International Journal of Theoretical & Applied Sciences, **18**(1): 10-16(2026)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Impact of Nutri-priming on Germination Dynamics and Early Seedling Vigour in Rice

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(Received 07 October 2024, Revised 16 December 2025, Accepted 08 January 2026)
(Published by Research Trend, Website: www.researchtrend.net)

DOI: https://doi.org/10.65041/IJTAS.2026.18.1.2

ABSTRACT: The development of effective, affordable, and ecologically friendly methods to increase seed vigour is crucial because seed resilience and performance are fundamental to sustainable agriculture. In order to enhance the physiological and biochemical characteristics of seeds, a promising pre-sowing method known as "seed priming" entails subjecting them to particular organic or inorganic compounds under carefully monitored circumstances. Nutri-priming is the process of soaking seeds in a nutrient solution to improve their growth and stress tolerance. It combines seed priming with the application of macro and micronutrients, resulting in increased nutrient content in the final crop, improved seedling vigour, and faster and more uniform germination. This approach, which has been successfully used in cereal crops to lessen the negative effects of environmental stressors, is both economical and environmentally friendly, making it a valuable strategy for increasing agricultural productivity. In light of the aforementioned, the current study used standardised physiological and germination metrics to assess the impact of nutri-priming on early seedling vigour and germination dynamics in rice. From banana stems, the various priming treatments were extracted. The extracted materials were prepared in various concentrations using the following methods: 0.25 mL (T_1), 0.50 mL (T_2), 1.00 mL (T_3), 2.00 mL (T_4), 3.00 mL (T_5), and 4.00 mL (T_6), diluted in 15 mL distilled water; for the control (T_0) only 15 mL distilled water was used. In rice, 1.00 mL (T_3) was the ideal concentration for enhancing germination behaviour, early seedling vigour, and a shorter mean germination time. So, 1.00 mL banana stem extracted nurti-priming increases biomass accumulation, maximises metabolic activation, and encourages elongation growth without causing toxic or osmotic stress.

Keywords: Nutri-priming, rice, germination energy, germination index, vigour.

INTRODUCTION

Uniform and rapid seedling establishment is the backbone for achieving optimal crop yield, as early vigor strongly ensures competitive ability, resource acquisition, and stand uniformity. Poor and erratic emergences concomitated with low-vigor seedlings exacerbate irregular canopy growth, induce weed proliferations (Farooq *et al*., 2019), and subsequent yield penalties. Seed priming is a robust pre-sowing strategy that fosters germination uniformity, seedling vigor, and early plant establishment through the regulation of pre-germinative metabolic activity without permitting radicle protrusions (Samanta *et al*., 2025; Singh *et al*., 2015). Within this framework, nutrient-based seed priming (nutri-priming) provides an additional functional advantage as it supplements macro- or micronutrients during imbibition to bolster cellular metabolism, enzyme activation, and antioxidative regulation. These mechanisms collectively enhance germination energy, shorten mean germination time (MGT), enhance root–shoot growth, and improve vigour indices—attributes essential for strong crop establishment (Nciizah *et al*., 2020). This approach is particularly relevant where early nutrient limitations often delay fifty percent germination (T_{50}), stunt root development, and suppresses early growth (Choudhury and Bordolui 2022a).

Rice (*Oryza sativa* L.) remains to be the most significant cereal in the world, accounting for more than 20% of the world's total caloric intake and being the major staple in Asia, Africa, and Latin America (FAO, 2025). Despite the importance, rice frequently suffer from poor field emergence, especially under suboptimal moisture, marginal soils, and nutrient-deficient conditions—constraints that directly impede germination potential and compromise early seedling vigour (Bordolui *et al*., 2018). Understanding how nutri-priming modifies different parameters can offer deep insight into its physiological modes of action and identifying scalable, crop-appropriate priming formulations. For instance, changes in MGT and T_{50}

reflect alterations in the speed and synchronicity of germination; increases in vigor indices indicate enhanced early growth potential; and alterations in root-to-shoot ratio may reflect shifts in resource allocation induced by priming.

Therefore, the present study aims to evaluate the influence of nutri-priming on germination dynamics and early seedling vigour in rice using a standardized physiological and germination metrics. By juxtaposing responses in rice, this study seeks to identify the concentration of nutri-priming that capable of influencing germination dynamics, seedling vigour, and strengthen early establishment thereby offering practical insights for scalable production enhancement strategies.

MATERIALS AND METHODS

Rice seeds (variety Bidhan Suruchi) were collected from the Department of Genetics and Plant Breeding, BCKV. Seeds were surface sterilized with 0.2% mercuric chloride solution for 2 to 3 minutes, followed by thorough rinsing with deionized water. Nutri-priming materials were extracted from banana stems by digestion. The different concentrations were prepared using the following methods: 0.25 mL (T_1), 0.50 mL (T_2), 1.00 mL (T_3), 2.00 mL (T_4), 3.00 mL (T_5), and 4.00 mL (T_6), of extracted materials diluted in 15 mL of distilled water, while 15 millilitres of distilled water were used for the control (no extracted material was used for T_0). Seeds were soaked in different concentrations of priming material for eight hours in order to prime them. To evaluate the germination-related parameters and seedling vigour, primed seeds were shade-dried to their initial moisture content and then put in petri dishes and roll towels. All tests were conducted under a completely randomized design (CRD) with four replications in the Seed Science and Technology Laboratory, Bidhan Chandra Krishi Viswavidyalaya.

Enumeration of Germination metrices

Germination parameters, including germination potential (GP), time to 50% germination (T_{50}), germination energy (GE), germination index (GI), and mean germination time (MGT), were calculated using standard equations (Table 1).

Table 1: Equations used to determine selected germination matrices.

Sr. No.	Parameters	Equation	Reference
1	Germination potential (%)	GP = Number of normal germinated seeds/ Total number of seeds) x 100	ISTA, 1996
2	Time to 50% germination (T_{50})	$T_{50} = ti + [\{(N / 2 – ni) × (tj – ti)\} / (nj – ni)]$ Where 'N'= the final number of seeds that germinated, and 'ni', 'nj' are the total number of seeds germinated by adjacent counts at times 'ti' and 'tj' when ni< N/2 <nj.	Coolbear *et al*., 1984; Farooq *et al*., 2005
3	Germination Energy (GE)	Percent of seeds germinated on 4th day after the initiation of the experiment, in relation to the total number of seeds tested	Ruan *et al*., 2002
4	Germination Index (GI)	$GI = \Sigma (ni / di)$, for i = 1 to k	AOSA, 1983
5	Mean Germination time (MGT)	$MGT = \Sigma (ni \times di) / \Sigma ni$, for i = 1 to k	Ellis and Roberts, 1981
Where 'ni' is the number of seeds that emerged on day "di" and "d" is the number of days counted from the start of the test, k is the day of final count (14 days).			

Seedling Parameters

Root and shoot lengths of ten randomly selected seedlings were measured on the 14th day after test initiation using a ruler and graph paper. The average values were used to calculate the root-to-shoot ratio. Seedling length (cm) was obtained by summing root and shoot lengths.

Fresh and dry weights of seedlings were measured using a digital balance. For dry weight determination, seedlings were oven-dried at 110 ± 2^{0}C for 24 hours. Both fresh and dry weights were expressed as mg seedling^{-1}.

Seedling vigor indices were computed according to Abdul-Baki and Anderson (1973):

SVI-I = Germination (%) × Average seedling length (cm)

SVI-II = Germination (%) × Average seedling dry weight (mg)

RESULTS AND DISCUSSION

The impact of various treatment concentrations on germination metrics shows distinct variations in seed performance. Overall, the data demonstrate that while excessively high concentrations (T_6: 4.00 mL) adversely affected certain parameters, moderate concentrations (especially T_3: 1.00 mL) significantly improved seed germination characteristics when compared to the control.

Germination Potential:

The germination potential varied from 95.15% (T_0) to 99.17% (T_3). The highest values were recorded by T_3 and T_4, both of which were statistically better than the other treatments. This suggests that concentrations between 1.00 and 2.00 mL maximise the early germination response. Though not to the same degree, lower concentrations (T_1 and T_2) also increased germination potential in comparison to the control. The decline in T_6 indicates that higher doses may begin to exert inhibitory or stressful effects on seeds (Fig. 1). According to Chakraborty and Bordolui (2021), priming green gram with GA_3 and Ag-Nanoparticles increases the germination rate. Ray *et al.* (2023) reported a similar outcome in tomatoes.

Time to 50% Germination (T_{50}):

Up to T_3, T_{50} exhibited a declining trend; at higher concentrations, it slightly increased (Fig. 1). T_3 showed the fastest germination (1.74 days), suggesting early emergence and increased vigour. Germination was delayed by treatments exceeding 1.00 mL, especially T_6 at 3.26 days, suggesting potential concentration-dependent inhibitory effects. Higher concentrations may slow down germination, as demonstrated by T_6's slowest germination time. Choudhury *et al.* (2023) discovered that PEG 6000 priming decreases chickpea time of 50% germination.

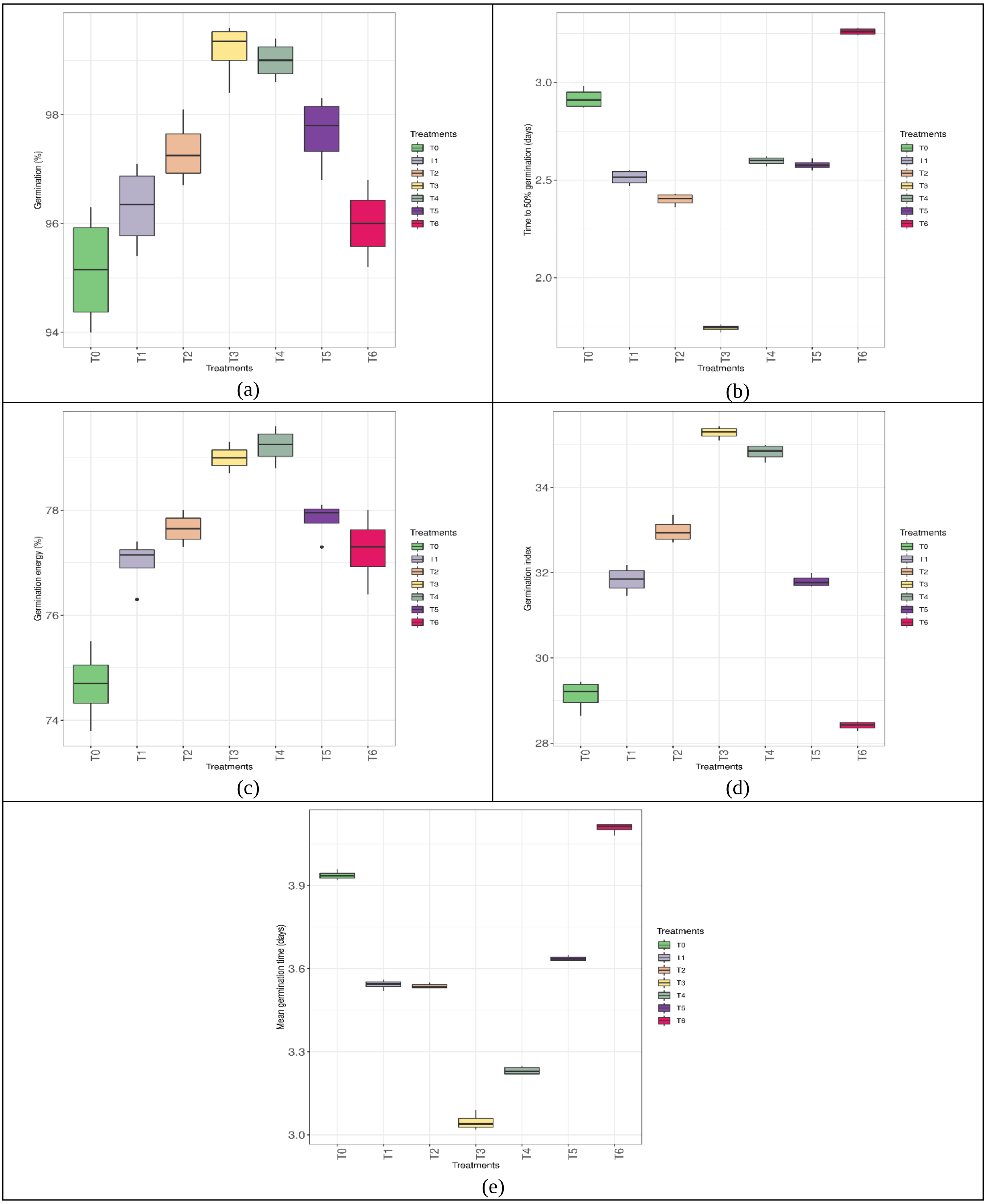

Fig. 1. Effect of Nutri-priming on (a) Germination (%), (b) Time to 50% germination (days), (c) Germination energy (%), (d) Germination index, (e) Mean Germination Time (days) in Rice (*Oryza sativa* L., cv. Bidhan Suruchi).

Germination Energy

The application of treatment resulted in a significant increase in germination energy (Fig. 1). The highest values (79.00–79.22%) were obtained by T_3 and T_4, indicating higher early seed vigour. While intermediate treatments (T_1, T_2, T_5, and T_6) produced moderate improvements, the control group had the lowest energy (74.67%). Once more, T_3 is clearly the best course of action. Similar findings were reported in rice by Dandapat and Bordolui (2025).

Germination Index

The pattern of the germination index was comparable to that of other vigour characteristics. The highest germination index values were recorded in T_3 (35.29) and T_4 (34.82), confirming improved speed and uniformity of germination (Fig. 1). Reduced vigour at high concentrations is suggested by T_6's lower germination index (28.41). The control had the lowest germination index, indicating that treatments improved germination performance. Choudhury *et al.* (2023) reported similar results in chickpea.

Mean Germination Time (MGT)

A lower mean germination time denotes more rapid and consistent germination. Mean germination time was lowest in T_3 (3.05 days), followed by T_4 (3.23 days). Slower germination was confirmed by higher mean germination time values in T_6 (4.11 days) and the control (3.94 days). MGT was moderately reduced by treatments T_1, T_2, and T_5 (Fig. 1). For rice, Dandapat and Bordolui (2025) reported similar findings.

Root to Shoot Length Ratio

The root-to-shoot ratio varied between 1.16 and 1.71 (Fig. 2). The highest ratio was recorded in T_4 (2.00 mL/15 mL), closely followed by T_3 (1.57). T_0, T_1, T_5, and T_6 showed statistically similar but significantly lower ratios. In T_3 and T_4, a higher root-to-shoot ratio indicates improved root development in relation to shoot length, suggesting better adaptation for nutrient and water uptake during early seedling establishment.

Seedling Length

Priming resulted in a significant increase in seedling length, which ranged from 19.35 cm (T_0) to 28.86 cm (T_3). The tallest seedlings were produced by T_3 and T_4 (27.40 cm), both of which were significantly better than all other treatments. Higher concentrations (T_5 and T_6) resulted in shorter seedlings, suggesting that high priming doses may inhibit elongation. Thus, by encouraging elongation growth, optimal priming (1.00–2.00 mL) successfully increased early seedling vigour (Fig. 2). Choudhury and Bordolui (2022b) found comparable outcomes in Bengal gram using Potassium Nitrate priming to lengthen shoots.

Seedling Fresh Weight

The fresh weight of average seedling ranged from 36.34 mg to 39.17 mg. The highest fresh weight was recorded by T_3, closely followed by T_2 and T_4. The lowest values were found in T_0 and T_6, suggesting either excessive concentration or limited biomass accumulation without priming. Improved metabolic activity and water absorption efficiency during germination are reflected in increased fresh weight in moderately primed seeds (Fig. 2). Similar results were found in tomato by Ray and Bordolui (2022a).

Seedling Dry Weight

Seed priming significantly improved the dry weight of average seedlings, which ranged from 6.10 mg to 7.55 mg. Both statistically superior treatments, T_4 (7.55 mg) and T_3 (7.47 mg), had the highest dry weights. Reduced reserve mobilisation or poor growth under unfavourable circumstances are suggested by lower dry weight in T_6 and T_0. Increased conversion of seed reserves into structural biomass is indicated by higher dry matter accumulation in optimally primed seeds (Fig. 2). In carrots, Kundu and Bordolui (2025) discovered a comparable outcome following osmo-priming.

Vigour Index I

The strongest reaction to priming was seen in Vigour Index I (Fig. 2). The values varied between 1841.29 (T_0) and 2862.15 (T_3). T_3 showed the most vigour, followed by T_4, suggesting better growth and establishment potential. Significant decreases were observed at higher concentrations (T_5 and T_6), almost reaching control levels. Vigour index-I makes it abundantly evident that a priming solution of 1.00 to 2.00 mL produces better early vigour. Chakraborty *et al*. (2020); Ray and Bordolui (2022b) reported similar results.

Vigour Index II

Vigour Index II increased significantly with priming, much like Vigour Index I. The highest value was obtained in T_4 (747.69), statistically comparable to T_3 (740.87). The control (595.51) and T_6 (585.64) had the lowest values. This demonstrates that moderate priming produces stronger, heavier seedlings in addition to improving germination (Fig. 2). In contrast to other treatments, Chakraborty and Bordolui (2021) discovered that Ag nano priming raised the fresh weight of green gram seedlings. In the case of carrots, Kundu and Bordolui (2023) observed similar results.

All the parameters were further supported by the correlogram (Fig. 3), which showed strong positive correlations ($r>0.75$) between germination potential, germination energy, germination, root to shoot ratio, shoot length, root length, and vigour index I and II. These correlations formed a coherent cluster that suggested coordinated germination and vigour. Time to 50% germination and mean germination time demonstrated a negative correlation with germination, highlighting its function as vigour.

The analyses highlighted the different trait relationships under nutri-priming and emphasised the vital role that seed vigour and germination play in maintaining physiological activity.

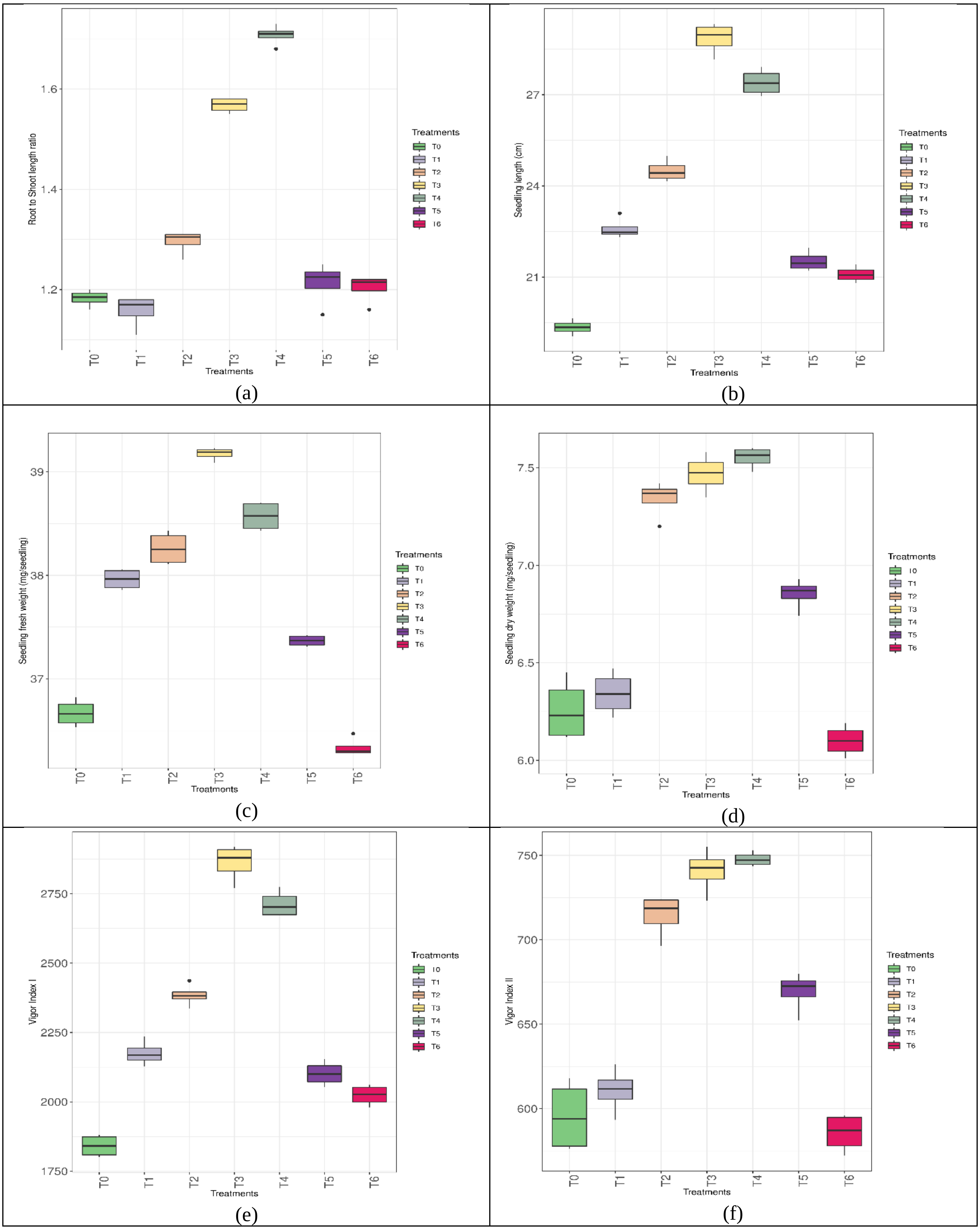

Fig. 2. Effect of Nutri-priming on (a) Root to shoot length ratio, (b) Seedling length (cm), (c) Seedling fresh weight (mg seedling^{-1}), (d) Seedling dry weight (mg seedling^{-1}), (e) Vigour index I, (f) Vigour index II in Rice (*Oryza sativa* L., cv. Bidhan Suruchi).

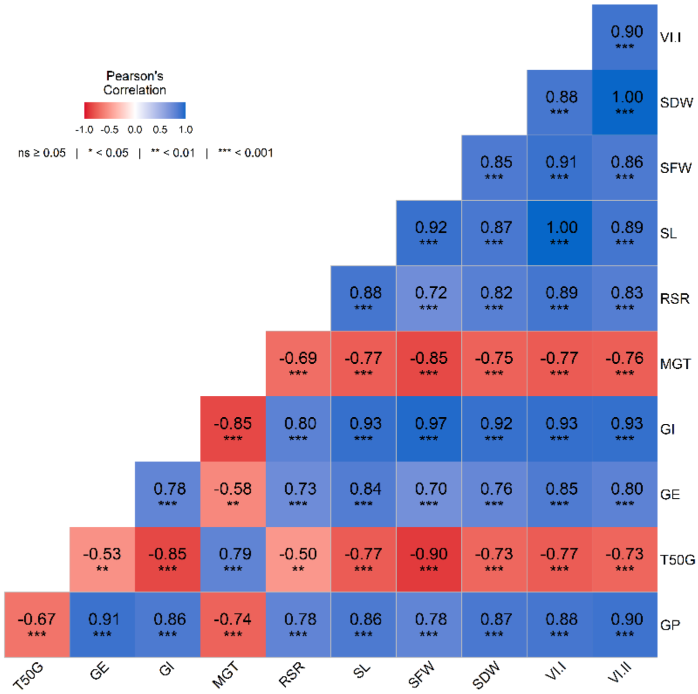

Fig. 3. *Pearson correlation matrix* depicting pairwise correlation coefficients (r) for GP (Germination Potential), T_{50} (Time to 50% Germination), GE (Germination Energy), GI (Germination Index), MGT (Mean Germination Time), RSR (Root–Shoot length Ratio), SL (Seedling Length), SFW (Seedling Fresh Weight), SDW (Seedling Dry Weight), VI-I and VI-II (Vigour Index I and II). Blue cells indicate positive correlations, red cells indicate negative correlations, and colour intensity reflects the magnitude of r. Significance levels are denoted as $p < 0.05$ (*), $p < 0.01$ (**), and $p < 0.001$ (***).

CONCLUSION

The findings show that when treatment is applied at optimal concentrations, it greatly improves seed germination characteristics. Highest germination potential, greatest germination energy, fastest germination, highest vigour, and lowest mean germination time were all consistently demonstrated by T_3 (1.00 mL) in comparison to all other treatments. Among the parameters root shoot ratio, seedling length, fresh and dry weight, and vigour index T_3 (1.00 mL) and T_4 (2.00 mL) consistently produced the best performance. By increasing elongation growth, biomass production, and metabolic efficiency, these treatments promoted superior seedling vigour. On the other hand, most traits decreased with high concentrations of priming (T_5 and T_6), suggesting possible osmotic stress or biochemical inhibition at higher concentrations. Higher concentrations (T_6), on the other hand, decreased seed performance, suggesting possible toxicity or osmotic stress at high concentrations. This implies that the treatment's positive effects are dose-dependent, with moderate dosages encouraging seed vigour and excessive application having negative effects. Therefore, the best treatment for improving early seedling growth and vigour in rice cv Bidhan Suruchi as well as overall germination behaviour is 1.00 mL.

FUTURE SCOPE

To understand the physiological mechanisms underlying increased metabolic activity, antioxidant balance, and nutrient assimilation during early germination, detailed biochemical and molecular analyses are required. Furthermore, standardising extraction protocols, assessing storage stability, and conducting economic feasibility studies will help farmers commercialise and adopt these technologies. Comparative evaluation with other organic byproducts, as well as integration with complementary priming approaches, may help to refine sustainable and environmentally friendly rice seed enhancement strategies.

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How to cite this article: Janapareddy Rajesh, Srijan Samanta and Sanjoy Kumar Bordolui (2026). Impact of Nutri-priming on Germination Dynamics and Early Seedling Vigour in Rice. *International Journal of Theoretical & Applied Sciences, 18*(1), 10–16.