



Enhancing Deteriorated Corn (*Zea mays*) Seed Quality through Priming Treatment Using Various Solutions and Soaking Duration

*Peningkatan Mutu Benih Jagung (*Zea mays*) yang Mengalami Deteriorasi melalui Berbagai Priming dan Durasi Perendaman*

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ABSTRAK

Jagung merupakan salah satu tanaman pangan utama sehingga banyak dibudidayakan di seluruh dunia. Benih bermutu tinggi diperlukan sebagai bahan tanam, namun selama penyimpanan akan mengalami kemunduran. Penelitian ini bertujuan untuk meningkatkan mutu benih yang mengalami kemunduran selama penyimpanan. Penelitian dilaksanakan menggunakan rancangan acak kelompok lengkap dengan dua faktor dan empat ulangan. Faktor pertama adalah varietas benih yang terdiri atas Bonanza F1, Favorite, dan P39. Faktor kedua adalah osmopriming, terdiri atas kontrol (tanpa perlakuan), GA₃ 200 ppm selama 18 jam, GA₃ 200 ppm selama 36 jam, PEG 10% selama 12 jam, PEG 10% selama 24 jam, KNO₃ 1% selama 12 jam, dan KNO₃ 1% selama 24 jam. Hasil penelitian menunjukkan Bonanza F1 dan Favorite (kedaluwarsa 2020) memiliki mutu benih lebih rendah dibandingkan dengan P39 (kedaluwarsa 2024). Osmopriming tidak meningkatkan perkecambahan pada Bonanza F1, namun osmopriming dengan PEG 10% dan KNO₃ 1% selama 12 jam meningkatkan daya berkecambah pada Favorite. Osmopriming meningkatkan mutu benih P39 dengan perlakuan terbaik GA₃ 200 ppm selama 18 jam dan PEG 10% selama 12 dan 24 jam pada daya berkecambah, sedangkan GA₃ 200 ppm selama 18 jam dan KNO₃ 1% selama 12 jam pada berat kering kecambah normal. Priming dengan GA₃ 200 ppm selama 18 jam menghasilkan kemunculan radikula yang tinggi pada P39 dan Favorite.

Kata Kunci:

Hormon;
Osmopriming;
Periode penyimpanan;
Perkecambahan;
Radicle emergence

ABSTRACT

Keywords:

Germination;

Hormone;

Osmopriming;

Radicle emergence;

Storage-period

Maize is one of the major staple food crops, so it is widely cultivated worldwide. High-quality seed is important as planting material, but it undergoes deterioration during storage. This study aimed to enhance the quality of deteriorated seeds during storage. The experiment was conducted using a randomized complete block design with two factors and four replications. The first factor was seed variety, comprising Bonanza F1, Favorite, and P39. The second factor was osmopriming treatment, which consisted of control (untreated seeds), GA₃ 200 ppm for 18 h, GA₃ 200 ppm for 36 h, 10% PEG for 12 h, 10% PEG for 24 h, 1% KNO₃ for 12 h, and 1% KNO₃ for 24 h. The results showed that Bonanza F1 and Favorite (expired 2020) had lower seed quality than P39 (expired 2024). Osmopriming did not enhance germination in Bonanza F1, but osmopriming with 10% PEG and 1% KNO₃ for 12 h did enhance germination percentage in Favorite. Priming enhanced the seed quality of seed stored for three months, with GA₃ 200 ppm for 18 h and 10% PEG for 12 and 24 h as the best treatments for germination percentage, while GA₃ 200 ppm for 18 h and 1% KNO₃ for 12 h for seedling dry weight. Priming with GA₃ 200 ppm for 18 hours resulted in higher radicle emergence in P39 and Favorite.

INTRODUCTION

Maize (*Zea mays*) is a member of the Poaceae family and a principal global staple food, making it an extensively cultivated food crop worldwide. Maize kernels are essential for consumption and plant propagation. Demand for maize is projected to increase due to population growth, thereby requiring high-quality seeds for cultivation (Ren et al., 2022). Furthermore, enhancing maize production and addressing climate change requires high-quality seeds consistently available at the onset of the planting season through proper storage.

High-quality seeds defined by viability and vigor are important factors that affect field establishment and maize yield (Lafta & Chilab, 2019). Seed viability assesses whether a seed is alive under controlled laboratory conditions, while seed vigor predicts field performance and storage potential (Vakeswaran, 2023). Seed vigor determines the capacity to germinate and develop robust, uniform seedlings under diverse and suboptimal field conditions. An increase of 1% in seed vigor can enhance maize production by 43.5 kg/ha (Reis et al., 2022). Nevertheless, seed quality deteriorates over extended periods in both controlled and uncontrolled conditions, ultimately leading to a decline in overall performance (Ngangoua et al., 2025).

Seed deterioration is a natural aging process that can be exacerbated by inadequate storage conditions. The deterioration process on seeds ultimately reduces germination capacity. Seeds initially have a high germination rate, but their viability and vigor decline significantly after storage periods prior to planting (Meitankeisangbam et al., 2024). The rate of seed deterioration is influenced by intrinsic seed properties, such as seed coats, genetics, and composition, as well as extrinsic environmental factors related to stored conditions (Deepa et al., 2011). The decline in carbohydrate, protein, and lipid levels during seed storage adversely affected seed quality (Xing et al., 2025). Although seed deterioration is irreversible and reduces quality, certain seed treatments before planting can initiate the early stages of hydration.

Seed hydration treatment or priming, also known as invigoration, was implemented to enhance seed performance prior to planting. Additionally, seed priming has been shown to enhance resistance to abiotic stresses such as drought and salinity (Heidarieh et al., 2024; Sghayar et al., 2023). Priming is a method that exposes seeds to various organic or inorganic chemicals or subjects them to low or high temperatures for a specified duration under controlled conditions (Ntshalintshali et al., 2025). Priming initiates a complex sequence of biochemical alterations in response to the exposure (Farooq et al., 2022). This process stimulates various cellular modifications, including ATP production, enhanced cellular energy, protein and antioxidant synthesis, DNA repair, and lipid accumulation (Arun et al., 2022; Thakur et al., 2022).

Various priming methods such as hydropriming, halopriming, and osmopriming have been used to improve seedling vigor of both staple and horticultural crops. Seed priming commonly uses compounds such as polyethylene glycol (PEG) for osmopriming, potassium nitrate (KNO₃) for halopriming, and kinetin or gibberellic acid (GA₃) for hormonal priming. These substances are utilized before the seeds undergo drying and subsequent planting (Ntshalintshali et al., 2025). Application of PEG₆₀₀₀ for seed priming has been shown to enhance leaf area significantly (Mouradi et al., 2016). It also improves the germination index and vigor of chickpea seeds and *Coronilla varia* seeds under water-stress conditions (Ma et al., 2024). Furthermore, osmopriming with KNO₃ has been shown to enhance seedling performance (Da Rocha et al., 2025), optimize germination rate in chickpea seeds (Choudhury & Bordolui, 2015), and support emergence of bambara groundnut seedlings

(Abdulkareem et al., 2024). Additionally, priming with GA₃ has been found to enhance root length, increase seedling dry weight, and improve vigor index in both soybeans (Ejeta, 2020) and groundnuts (Anivta & Kuswanto, 2026).

Although priming has been applied to various seeds, the specific application of priming to maize seeds that have deteriorated for more than a year remains inadequately defined, particularly regarding suitable solutions and durations needed to improve seedling performance. This research aimed to determine the most effective priming solution and duration for maize seeds stored for over three years.

MATERIALS AND METHODS

Experimental Site and Design

The experiments were conducted at the Agronomy and Horticulture Laboratory, Faculty of Agriculture, Jenderal Soedirman University, from November 2025 to February 2026. This study used a randomized complete block design (RCBD) with two factors and four replications. The first factor was seed variety, which consisted of Bonanza F1 (V1), Favorite (V2), and P39 (V3). The second factor was osmopriming treatment, which consisted of untreated seeds/control (P0), GA₃ 200 ppm for 18 h (P₁), GA₃ 200 ppm for 36 h (P₂), 10% PEG for 12 h (P₃), 10% PEG for 24 h (P₄), 1% KNO for 12 h (P₅), and 1% KNO for 24 h (P₆).

Seed Material and Priming Treatment

The seed materials used in this experiment consisted of three maize varieties with different expiration date labels (Table 1), which were stored at room temperature (29-30 °C) in the laboratory prior to use. Seed priming was performed by soaking the seeds in different osmopriming solutions, viz., GA₃ 200 ppm, PEG 10%, and KNO 1%. The ratio of seeds to priming solution was 1:5 (g/ml). Seeds were then air-dried to their initial moisture content (12%) after the priming treatment finished.

Table 1. Seed characteristics used in the experiment

Seed Variety	Expired Date on Packaging Label	Initial Germination Rate (%)
Bonanza F1	July 2020	93%
Favorite	July 2020	93%
P39	October 2024	93%

Measurement of Germination Indices

Maize seeds were germinated using between paper method in the germination chamber at 23 ±2 °C, 80% relative humidity, and a 12-hour light/dark photoperiod. Each germination experimental unit used 100 seeds. Germination observations were conducted to observe germination percentage (GP), maximum growth potential (MGP), seedling dry weight (SDW), dead seeds, and fresh seeds. GP was calculated using the formula according to ISTA (2024):

$$GP = \frac{NS\ I + NS\ II}{total\ seed\ sown} \times 100\%$$

Note:

NS: normal seedlings on the first count (day 4)

NS II: normal seedlings on the final count (day 7)

MGP was calculated by counting the number of normal and abnormal germinated seed at day 7 using formula according to Sadjad (1994):

$$\text{MGP} = \frac{\Sigma \text{Germinated Seed}}{\Sigma \text{Seed Planted}} \times 100\%$$

Seedling dry weight was determined by weighing the total amount of normal seedlings after drying in the oven at 80 °C for 24 hours, following the method of ISTA 1995. Hard seed was determined by counting the number of seeds that were neither hard nor fresh and had not produced any part of a seedling at the end of the test period (ISTA, 2024). Fresh seed was determined by counting the number of seeds which remain clean and firm and had the potential to develop into a normal seedling at the end of the test period (ISTA, 2024). Radicle emergence (RE) was noted when radicle reached a length of 2 mm. This measurement was taken on the first day of seed planting for the first count at forth days.

Statistical Analyses

The data were analyzed by analysis of variance (ANOVA) using Microsoft Excel 2019. The differences between treatments were analyzed using Duncan's Multiple Range Test (DMRT) at 0.05 probability levels.

RESULT AND DISCUSSION

Germination Percentage

This study reveals a significant interactive effect between seed variety and osmopriming treatments on maize germination percentage (Figure 1). It was observed that long-storage seeds of Bonanza F1 and Favorite (expired 2020) had a lower germination percentage than P39 (expired 2022). Maize seeds experienced a significant decline in germination percentage after 12 months of storage (Raghunauth et al., 2025). Decline in seed viability of maize due to the deterioration process during storage (Anjani et al., 2023). An extended seed storage period triggers oxidative stress that damages biomolecules (carbohydrates, lipids, proteins, and nucleic acids), reduces respiration, causes enzyme degradation and inactivation, and ultimately diminishes germinability (Adetunji et al., 2021).

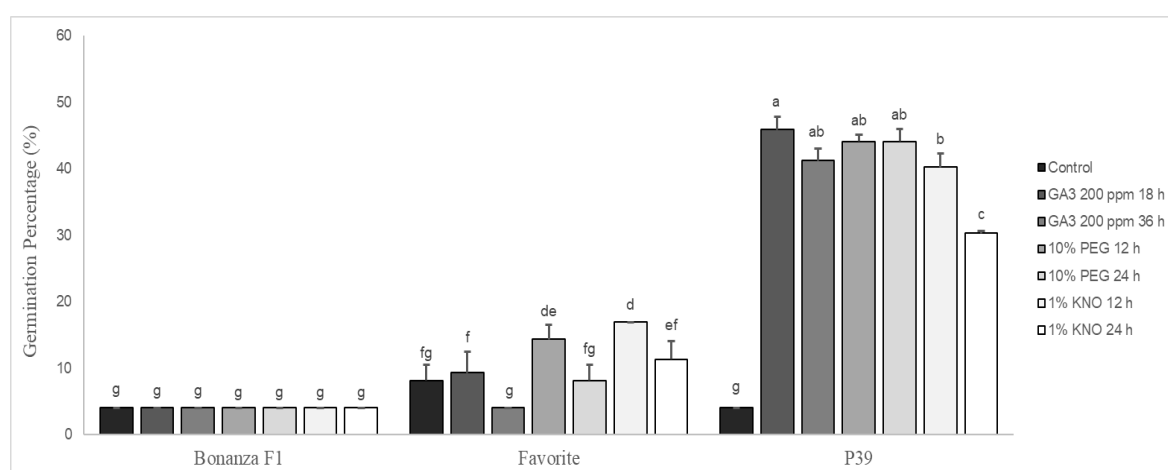


Figure 1. Effect of seed treatments on germination percentage of different maize varieties. Values with the same letter show no significant difference based on the DMRT test at $P < 0.05$. Error bars represent standard errors. Data were transformed using the arcsin+0.5 function.

Among the varieties, Bonanza F1 showed the lowest germination percentage, and none of the seed treatments improved its performance. There was no significant difference in germination percentage among untreated seeds from all varieties. The result revealed that osmopriming with 10% PEG for 12 h and 1% KNO for 12 h enhanced the germination percentage of Favorite by 14.36% and 16.95%, respectively, compared to untreated seeds by 8.15%. All osmopriming treatments increased germination percentage in P39, resulting in better germination performance than untreated seeds. The best osmopriming treatments to increase germination percentage in P39 varieties were GA₃ at 200 ppm for 18 h and 36 h (45.87% and 41.24%), and 10% PEG for 12 h and 24 h (44.14% and 44.13%), compared with the control (4.05%).

Application of GA₃ 200 ppm for 18 hours as a priming treatment has been shown to enhance germination of maize seed stored for five years compared to the control and other treatments (Figure 1). This treatment also enhanced germination of deteriorated bambara groundnut (Anivta & Kuswanto, 2026) and promotes seedling growth in wheat under aging conditions (Ardebili et al., 2019). GA₃ is an essential diterpenoid plant growth regulator that significantly influences various developmental processes within the plant life cycle, including seed germination (Vishal & Kumar, 2018). The appropriate concentration and durations of GA₃ treatment facilitated the breakdown of starch and fat, while also promoting vacuole formation within the cell (Luo et al., 2025).

Maximum Growth Potential

A significant interactive effect was also found between seed variety and osmopriming treatment on the maximum growth potential (Figure 2). The highest maximum growth potential was recorded from P39 varieties, while the lowest was from Bonanza F1. Aged maize seeds exhibited lower germination parameters than fresh seeds due to a decline in the weight of mobilized seed reserve in aging tissues (Kandil et al., 2019). Expression of α -amylase in maize seeds decreased after the ninth month of storage, thereby affecting starch hydrolysis and energy release for germination (Oliveira et al., 2020).

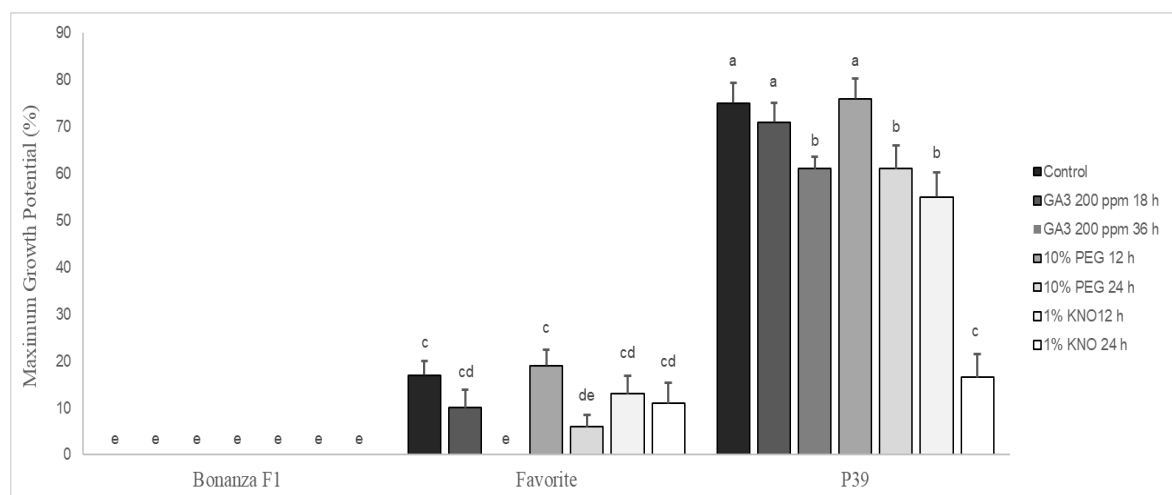


Figure 2. Effect of seed treatments on the maximum growth potential of different maize varieties. Values with the same letter show no significant difference based on the DMRT test at $P < 0.05$. Error bars represent standard errors.

Osmopriming did not enhance maximum growth potential across all varieties. In contrast, GA₃ 200 ppm for 36 h, 10% PEG for 24 h, and 1% KNO for 12 and 24 h reduced the maximum growth potential in P39. Similarly, GA₃ 200 ppm for 36 h and 10% PEG for 24 h reduced the maximum growth potential in Favorite compared to the control. Higher concentrations of KNO₃ delayed seed imbibition and prolonged times to complete phases 1 and 2 during priming, thereby affecting germination performance (Ruttanaruangboworn et al., 2017). Increasing PEG levels during priming treatment reduced germination traits due to high nutrient imbalance in seeds, toxic ions, and reduced soluble osmotic potential (Abiri et al., 2016).

Seedling Dry Weight

Seedling dry weight was also affected by the interaction of seed varieties and osmopriming treatments (Figure 3). The P39 varieties had the highest seedling dry weight among other varieties that had been stored longer. A shorter storage period in maize seed produced higher seedling dry weight, indicating optimal tissue and organ formation through active respiration and biosynthesis of mobilized carbohydrates (Arief et al., 2020). Meanwhile, deteriorated seeds exhibit shrunken embryos, irregular shapes, and structural alterations resulting from substrate depletion and cellular damage (Xing et al., 2025).

No significant difference in seedling dry weight was observed between Bonanza F1 and Favorite across all treatments. Osmopriming treatments did not enhance seedling dry weight in Bonanza F1 and Favorite. Conversely, all osmopriming treatments except 1% KNO for 24 h increased seedling dry weight in P39 compared with untreated seed. The best osmopriming treatments to improve seedling dry weight in P39 were shown to be GA₃ 200 ppm for 18 h (1.40 g) and 1% KNO for 12 h (1.37 g), compared to untreated seed (1.22 g).

Seed hydration triggers the reactivation of metabolic pathways, including respiration and protein synthesis, repairs cellular damage, and accumulates transcripts and enzymes involved in the germination process (Hasanović et al., 2025). Seed priming with GA₃ promotes cell elongation and division, increasing shoot and root length and resulting in higher seedling dry weight (Kumari et al., 2017; Mohammed & Baldwin, 2023). Seed priming with KNO₃ increased seedling dry weight of maize due to the result of a prior increase in radicle and plumule length (Khudhair & Hamza, 2023). Seed presoaking in KNO₃ may reactivate aquaporins and activate amylase activity, which support embryo development (Abdel-Baki et al., 2018).

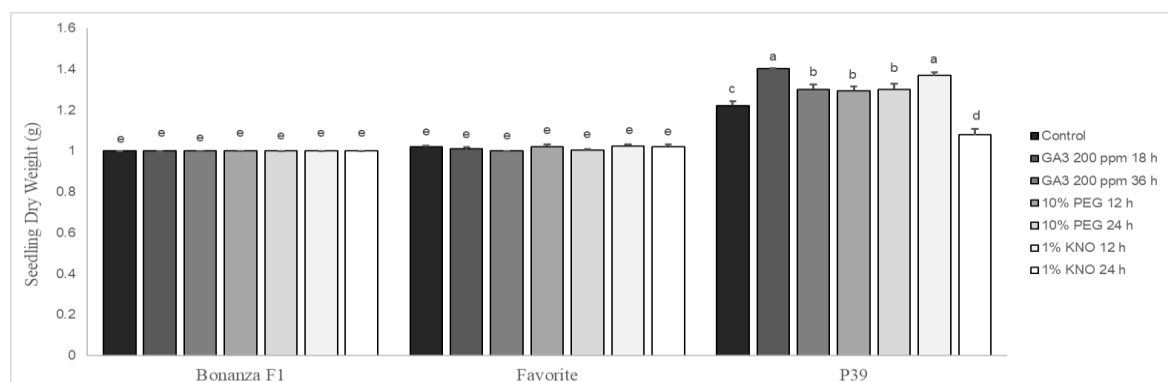


Figure 3. Effect of seed treatments on the maximum growth potential of different maize varieties. Values with the same letter show no significant difference based on the DMRT test at $P < 0.05$. Error bars represent standard errors. Data were transformed using the square root + 1 function.

Dead Seed

The interaction between seed variety and priming treatment was also observed in the dead seed percentage. The P39 showed the lowest percentage of dead seed among all varieties, whereas seed stored longer showed a higher value (Figure 4). Seed deterioration is primarily driven by ROS accumulation, which triggers lipid peroxidation, protein and enzyme degradation, damage to genetic material, loss of membrane integrity, ultimately leading to seed death (Sharma et al., 2025).

Seed treatment with 1% KNO₃ as osmopriming resulted in the highest percentage of dead seeds across all varieties compared to the control (Figure 4). High or unbalanced concentrations of KNO₃ during priming may induce metabolic stress, disrupt hormonal regulation, and lead to a negative outcome due to potential ionic toxicity (Nyasasi et al., 2025). In P39 varieties, the lowest dead seed was observed in all treatments except 1% KNO treatment for 24 h. Whereas in Bonanza F1 and Favorite, the lowest dead seeds were observed in the control and in osmopriming with GA₃ at 200 ppm for 24 h and 36 h. Seed priming with GA₃ activates protective mechanisms such as superoxide dismutase and catalase activities, thereby reducing cellular damage (Fregonezi et al., 2024).

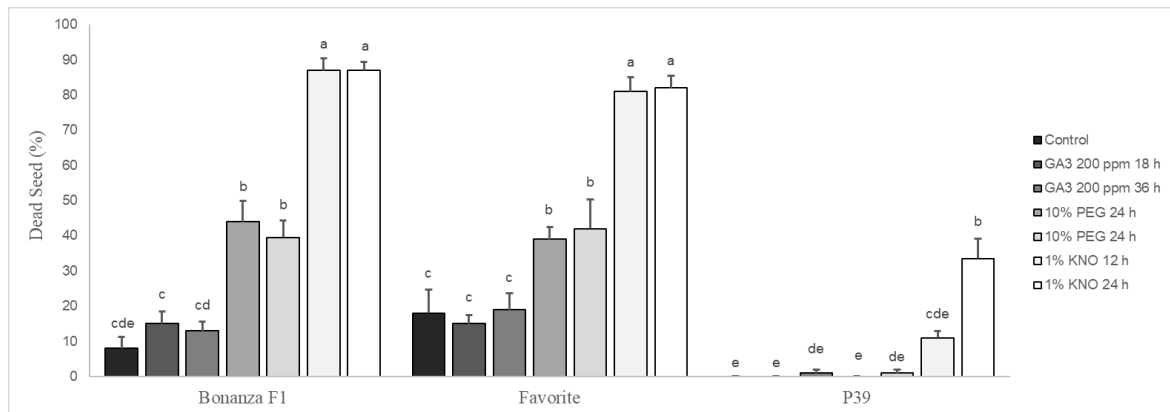


Figure 4. Effect of seed treatments on dead seeds of different maize varieties. Values with the same letter show no significant difference based on the DMRT test at $P < 0.05$. Error bars represent standard errors.

Fresh Seed

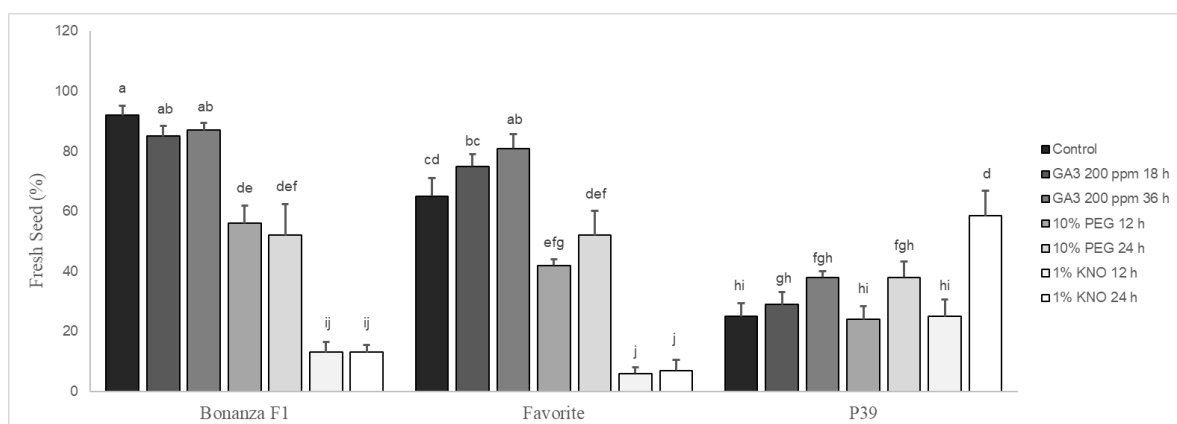


Figure 5. Effect of seed treatments on fresh seeds of different maize varieties. Values with the same letter show no significant difference based on the DMRT test at $P < 0.05$. Error bars represent standard errors.

The result showed a significant interactive effect between seed variety and osmopriming treatment on fresh seed percentage. The P39 showed lower fresh seed percentage than other varieties. In P39, there was no significant difference in the fresh seed percentage, except for osmopriming with 1% KNO₃ for 24 h, which showed the highest value (Figure 5). Bonanza F1 and Favorite, on the other hand, showed a lower fresh seed percentage after treatment with 10% PEG and 1% KNO₃ for 12 and 24 h than in untreated seeds, indicating a decrease in fresh seed but a high increase in dead seed. Bonanza F1 and Favorite have been expired for five years, which is longer than P3, which has been expired for three years since the seeds were primed. The quality of seeds may vary depending on storage conditions, particularly when the seeds are different ages, which affect their potential longevity (Day, 2022). The experiment involving fresh seed viability demonstrated the physical characteristics of the seeds. The viability of the seed must be assessed using tetrazolium test, which serves as an accelerated method to evaluate viability by identifying damage to the seed embryo, a critical component for initial plant development.

Radicle Emergence

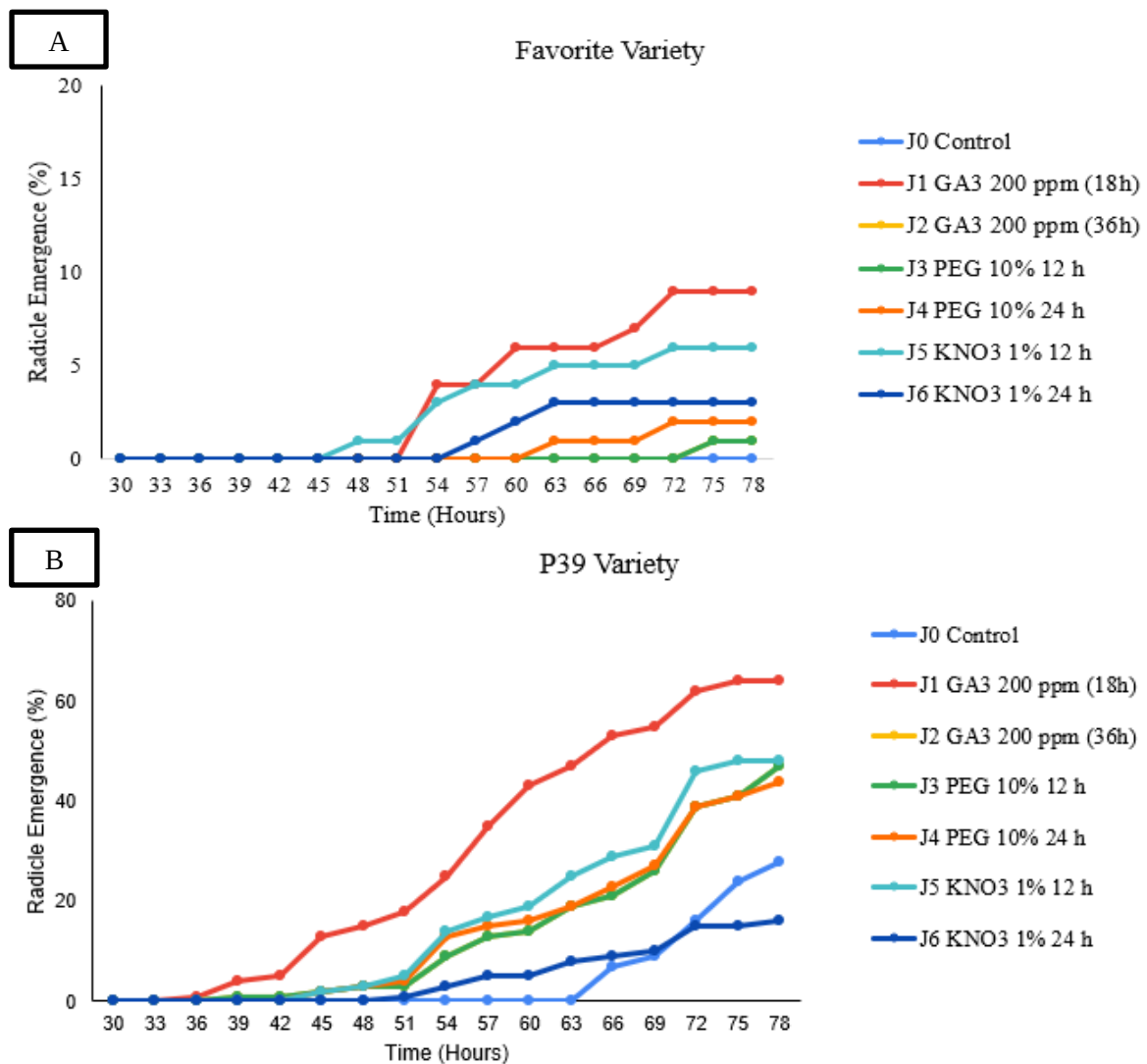


Figure 6. Radicle emergence of Favorite (A) and P39 Variety (B) after priming with various priming solutions and durations

Further evaluation of priming effects on deteriorated seeds focuses on radicle emergence. The P39 variety showed better radicle emergence than Favorite (Figure 6). RE was negatively correlated with maize seed storage period, which tended to decrease as the storage period increased (Anuruk & Thanapornpoonpong, 2024). Priming with 200 ppm of GA₃ 200 ppm for 18 hours resulted in higher radicle emergence in both P39 and Favorite (Figure 6). Priming not only reduced the time required for maize seed emergence but also enhanced the relative emergence percentage of maize (Hacisalihoglu et al., 2018). Particularly, GA₃ improves the performance of maize seedlings under conditions of low water potential (Gnawali & Subedi, 2021). GA₃ functions as an antioxidant and mitigates lipid peroxidation, and thereby facilitating enhanced germination (Shah et al., 2023). Additionally, its increased metabolic plasticity, which constitutes the principal cellular mechanism responsible for inducing growth (Adhikari & Subedi, 2022).

CONCLUSION

Priming treatment with 10% PEG and 1% KNO₃ for 24 and 12 h, respectively, enhances germination in seeds stored for three and five years. Additionally, priming with GA₃ 200 ppm for 18 hours facilitates radicle emergence of seed stored for three and five years. Meanwhile, the most effective priming method for seed stored for three years is GA₃ 200 ppm, which optimizes both germination percentage and radicle emergence.

DAFTAR PUSTAKA

- Abdel-Baki, G. K., Shaddad, M. A. K., Mostafa, D., & Rafat, A.-S. (2018). The Effect of Seed Presoaking with KNO₃ on Seed Germination, Proline, Protein Pattern, β -Amylase and Mineral Composition of Two Faba Bean Cultivars Treated with NaCl. *Egyptian Journal of Botany*, 58(3), 445–461.
- Abdulkareem, Y. J., Muhammad, A. N., Alaba, N. I., Shuaib, M. B., & Musa, A. G. (2024). Effect of seed priming using potassium dihydrogen phosphate on seedlings emergence, growth and yield of Bambara groundnut (*Vigna subterranea* (L) Verdc.). *Journal of Agriculture and Environment*, 20(1), 239–251.
- Abiri, R., Shaharuddin, N. A., Maziah, M., Yusof, Z. N. B., Atabaki, N., Sahebi, M., & Azizi, P. (2016). Quantitative assessment of indica rice germination to hydropriming, hormonal priming and polyethylene glycol priming. *Chilean Journal of Agricultural Research*, 76(4), 392–400.
- Adetunji, A. E., Adetunji, T. L., Varghese, B., Sershen, & Pammenter, N. W. (2021). Oxidative Stress, Ageing and Methods of Seed Invigoration: An Overview and Perspectives. *Agronomy* 2021, Vol. 11, Page 2369, 11(12), 2369.
- Adhikari, S., & Subedi, R. (2022). Effect of seed priming agents (GA₃, PEH, Hydropriming) in the early development of maize. . *RJOAS*, 9(129), 113–633.
- Anivta, P. O., & Kuswanto. (2026). Effect of GA₃ Application on the Germination of 5-Year Stored Bambara Groundnut (*Vigna subterranea* (L.) Verdc.). *Journal of Tropical Crop Science*, 13(01), 148–159.
- Anjani, I. G., Suhartanto, M. R., & Purwito, A. (2023). Pengembangan Metode Devigorasi dengan Pengusangan Cepat untuk Menduga Vigor Daya Simpan Benih Jagung (*Zea mays* L.). *Buletin Agrohorti*, 11(3), 346–357.

- Anuruk, P., & Thanapornpoonpong, S. N. (2024). Effects of Storage Period, Storage Conditions and Packaging Type on Maize Inbred Line Seed Qualities. *Current Applied Science and Technology*, 24(5), e0257439–e0257439.
- Ardebili, Z. M., Abbaspour, H., Afshari, R. T., & Kalat, S. M. N. (2019). Evaluation of Germination and Antioxidant Activity in GA3-Primed Deteriorated Wheat Seed. *Russian Journal of Plant Physiology* 2019 66:6, 66(6), 958–965.
- Arief, R., Koes, F., & Komalasari, O. (2020). Effects of Seed Storage Duration and Matriconditioning Materials on Germination and Seedling Characteristics of Maize. *AGRIVITA Journal of Agricultural Science*, 42(3), 425–434.
- Arun, M. N., Hebbar, S. S., Bhanuprakash, Senthivel, T., Nair, A. K., Padmavathi, G., Pandey, P., & Singh, A. (2022). Seed Priming: The Way Forward to Mitigate Abiotic Stress in Crops. In *Plant Stress Physiology - Perspectives in Agriculture*. IntechOpen.
- Choudhury, A., & Bordolui, S. K. (2015). Inducement of Seed Priming with Potassium Nitrate on quality Performance of Chickpea (*Cicer arietinum* L.). *Biological Forum - An International Journal*, 14(4), 779–783.
- Da Rocha, L. G., Rau, B. A., Da Silva, D. M., De Araújo, R. M., & Masetto, T. E. (2025). Potassium nitrate (KNO_3) seed priming enhances soybean seed performance. *Scientific Reports*, 15(1), 33640-.
- Day, S. (2022). Impact of seed priming on germination performance of fresh and aged seeds of Canola. *International Journal of Agriculture Environment and Food Sciences*, 6(1), 37–40.
- Deepa, G. T., Chetti, M. B., Khetagoudar, M. C., & Adavirao, G. M. (2011). Influence of vacuum packaging on seed quality and mineral contents in chilli (*Capsicum annum* L.). *Journal of Food Science and Technology* 2011 50:1, 50(1), 153–158.
- Ejeta, M. (2020). Effect of Priming on Seed Quality of Soybean [*Glycine max* (L.) Merrill] Varieties at Assosa, Western Ethiopia. *Science Research* 2020, Volume 8, Page 59, 8(3), 59–72.
- Farooq, M. A., Ma, W., Shen, S., & Gu, A. (2022). Underlying Biochemical and Molecular Mechanisms for Seed Germination. *International Journal of Molecular Sciences*, 23(15), 8502.
- Fregonezi, B. F., Pereira, A. E. S., Ferreira, J. M., Fraceto, L. F., Gomes, D. G., & Oliveira, H. C. (2024). Seed Priming with Nanoencapsulated Gibberellic Acid Triggers Beneficial Morphophysiological and Biochemical Responses of Tomato Plants under Different Water Conditions. *Agronomy*, 14(3), 588.
- Gnawali, A., & Subedi, R. (2021). Gibberellic acid priming enhances maize seed germination under low water potential. *Indonesian Journal of Agricultural Science*, 22(1), 17–26.

- Hacisalihoglu, G., Kantanka, S., Miller, N., Gustin, J. L., & Mark Settles, A. (2018).  Modulation of early maize seedling performance via priming under sub-optimal temperatures. *PLOS ONE*, 13(11), e0206861.
- Hasanović, M., Durmić-Pašić, A., & Karalija, E. (2025).  Seed Priming Beyond Stress Adaptation: Broadening the Agronomic Horizon. *Agronomy*, 15(8), 1829.
- Heidarieh, Z., Jafari, A., Ebrahimi, H. R., Jafari Haghighi, B., & Miri, H. R. (2024).  Seed priming alleviates the adverse effects of drought stress on sesame genotypes by improving biochemical and physiological characteristics. *South African Journal of Botany*, 167, 256–269.
- ISTA. (2024).  *International Rules for Seed Testing 2024*. International Seed Testing Association.
- Kandil, A. A., Sharief, A. E., & Ahmed, M. S. (2019).  Seed Germination Characters of New and Aging Seed of Some Maize Hybrids as Influenced by Antioxidant and Growth Hormones. *Global Advanced Research Journal Agricultural Science (GARJAS)*, 8(3), 138–150.
- Khudhair, M. M., & Hamza, J. H. (2023).  Effect of Stimulating Maize Seeds with Potassium Nitrate and Licorice Extract on the Seed Viability and Vigor. *IOP Conference Series: Earth and Environmental Science*, 1225(1), 012093.
- Kumari, N., Rai, P. K., Bara, B. M., Singh, I., & Rai, K. (2017).  Effect of halo priming and hormonal priming on seed germination and seedling vigour in maize (*Zea mays* L.) seeds. *Journal of Pharmacognosy and Phytochemistry*, 6(4), 27–30.
- Lafta, A. K., & Chilab, Y. K. (2019).  Evaluation of the vigor and viability of maize (*Zea mays* L.) Seeds which resultant from planting date and plant density on yield character. *Plant Archives*, 19, 1663–1671.
- Luo, Y., Wang, K., Yao, Y., & Nan, L. (2025).  Exogenous GA3 Promotes Germination by Reducing Endogenous Inhibitors in Sainfoin (*Onobrychis viciifolia*) Seeds. *Plants*, 14(10), 1464.
- Ma, L., Wei, J., Han, G., Sun, X., & Yang, X. (2024).  Seed osmopriming with polyethylene glycol (PEG) enhances seed germination and seedling physiological traits of *Coronilla varia* L. under water stress. *PLOS ONE*, 19(5), e0303145.
- Meitankeisangbam, B., Singh, T. B., Devi, Y. M., & Devi, S. C. (2024).  Physiological Impacts of Seed Ageing on Germination and Seedling Vigour in Brassica Species. *IJFMR - International Journal For Multidisciplinary Research*, 6(6).
- Mohammed, A. H., & Baldwin, B. S. (2023).  Effect of seed priming with gibberellic acid (GA3) on seed germination and seedling growth of some barley varieties (*Hordeum vulgare* L.). *Tikrit Journal for Agricultural Sciences*, 23(2), 190–200.
- Mouradi, M., Bouizgaren, A., Farissi, M., Makoudi, B., Kabbadj, A., Very, A. A., Sentenac, H., Qaddoury, A., & Ghoulam, C. (2016).  Osmopriming improves seeds germination, growth, antioxidant responses and membrane stability during early stage of Moroccan

alfalfa populations under water deficit. *Chilean Journal of Agricultural Research*, 76(3), 265–272.

 Ngangoua, M. H. F., Fokou, R. K., & Kouam, E. B. (2025). Deterioration of maize seeds (*Zea mays* L.) during storage: Evaluating quality components of grains under conservation. *International Journal of Agronomy and Agricultural Research*, 26(4), 20–26.

 Ntshalintshali, S., Sibiya, S. G. P., Mabuza, N., Nkomo, M., & Buthelezi, L. G. (2025). Seed Priming in Legume Crops: Mechanisms, Applications and Future Directions for Enhanced Germination, Growth and Abiotic Stress Tolerance in Sustainable Agriculture: A Review. *Journal of Agronomy and Crop Science*, 211(5), e70115.

 Nyasasi, M., Madege, R., Mwaipopo, B., Nyasasi, M., Madege, R., & Mwaipopo, B. (2025). Effects of KNO₃ on Germination Rate and Seedling Vigor of Macadamia Seeds in Morogoro, Tanzania. *Open Access Library Journal*, 12(9), 1–11.

 Oliveira, T. L. de, Von Pinho, R. G., Dos Santos, H. O., Silva, K. M. D. J., Pereira, E. D. M., & Souza, J. L. D. (2020). Biochemical changes and physiological quality of corn seeds subjected to different chemical treatments and storage times. *Journal of Seed Science*, 42, e202042038.

 Raghunauth, R., Bacchus, Z., Chandranauth, R., & Singh, J. (2025). Evaluation of seed viability at various storage temperatures for different types of seed. *Agricultural Sciences*, 16(5).

 Reis, V. U. V., Penido, A. C., Carvalho, E. R., Rocha, D. K., Reis, L. V., & Semolini, P. H. Z. (2022). Vigor of maize seeds and its effects on plant stand establishment, crop development and grain yield. *Journal of Seed Science*, 44, e202244020.

 Ren, H., Liu, M., Zhang, J., Liu, P., & Liu, C. (2022). Effects of agronomic traits and climatic factors on yield and yield stability of summer maize (*Zea mays* L) in the Huang-Huai-Hai Plain in China. *Frontiers in Plant Science*, 13, 1050064.

 Ruttanaruangboworn, A., Chanprasert, W., Tobunluepop, P., & Onwimol, D. (2017). Effect of seed priming with different concentrations of potassium nitrate on the pattern of seed imbibition and germination of rice (*Oryza sativa* L.). *Journal of Integrative Agriculture*, 16(3), 605–613.

Sadjad, S. (1994). *Kuantifikasi Metabolisme Benih*. Grasindo.

 Sghayar, S., Debez, A., Lucchini, G., Abruzzese, A., Zorrig, W., Negrini, N., Morgutti, S., Abdelly, C., Sacchi, G. A., Pecchioni, N., & Vaccino, P. (2023). Seed priming mitigates high salinity impact on germination of bread wheat (*Triticum aestivum* L.) by improving carbohydrate and protein mobilization. *Plant Direct*, 7(6), e497.

 Shah, S. H., Islam, S., Mohammad, F., & Siddiqui, M. H. (2023). Gibberellic Acid: A Versatile Regulator of Plant Growth, Development and Stress Responses. *Journal of Plant Growth Regulation*, 42(12), 7352–7373.

Sharma, D., Deorari, M., Rawat, D., & Tomar, A. (2025). Seed ageing and deterioration: A comprehensive review of mechanisms and management. *The Pharma Innovation Journal*, 14(12), 185–189.

Thakur, M., Tiwari, S., Kataria, S., & Anand, A. (2022). Recent advances in seed priming strategies for enhancing planting value of vegetable seeds. *Scientia Horticulturae*, 305, 111355.

Vakeswaran, V. (2023). Assessing the Potential Seed Vigor of Rice Varieties. *International Journal of Environment and Climate Change*, 13(11), 1765–1769.

Vishal, B., & Kumar, P. P. (2018). Regulation of seed germination and abiotic stresses by gibberellins and abscisic acid. *Frontiers in Plant Science*, 9, 368905.

Xing, W., Li, Y., Zhou, L., Hong, H., Liu, Y., Luo, S., Zou, J., Zhao, Y., Yang, Y., Xu, Z., & Tan, B. (2025). Deciphering Seed Deterioration: Molecular Insights and Priming Strategies for Revitalizing Aged Seeds. *Plants*, 14(11), 1730.