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EFFECT OF STORAGE CONDITIONS ON THE LONGEVITY OF NUTRI AND VERMI PRIMED RICE (*Oryza sativa* L.) SEEDS

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ABSTRACT

Seed priming enhances seed germination and early seedling establishment; however, the reduced storability of primed seeds limits its practical application. The present study evaluated the effect of different storage conditions on the germination, viability, and seed vigour of nutriprimed and vermi-primed rice (*Oryza sativa* L.) seeds during a three-month storage period. The experiment was conducted in a completely randomized design with three replications, comprising 16 treatment combinations. The priming treatments included nutripriming with 0.02% ZnSO₄ + 0.002% Na₂B₈O₁₃ followed by hydropriming, nutripriming with 0.05% Sampoorna followed by vermi-priming with 5% vermiwash, nutripriming with 0.1% Sampoorna followed by vermi-priming with 5% vermiwash, and hydropriming. Seeds were stored under ambient conditions in paper bags, cloth bags, airtight polyethylene bags and airtight polyethylene bags at 2°C. Germination percentage, seed viability, and electrical conductivity were assessed at monthly intervals for three months. Germination and viability gradually declined, whereas electrical conductivity increased with storage duration. Nutripriming with 0.02% ZnSO₄ + 0.002% Na₂B₈O₁₃ followed by hydropriming and stored at 2°C (p₁s₄), nutripriming with 0.1% Sampoorna followed by vermi-priming with 5% vermiwash and stored at 2°C (p₃s₄), and hydropriming stored at 2°C (p₄s₄) maintained higher germination and viability with lower electrical conductivity throughout the storage period. In contrast, primed seeds stored under ambient conditions, particularly in paper and cloth bags, deteriorated rapidly. The results demonstrate that storage in airtight polyethylene bags at 2°C effectively preserves the quality and longevity of primed rice seeds.

Key words : Electrical conductivity, Low temperature storage, Nutripriming, Rice, Seed longevity, Seed longevity, Vermipriming.

Introduction

Rice (*Oryza sativa* L.) is a major staple crop cultivated worldwide and serves as a primary source of carbohydrates. In addition to its nutritional importance, rice contains a wide range of bioactive secondary metabolites that contribute to human health (Sen *et al.*, 2020). High-quality seed is a key component of agricultural production, as it plays a crucial role in improving crop productivity.

Seed priming is an effective pre-sowing technique in which seeds are partially hydrated under controlled

conditions, initiating metabolic activities associated with germination without allowing radicle emergence (Hussain *et al.*, 2015). The primary objective of seed priming is to reduce the time required for seed emergence and enhance seed tolerance to environmental stresses during the critical stages of crop growth, thereby improving crop productivity (Sisodia *et al.*, 2018). During the imbibition phase, controlled water uptake promotes protein synthesis and stimulates respiratory activity. In the pre-germination (Phase II) stage, important metabolic processes are initiated without radicle protrusion. The seeds are

subsequently dried back to their original moisture content to suspend these metabolic activities until sowing (Corbineau *et al.*, 2023). Seed priming activates enzymatic activities, enhances metabolic processes, promotes cellular repair mechanisms, and improves osmotic adjustment, thereby resulting in better seed performance (Arun *et al.*, 2022).

Among the various seed priming techniques, nutripriming has gained considerable attention. Priming seeds with micronutrients has been shown to improve crop growth, development and grain yield by positively influencing the physiological, biochemical, and molecular processes governing plant growth and productivity (Mondal and Bose, 2019). Another promising seed enhancement technique is vermipriming, in which seeds are soaked in vermiwash for a specified period and then dried back to their original moisture content. Vermiwash, an aqueous extract of freshly prepared vermicompost and earthworm surface washings, is rich in beneficial microorganisms and essential nutrients that enhance seed germination and seedling establishment (Khan *et al.*, 2016).

Despite the numerous benefits of seed priming, one of its major limitations is the reduced storability of primed seeds, as they tend to lose viability more rapidly during storage. The effect of seed priming on seed storability may be either beneficial or detrimental, depending on the priming technique, treatment duration and storage environment (Parera and Cantliffe, 1994). Seed deterioration is accelerated under conditions of elevated seed moisture content and oxygen availability, which promote ageing and oxidative damage, ultimately leading to a loss of viability (Tahir *et al.*, 2023). In orthodox seeds, longevity is primarily determined by seed moisture content and storage temperature, with lower moisture content and lower temperatures favouring extended seed longevity (Corbineau *et al.*, 2023). Seed deterioration is accompanied by physiological changes such as reduced germination, increased mean germination time, and a decline in seed vigour. In addition, the type of storage container plays a significant role in maintaining seed quality during storage (Kurubar *et al.*, 2021; Moharana *et al.*, 2017). Therefore, the use of moisture-proof containers, such as polyethylene bags, is essential for preserving seed quality during storage (Vijayalakshmi and Malabasari, 2018).

Although, seed priming has been widely reported to improve seed germination, vigour, and crop establishment, maintaining the quality of primed seeds during storage remains a major challenge. The influence of storage conditions on the longevity of nutriprimed and

vermiprimed seeds has received limited attention. To the best of our knowledge, information on the storability of sequentially nutriprimed and vermiprimed rice seeds under different storage environments is scarce. Furthermore, the interaction between sequential priming treatments and storage conditions has not been adequately investigated. Therefore, the present study was undertaken to evaluate the effects of different storage conditions on the germination and viability of sequentially nutriprimed and vermiprimed rice seeds during storage, with the objective of identifying suitable storage conditions for maintaining the quality of primed seeds

Materials and Methods

Rice (*Oryza sativa* L.) seeds of the variety Prathyasa were used in the experiment. The experiment was laid out in a completely randomized design (CRD) with three replications and consisted of two factors.

The first factor was seed priming, comprising four treatments: (i) nutripriming with 0.02% ZnSO_4 + 0.002% $\text{Na}_2\text{B}_8\text{O}_{13}$ followed by (fb) hydropriming, (ii) nutripriming with 0.05% Sampoorna fb vermipriming with 5% vermiwash, (iii) nutripriming with 0.1% Sampoorna followed by vermipriming with 5% vermiwash and (iv) hydropriming.

The second factor consisted of four storage conditions: (i) ambient temperature in a paper bag, (ii) ambient temperature in a cloth bag, (iii) ambient temperature in an airtight 700-gauge polyethylene bag, and (iv) storage at 2°C in an airtight 700-gauge polyethylene bag. The experiment comprised 16 treatment combinations.

Vermiwash was prepared according to the method recommended by KAU (KAU, 2017). A mixture of 5 kg of cow dung and dried leaves was placed in a transparent 10 L plastic container, and 50–70 g of earthworms was introduced to facilitate the decomposition of the organic matter. The collected vermiwash was considered the 100% stock solution and was diluted with water to obtain the required concentration for seed priming.

Seeds were first nutriprimed in the respective nutrient solutions and dried back to a moisture content of 12%, after which they were vermiprimed with 5% vermiwash according to the treatment. The soaking duration was 12 h for both nutripriming and vermipriming. The primed seeds were stored under the respective storage conditions for a period of three months. Separate containers were maintained for each monthly sampling to avoid disturbance of the remaining seeds during storage. Germination and viability tests were conducted at monthly intervals using the Petri plate assay. Ten seeds were

Table 1 : Treatment combination.

Treatment abbreviation	Treatment combination
p ₁ s ₁	Nutrient priming with 0.02%ZnSO ₄ +0.002% Na ₂ B ₈ O ₁₃ <i>fb</i> hydropriming and stored in paper bag
p ₁ s ₂	Nutripriming with 0.02%ZnSO ₄ +0.002% Na ₂ B ₈ O ₁₃ <i>fb</i> hydropriming and stored in cloth bag
p ₁ s ₃	Nutripriming with 0.02%ZnSO ₄ +0.002% Na ₂ B ₈ O ₁₃ <i>fb</i> hydropriming and stored in 700-gauge airtight polyethylene cover
p ₁ s ₄	Nutripriming with 0.02%ZnSO ₄ +0.002% Na ₂ B ₈ O ₁₃ <i>fb</i> hydropriming stored in 700-gauge airtight polyethylene cover at 2° C
p ₂ s ₁	Nutripriming with 0.05% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in paper bag
p ₂ s ₂	Nutripriming with 0.05% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in cloth bag
p ₂ s ₃	Nutripriming with 0.05% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in 700-gauge airtight polyethylene cover
p ₂ s ₄	Nutripriming with 0.05% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in 700-gauge airtight polyethylene cover at 2° C
p ₃ s ₁	Nutripriming with 0.1% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in paper bag
p ₃ s ₂	Nutripriming with 0.1% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in cloth bag
p ₃ s ₃	Nutripriming with 0.1% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in 700-gauge air tight polyethylene cover
p ₃ s ₄	Nutripriming with 0.1% Sampoorna <i>fb</i> vermipriming with 5% vermiwash and stored in 700-gauge airtight polyethylene cover at 2° C
p ₄ s ₁	Hydropriming and stored in paper bag
p ₄ s ₂	Hydropriming and stored in cloth bag
p ₄ s ₃	Hydropriming and stored in 700-gauge airtight polyethylene cover
p ₄ s ₄	Hydropriming and stored in 700-gauge airtight polyethylene cover at 2° C

placed in each Petri plate per replication and incubated for 14 d. Germination percentage was recorded on the 14th day.

Seed quality assessment

Germination percentage (GP) of the seeds by ISTA (1985) and calculated by

$$GP = \left(\frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \right) \times 100$$

Seed viability was assessed using the tetrazolium test with 1% 2,3,5-triphenyl tetrazolium chloride (TTC) solution, following the method proposed by Lakon (1949). Twenty-five seeds were used for each treatment. Seed vigour was evaluated using the electrical conductivity test. Fifty seeds from each treatment were soaked in deionized water in separate beakers for 24 h, after which the electrical conductivity of the seed leachate was measured using a conductivity meter (Matthews and Powell, 1981).

Statistical analysis

The experimental data were subjected to analysis of

variance (ANOVA) as described by Panse and Sukhatme (1985). Statistical analysis was performed using RAISINS software (Hisham *et al.*, 2025).

Results

Effect of storage of primed seeds on germination percentage

The interaction between priming treatments and storage conditions had a significant effect on germination percentage from 1 to 3 months after storage (MAS), as presented in Table 2. No significant differences among treatments were observed at 1 MAS. At 2 MAS, the treatments p₂s₃ and p₄s₄ recorded the highest germination percentage (100.00 ± 0.00%), which was statistically similar to p₁s₄, p₂s₄, and p₃s₄. The lowest germination percentage (26.67 ± 5.77%) was recorded in p₁s₁.

At 3 MAS, the treatment p₄s₄ recorded the highest germination percentage (100.00 ± 0.00%), which was statistically similar to p₁s₄, p₂s₄, and p₃s₄. The lowest germination percentage (13.33 ± 5.77%) was observed in p₁s₃ and p₃s₃, which were statistically similar to p₂s₁.

Table 2 : Effect of priming and storage condition on the germination percentage (%).

Treatments	Different months of storage (MAS)		
	1	2	3
p ₁ s ₁	100.00±0.00	26.67±5.77 ⁱ	26.67±5.77 ^{ghi}
p ₁ s ₂	96.67±5.77	70.00±0.00 ^{de}	36.67±5.77 ^{ef}
p ₁ s ₃	100.00±0.00	90.00±0.00 ^b	13.33±5.77 ^j
p ₁ s ₄	96.67±5.77	93.33±5.77 ^{ab}	93.33±5.77 ^a
p ₂ s ₁	100.00±0.00	50.00±0.00 ^{gh}	20.00±0.00 ^{ij}
p ₂ s ₂	100.00±0.00	73.33±5.77 ^{cd}	73.33±5.77 ^b
p ₂ s ₃	96.67±5.77	100.00±0.00 ^a	23.33±2.89 ^{hi}
p ₂ s ₄	93.33±11.55	93.33±5.77 ^{ab}	93.33±5.77 ^a
p ₃ s ₁	96.67±5.77	43.33±5.77 ^h	30.00±0.00 ^{fgh}
p ₃ s ₂	96.67±5.77	80.00±10.00 ^c	33.33±5.77 ^{fg}
p ₃ s ₃	96.67±5.77	90.00±0.00 ^b	13.33±5.77 ^j
p ₃ s ₄	96.67±5.77	93.33±5.77 ^{ab}	93.33±5.77 ^a
p ₄ s ₁	96.67±5.77	56.67±5.77 ^{fg}	53.33±5.77 ^c
p ₄ s ₂	100.00±0.00	63.33±5.77 ^{ef}	43.33±5.77 ^{de}
p ₄ s ₃	96.67±5.77	90.00±0.00 ^b	46.67±5.77 ^{cd}
p ₄ s ₄	100.00±0.00	100.00±0.00 ^a	100.00±0.00 ^a
SE m (±)	3	2.76	2.92
CD (p=0.05)	NS	7.962	8.402

NS: Not significant; Values are mean ± SD

Table 3 : Effect of priming and storage condition on the viability percentage (%).

Treatments	Different months of storage (MAS)		
	1	2	3
p ₁ s ₁	100.00±0.00	100.00±0.00	43.33±5.77 ^e
p ₁ s ₂	100.00±0.00	100.00±0.00	46.67±5.77 ^e
p ₁ s ₃	100.00±0.00	100.00±0.00	31.67±2.89 ^g
p ₁ s ₄	100.00±0.00	100.00±0.00	100.00±0.00 ^a
p ₂ s ₁	100.00±0.00	100.00±0.00	35.00±5.00 ^{fg}
p ₂ s ₂	100.00±0.00	100.00±0.00	83.33±5.77 ^b
p ₂ s ₃	100.00±0.00	100.00±0.00	33.33±2.89 ^g
p ₂ s ₄	100.00±0.00	100.00±0.00	100.00±0.00 ^a
p ₃ s ₁	100.00±0.00	100.00±0.00	41.67±2.89 ^{ef}
p ₃ s ₂	100.00±0.00	100.00±0.00	45.00±5.00 ^e
p ₃ s ₃	100.00±0.00	100.00±0.00	35.00±5.00 ^{fg}
p ₃ s ₄	100.00±0.00	100.00±0.00	100.00±0.00 ^a
p ₄ s ₁	100.00±0.00	100.00±0.00	66.67±5.77 ^c
p ₄ s ₂	100.00±0.00	100.00±0.00	58.33±2.89 ^d
p ₄ s ₃	100.00±0.00	100.00±0.00	56.66±5.77 ^d
p ₄ s ₄	100.00±0.00	100.00±0.00	100.00±0.00 ^a
SE m (±)	-	-	2.39
CD (p=0.05)	NS	NS	6.900

NS: Not significant; Values are mean ± SD

Table 4 : Effect of priming and storage condition on electrical conductivity (dS m⁻¹).

Treatments	Different months of storage (MAS)		
	1	2	3
p ₁ s ₁	0.23±0.03	0.30±0.00	0.40±0.00 ^a
p ₁ s ₂	0.20±0.00	0.27±0.06	0.40±0.00 ^a
p ₁ s ₃	0.23±0.06	0.23±0.06	0.40±0.00 ^a
p ₁ s ₄	0.20±0.00	0.20±0.00	0.31±0.01 ^d
p ₂ s ₁	0.27±0.06	0.30±0.00	0.40±0.00 ^a
p ₂ s ₂	0.23±0.06	0.27±0.06	0.34±0.01 ^c
p ₂ s ₃	0.20±0.00	0.20±0.00	0.40±0.00 ^a
p ₂ s ₄	0.22±0.03	0.27±0.06	0.31±0.01 ^d
p ₃ s ₁	0.27±0.06	0.30±0.00	0.40±0.00 ^a
p ₃ s ₂	0.20±0.00	0.20±0.00	0.40±0.00 ^a
p ₃ s ₃	0.27±0.06	0.27±0.06	0.40±0.01 ^a
p ₃ s ₄	0.20±0.00	0.21±0.01	0.32±0.01 ^d
p ₄ s ₁	0.23±0.06	0.27±0.06	0.37±0.01 ^b
p ₄ s ₂	0.23±0.06	0.23±0.06	0.37±0.01 ^b
p ₄ s ₃	0.20±0.00	0.20±0.00	0.37±0.02 ^b
p ₄ s ₄	0.21±0.01	0.23±0.03	0.31±0.01 ^d
SE m (±)	0.02	0.02	0.00
CD (p=0.05)	NS	NS	0.010

NS: Not significant; Values are mean ± SD

Effect of storage of primed seeds on viability percentage

Table 3 presents the effect of the interaction between priming treatments and storage conditions on seed viability from 1 to 3 months after storage (MAS). No significant differences among treatments were observed at 1 and 2 MAS. However, at 3 MAS, the treatments p₁s₄, p₂s₄, p₃s₄, and p₄s₄ recorded higher viability percentages. The lowest viability percentage was recorded in p₁s₃ (31.67 ± 2.89%), which was statistically similar to p₂s₃, p₂s₁, and p₃s₃.

Effect of storage of primed seeds on electrical conductivity

Table 4 presents the electrical conductivity (EC) of primed rice seeds during three months of storage. No significant differences among the treatments were observed at one and two months after storage (MAS). However, significant differences were recorded at three MAS. The highest EC value (0.40 ± 0.00 dS m⁻¹) was observed in P1S1, which was statistically on par with p₁s₂, p₁s₃, p₂s₁, p₂s₃, p₃s₁, p₃s₂ and p₃s₃. In contrast, the lowest EC value (0.31 ± 0.00 dS m⁻¹) was recorded in p₁s₄, which was statistically similar to p₂s₄, p₃s₄ and p₄s₄.

Discussion

Germination percentage and seed viability declined, whereas the electrical conductivity (EC) of seeds increased from the first to the third month of storage (MAS) in all treatments, indicating progressive seed deterioration during storage. This decline may be attributed to membrane degradation, lipid peroxidation, enzyme inactivation and reduced metabolic activity associated with seed ageing. Prolonged storage enhances the peroxidation of unsaturated fatty acids, resulting in membrane disruption and leakage of cellular solutes, thereby reducing seed longevity and germination capacity (Inayat-ur-Rahman *et al.*, 2013). Membrane deterioration also affects starch metabolism in seed embryos and endosperm tissues, leading to reduced germination during storage (Riewe *et al.*, 2017; Wiebach *et al.*, 2020). Oxidative stress and reduced starch degradation capacity in aged seeds further contribute to seed deterioration (Wang *et al.*, 2018). Similar reductions in germination and seed vigour with prolonged storage have been reported by Vange *et al.* (2016) and Kandil *et al.* (2013).

The decline in germination was accompanied by reduced seed viability, as viable seeds possess greater physiological capacity to support successful germination and early seedling establishment (Mangena and Mokwala, 2019). Loss of viability during storage is closely associated with deterioration of membrane integrity and reduced physiological activity, while unfavourable storage conditions accelerate ageing and impair germination performance (Selemani *et al.*, 2023). Similarly, increased EC values reflect reduced seed vigour due to membrane deterioration and leakage of cellular electrolytes during ageing, whereas lower EC values indicate better membrane integrity and reduced deterioration (Han *et al.*, 2023; McDonald, 2000).

Among the interaction treatments, p_1s_4 (nutripriming with 0.02% $ZnSO_4$ + 0.002% $Na_2B_8O_{13}$ *fb* hydropriming and storage at 2°C in an airtight polyethylene bag), p_2s_4 (nutripriming with 0.05% Sampoorna *fb* vermipriming with 5% vermiwash and storage at 2°C), p_3s_4 (nutripriming with 0.1% Sampoorna *fb* vermipriming with 5% vermiwash and storage at 2°C), and p_4s_4 (hydropriming and storage at 2°C) maintained higher germination and viability percentages with lower EC values up to the third month of storage. The superior performance of these treatments may be attributed to the combined effects of priming-induced physiological improvements and favourable storage conditions. Low-temperature airtight storage reduces respiration, oxidative damage, and molecular mobility, thereby slowing deteriorative reactions

and preserving seed longevity. Low temperatures suppress biochemical reactions associated with seed ageing, and storage temperature is a major factor influencing seed deterioration (Buitink *et al.*, 2000; Mira *et al.*, 2015). Seeds stored under low-temperature airtight conditions maintained higher germination and viability percentages with lower EC values compared with those stored under ambient conditions in paper and cloth bags. Porous storage materials facilitate moisture exchange, accelerating deterioration and increasing electrolyte leakage (Kehinde *et al.*, 2022; Kamara *et al.*, 2014). The higher EC values observed under cloth bag storage may be associated with increased membrane damage, lipid peroxidation and solute leakage, which adversely affect germination and seedling performance. Similar improvements in seed quality preservation under favourable storage conditions have been reported by Tu *et al.* (2022) and Hussain *et al.* (2015).

The improved performance of p_1s_4 may also be attributed to zinc and boron supplementation, which enhance membrane stability, enzymatic activity, and antioxidative defence mechanisms. Zinc plays an important role in enzyme activation and membrane protection, whereas boron contributes to membrane functioning, metabolite translocation, protein metabolism, and seed reserve accumulation, thereby improving seed longevity and vigour (Singh *et al.*, 2025; Reddy *et al.*, 2025). Optimum zinc concentration combined with moisture-proof storage has been reported to reduce moisture absorption, fungal infection, and oxidative deterioration, thereby maintaining seed viability and vigour in onion (Abhilash *et al.*, 2023). Similarly, adequate boron availability supports protein synthesis and seed reserve accumulation, contributing to improved seed quality (Archana *et al.*, 2021).

The better performance of p_2s_4 and p_3s_4 may be attributed to the synergistic effects of Sampoorna and vermiwash. Sampoorna provides secondary nutrients such as magnesium and sulphur along with micronutrients including zinc, boron, iron, manganese, copper and molybdenum, which contribute to physiological regulation and maintenance of seed vigour during storage (Thomas *et al.*, 2022). Vermiwash contains essential nutrients, beneficial microorganisms, enzymes such as dehydrogenase, acid phosphatase, and urease, amino acids, humic substances and phytohormones, which enhance metabolic activity, nutrient utilization, membrane stability, and antioxidative defence (Ali *et al.*, 2022; Ramteke *et al.*, 2025). Its neutral pH and mineral composition, including nitrogen, phosphorus, potassium, calcium, magnesium, iron, zinc, and copper, may further

promote reserve mobilization and seedling vigour (Dubey *et al.*, 2025).

Hydropriming alone (p_4s_4) also maintained comparatively higher seed quality during storage. Hydropriming may activate repair mechanisms before drying, improve membrane organization, and reduce deterioration processes, thereby maintaining seed vigour, reducing electrolyte leakage, and preserving germination performance during storage (Toselli and Casenave, 2014).

Conclusion

Priming treatments and storage conditions significantly influenced the longevity of rice seeds. Storage in 700-gauge airtight polyethylene bags at 2°C effectively reduced seed deterioration and maintained germination, viability, and membrane integrity. Among the priming treatments, 0.02% $ZnSO_4$ + 0.002% $Na_2B_8O_{13}$ *fb* hydropriming (p_1s_4), 0.05% Sampoorina *fb* vermi-priming with 5% vermiwash (p_2s_4) and nutripriming with 0.1% Sampoorina *fb* 5% vermi-priming with 5% vermiwash (p_3s_4) were the most effective in maintaining seed quality during three months of storage. Therefore, the integration of suitable seed priming treatments with low-temperature, airtight storage is recommended as an effective strategy for improving the storability of primed rice.

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