lack of standardized recommendations for the seed rate of BAU chia-1 makes it necessary to identify a suitable seed rate for achieving optimal planting density. Accordingly, the study aims to evaluate the effects of different seed rates on the growth of BAU chia-1, its yield components, and overall productivity. By identifying the most suitable seed rate, this research will contribute to improving BAU Chia 1 productivity, reducing input costs, and enhancing farmers' income. The outcomes will not only benefit local farmers but also contribute to the national goal of sustainable agriculture and food security.

Materials and methods

BAU Chia-1, registered in 2019 by the Ministry of Agriculture, was used in this study. This research was conducted from November 2024 to February 2025 at the Crop Botany Research Field, Bangladesh Agricultural University, Mymensingh, Bangladesh. This region is situated at a latitude of 24°38′ N, a longitude of 90°50′ E, and an elevation of 18 m above mean sea level. It has a semiarid climate. Between November 2024 and February 2025, Mymensingh experienced temperatures ranging from 30°C to 16°C. The Bangladesh Meteorological Department reported monthly relative humidity levels within 77% to 79%. The site belongs to the Sonatola series of the Old Brahmaputra Floodplain AEZ-9. The soil at the experimental site was clay loam. The experimental land was prepared using a power tiller and leveled with a ladder. Fertilizer was applied after the previous crop stubble and weeds were cleared. A balanced fertilizer of 90 kg urea, 40 kg TSP, and 20 kg MoP was applied for nitrogen, phosphorus, and potassium, respectively. Urea was applied in split doses: half at sowing and half at the vegetative stage (45 DAS). As soil moisture was sufficient, irrigation was not given throughout the crop growth period. Weeds were manually eliminated at 25 DAS and 40 DAS. The insect pest infestations were negligible.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four treatments and three replications. The treatments were T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}. Each plot measured 3m × 3m, with a buffer zone of 1m between plots for cultural practices. BAU chia-1 seeds were sown using the broadcasting method, ensuring uniform distribution across the plots. The seeds were lightly covered with soil to facilitate germination. Regular field visits were conducted to assess crop growth and development throughout the growing season. BAU chia-1 was ready for harvesting when the vibrant purple flower stalk began to desiccate and the petals had shed.

Plant height, root length, fresh weight, dry weight, and photosynthetically active radiation efficiency (PAR efficiency) were recorded during the growing period. At 70 Days after sowing (DAS), leaf number, starting branches at the nodal position, and canopy spread were recorded. Canopy spread was measured using a measuring tape from edge to edge of the. branches and expressed as cm. At harvesting time, some yield-related parameters were recorded, such as inflorescence number plant^{-1}, main inflorescence length (inflorescence in main stem), spikes per main inflorescence, spikelets per spike, and seed yield. Photosynthetically active radiation efficiency (PAR) was calculated using the following formula –

PAR efficiency (%) =

$$\frac{(PAR\,at\,top\,canopy - PAR\,at\,ground\,canopy)}{PAR\,at\,top\,canopy} \times 100$$

Data were initially organized using Microsoft Excel 2021 and statistically analyzed using Minitab 21 software. One-way ANOVA of the agronomic traits was performed at the 0.05 significance level.

Result and discussion

Plant height

Plant height was significantly influenced by different seed rates and measured at 30, 40, 50, 60, 70, 80, and 90 DAS, as shown in Figure 1. At 30 DAS, the tallest plant (37.67 cm) was recorded under T_4 treatment, while the shortest (24.67 cm) was observed in T_1 treatment. However, T_4 consistently resulted in the tallest plants up to 50 DAS. From 60 DAS, T_3 produced the tallest plant up to 90 DAS. The plant height under the T_3 treatment reached a maximum of 145.1 cm, followed by the T_4 (141.9 cm), T_2 (135.2 cm), and T_1 (131.27 cm) treatments at 90 DAS. Plant height increased progressively with time across all seed rates, but the rate of increase varied significantly among different seed rates. However, the tendency to a towering type of plant height with increasing seed rate suggests that there may be competition among plants for light, which has stimulated vertical growth (Stanghellini and Katzin, 2024; Chauvel *et al.,* 2005). Although the plants under T_3 treatments exhibited the most vigorous growth, a slight decrease in plant height was observed in T_4 from 60 DAS to 90 DAS. The inverse relationship between T_4 and plant height may be due to excessive intraspecific competition among the chia plants (Yang *et al.,*2024).

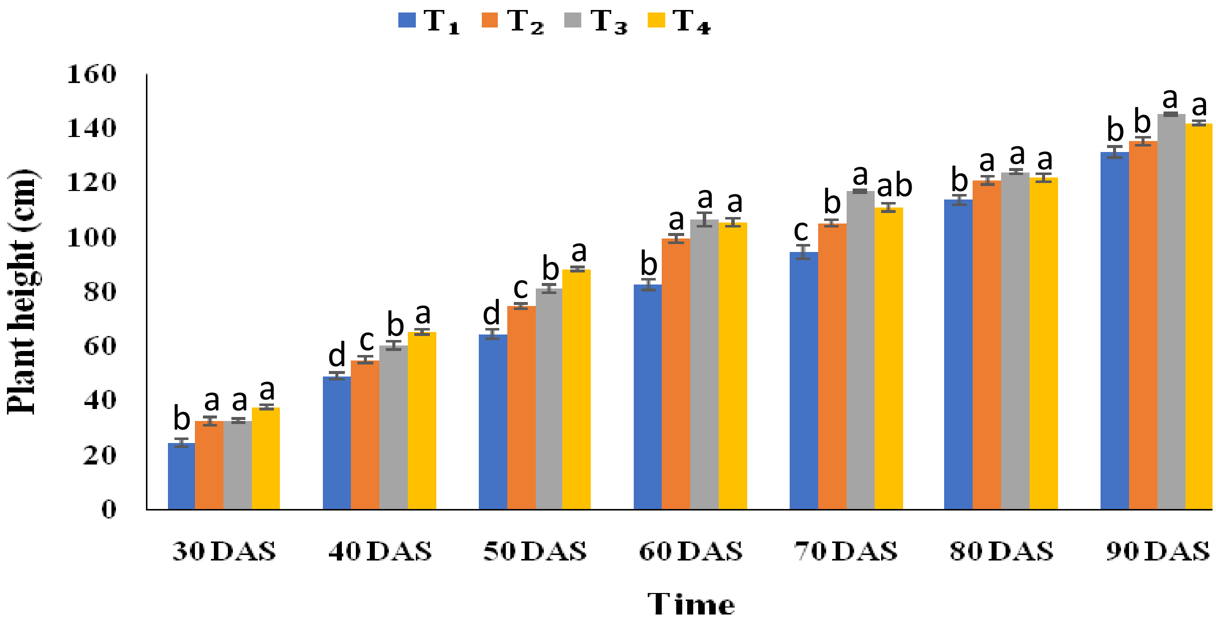

Figure 1: Plant height of BAU chia-1 at different growth stages under different seed rate levels. The vertical bars represent the standard error. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Dry weight plant^{-1}

able 1 shows the effect of four seed rates on different growth stages. At 30 DAS, dry weight ranged from 0.63 g (T_1) to 0.77 g (T_3 and T_4). The dry weight peaked at 80 DAS, with the highest value observed under T_3 (8.9 g), followed by T_4 (8.56 g), T_2 (7.2 g), and T_1 (6 g). A slight decrease in dry weight was noticed at 90 DAS across all treatments, although T_3 still maintained the highest dry weight (8.1 g), while T_1 showed the lowest (5.73 g). The peak observed at 80 DAS denotes the phase of maximum vegetative and early reproductive growth, during which dry matter accumulation typically reaches its maximum (so-called physiologically matured annual crop plant). The slight reduction in dry weight at 90 DAS across all seed rates may be attributed to the onset of senescence, natural decline in tissue moisture, and biomass, similar to fresh weight (Thomas, 2013). Although T_4 showed relatively high dry weight, it was slightly lower than T_3, suggesting that a higher seed rate may cause inefficiencies in resource utilization, as reported in Sumi *et al.,* (2023). Thus, T_3 appears optimal for maximizing dry weight and fresh weight as well. Dalley *et al.,* (2004) also reported that less competition produces higher biomass.

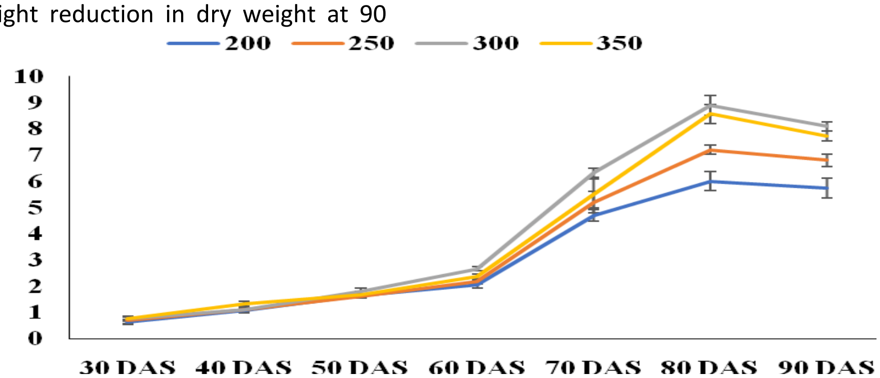

Figure 2: Dry weight of BAU chia-1 at different growth stages under different seed rate levels. The vertical bars represent the standard error. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Leaf number plant^{-1}

Table 2 indicates a relationship between seed rate and the average number of leaves per plant. As the seed rate increases, the leaf number plant^{-1} increases from approximately 41 to 54. The highest leaf number (54) was observed at the highest seed rate (T_4). Conversely, the lowest leaf number (41) was recorded at the lowest seed rate (T_1). These findings align with common agronomic observations where optimal plant spacing enhances individual plant performance. Lower seed rates of T_1 may result in competition with weeds for available light, nutrients, and water resources (Holdsworth, 1956; Bernier *et al.,* 2018). This competition decreases the plant height, node number, and ultimately the leaf number in an individual plant.

Branch starting at the Nodal Position: Table 2 showed that branching began at 3 to 4 nodes across the treatments, indicating a moderate impact of seed rate on the timing of branching. At lower seed rates (T_1 and T_2), branching initiated at the 3rd node, whereas in higher seed rates (T_3 and T_4), branching starts with the 4th node. This slight delay in branch initiation at higher seed rates may be due to increased inter-plant competition. This competition delays the expression of secondary structures like branches. However, denser populations possibly prioritize vertical growth and leaf expansion before branching begins (Biswas *et al.,* 2020; Bennett *et al.,*2012).

Canopy spread: The canopy spread showed a consistent decrease with increasing seed rate, reflecting a pattern similar to that observed in leaf number and branch initiation (Table 2). The widest canopy spread (44.67 cm) was recorded at the lowest seed rate (T_1), while the narrowest spread (35.33 cm) was at the highest seed rate (T_4). Plants grown at lower rates benefit from more available resources, which supports the broader canopy development (Biswas *et al.,* 2020). A wider canopy allows for better light interception and may contribute to enhanced photosynthetic capacity, potentially improving biomass accumulation and yield. Conversely, increased plant density leads to reduced lateral growth, thus restricting canopy spread. This may limit light penetration, reduce the photosynthetic efficiency of lower leaves, possibly affecting crop performance (Huber *et al.,* 2021).

Table 1: Effect of seed rates on leaf number plant^{-1}, starting branches at the nodal position, and canopy spread of BAU chia 1 at different days after sowing (DAS)

Treatment	Leaf number plant^{-1}	Starting branches at the nodal position (count from the base)	Canopy spread (cm)
T_1	41^{c}	3^{c}	44.67^{a}
T_2	45^{bc}	3^{b}	40.33^{b}
T_3	50^{ab}	4^{a}	37.33^{bc}
T_4	54^{a}	4^{a}	35.33^{c}
% CV	11.66	16.49	12.66

In a column, figures with the same letter do not differ significantly. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Photosynthetically Active Radiation Efficiency: A clear increase in photosynthetically active radiation (PAR) was shown in Figure 2. PAR progressively increased across all treatments starting from 30 DAS. At 70 DAS, it peaked in all treatments, then slightly declined, as observed at 90 DAS. Among the treatments, T_4 consistently recorded the highest PAR at nearly all stages, followed by T_3. At 70 DAS, PAR of T_4 was 87.48%, followed by T_3 (86.51%), T_2 (84.23%), and T_1 (82.89%). On the other hand, T_1 exhibited the lowest PAR throughout the growth period. This suggests that increasing the seed rate positively influenced PAR efficiency and biomass accumulation up to a certain period. It is reasonable since land was covered by leaves (full canopy) and received maximum light (Pei *et al.,* 2022). However, the decline in PAR efficiency may be due to leaf senescence and canopy aging (Li *et al.,* 2022). The marginal difference between T_3 and T_4 indicates that both optimize PAR efficiency in the chia field.

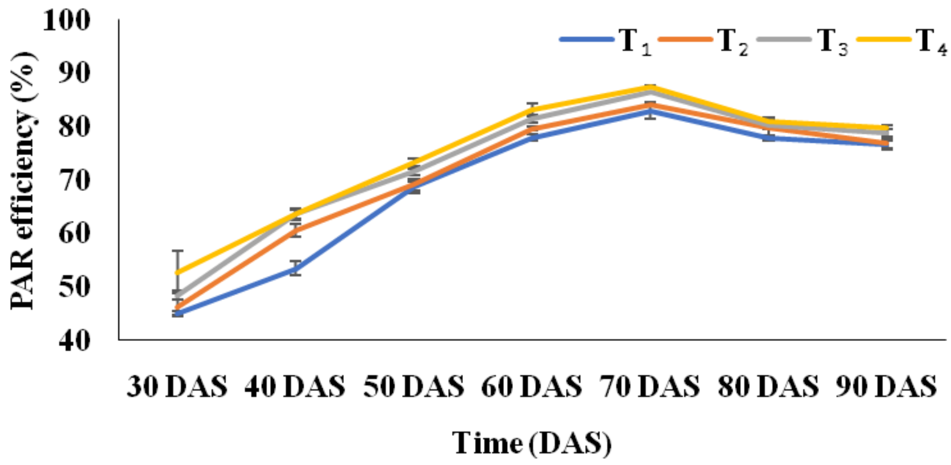

Figure 3: Photosynthetically Active Radiation efficiency of BAU chia-1 at different growth stages under different seed rate levels. The vertical bars represent the standard error. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Inflorescence number plant^{-1}

The inflorescence number plant^{-1} ranged from 6 to 8, as shown in Table 3. The highest value was observed in T_1 (8), indicating better reproductive development. T_3 and T_4 showed fewer inflorescences (6), and T_2 showed 7 inflorescences plant^{-1}. The highest inflorescence number in T_1 indicates more favorable growing conditions, such as lower plant competition or better nutrient availability. On the other hand, the higher plant density or limited resources might have suppressed reproductive branching. A higher number of inflorescences is generally advantageous, contributing to more sites for seed production (LeHeiget *et al.,* 2023).

Main inflorescence length (cm)

Table 3 shows that the main inflorescence length varied from 11.1 cm to 14.83 cm. T_2 showed superior performance, which could be attributed to optimal plant spacing or resource availability. A longer main inflorescence can accommodate more spikelets and ultimately, more seeds, contributing positively to yield (LeHeiget *et al.,* 2023). Shorter lengths in T_4 suggest possible limitations in growth due to a lack of nutrients or other factors.

Spikes main inflorescence^{-1}

The number of spikes on the main inflorescence varied across treatments. The highest number of spikes (18) was observed in T_2, followed by T_1 (17). T_3 and T_4 treatments recorded lower values, with 15 and 14 spikes, respectively. The decline in spike number in T_3 and T_4 could be due to excessive plant population, which may hinder spike initiation and development.

Spikelets spike^{-1}

Spikelets spike^{-1} ranged from 5.33 in T_4 to 7.67 in T_1. A higher number of spikelets indicates a better potential for seed. T_1 showed the highest value, slightly outperforming T_2. Lower spikelet counts in T_3 and T_4 suggest that denser planting or suboptimal growing conditions may have restricted spike development.

Table 2: Effect of seed rates on inflorescence number plant^{-1}, main inflorescence length, spikes main inflorescence^{-1}, and spikelet spike^{-1} of chia at different days after sowing (DAS)

Treatment	Inflorescence number plant^{-1}	Main inflorescence length (cm)	Spikes main inflorescence^{-1}	Spikelet spike^{-1}
T_1	8^{a}	13.43^{ab}	17^{ab}	7^{a}
T_2	7^{a}	14.83^{a}	18^{a}	7^{a}
T_3	6^{a}	12.90^{ab}	15^{bc}	6^{ab}
T_4	6^{a}	11.10^{b}	14^{c}	5^{b}
% CV	12.66	11.82	11.18	15.81

In a column, figures with the same letter do not differ significantly. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Seed yield

The seed yield varied noticeably among treatments, as depicted in Figure 3. The highest yield (1116.67 kg ha^{-1}) was observed in T_2, followed by T_3 (1083.33 kg ha^{-1}). The lowest yield was recorded in T_1 (883.33 kg ha^{-1}). This indicates that moderate seed rates yielded better outcomes. Despite T_1 showing superior vegetative growth, its lower yield suggests that vegetative vigor alone does not assure higher productivity. However, T_4 showed a higher yield than T_1 but still underperformed compared to T_2 and T_3. This may be due to increased competition at high plant densities, limiting individual plant performance.

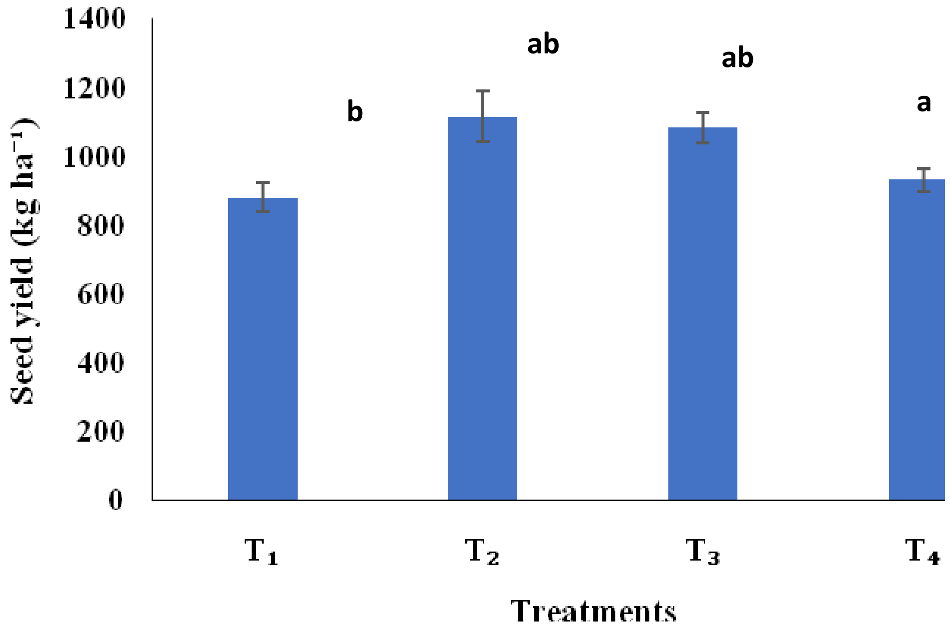

Figure 4: Seed yield of BAU Chia 1 at different seed rate levels. The vertical bars represent the standard error. Here, T_1 = 200 g ha^{-1}, T_2 = 250 g ha^{-1}, T_3 = 300 g ha^{-1}, and T_4 = 350 g ha^{-1}.

Conclusion

This study demonstrates the profound impact of seed rate on both vegetative and reproductive growth parameters, ultimately influencing seed yield. Four seed rates were evaluated, and different vegetative and reproductive parameters were assessed. The study highlighted that a 250 g ha^{-1} seed rate is the most effective in achieving optimal growth and seed yield as well. However, excessive seed rate (350 g ha^{-1}) is not ideal for maximizing yield. Instead, as seen in 250 g ha^{-1} (optimal seed rate), a balanced approach ensures optimal resource utilization, promotes efficient reproductive development, and enhances overall productivity. Finally, it might be helpful for seed rate recommendations and improving yield outcomes. Multilocation trials are needed to confirm the findings.

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