

# Advances In Seed Technology: Improving Germination And Vigor For Agricultural Productivity

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## Abstract

The present research focuses on the effects of seed enhancement technologies genetic modification, seed priming, and seed coating on germination capacity and seed vigor under laboratory conditions. Seeds were evaluated for physical characteristics, treated for microbiological quality control, and tested for germination and vigor following ISTA standards. Germination percentages were significantly higher in Genetic Modification seeds (95%) seeds treated with fertilizer (90%) and primed seeds (85%) than in the control seeds (70%). Vigor test results revealed that the genetically modified seeds had a higher vigor index of 4275, with an appreciable increase in seeds coated with fertilizer 4050 and primed seeds 3825. The result of the seedling growth study also showed that the genetically modified seeds had the longest root (6.5 cm) and shoot (5.5 cm) length. Higher levels of treatments were found to be effective in increasing germination, vigor, and seedling growth parameters with the prospects of increasing crop emergence and yield. These differences were confirmed by a one-way ANOVA test at a significance level of 0.05. The study focuses on the application of new-generation seeds in solving issues affecting agriculture and finding ways of enhancing the productivity and survival of crops.

**Keywords:** Germination, seed quality, genetic engineering, seed treatments, seed enhancement

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## INTRODUCTION

Seed technology is a relatively young science that studies the quality, performance, and adaptability of seeds in agricultural production. It covers a broad field of science such as genetics, agronomy, seed physiology, and biotechnology to improve seed quality and the likelihood of germination and seedling vigor (Yadav & Singh 2024). Seed technology goes beyond the technical handling of seeds through cleaning, coating, and packaging, but encompasses new trends in seed technology like seed priming, genetic engineering, and the use of biotechnology to enhance seed performance under different conditions (Haidar *et al.*, 2024). Every process of cultivation begins with seeds these are the key to crop production. Agricultural practices are greatly determined by the type of seed that is planted in the ground (Molina *et al.*, 2024). New-generation seed technology has made much progress in enhancing seed quality including vigor, resistance to diseases, and drought which has paramount importance in determining yield and food security (Ali *et al.*, 2024). This continuous improvement of seed technology is important to feed the growing world population and this is more so due to climate change and changing methods of farming (Raji *et al.*, 2024). Germination and its vigor are some of the most important plant parameters that determine crop emergence and yield. Germination typically refers to the stages of seed development for which, once a seed absorbs water, the radicle or root, emerges from the seed coat (Silva *et al.*, 2024). Germination rates and uniformity have a major influence on the establishment of crops in the field. Germination is not the ultimate factor, seed vigor is as important as germination, and vigor is the ability of the seed to perform under less than optimum conditions for germination and seedling emergence and growth (Zhang, 2021). Seed vigor is a measure of seed potential for germination and growth under less than optimum conditions such as drought, low temperatures, or poor soil conditions. Vigor is an attribute of seed, which is a function of its physiological and biochemical properties that define seed's ability to withstand stress during early growth stages (Chandra *et al.*, 2024). Fast germinating and uniform emergence high vigor seeds are associated

with better stand establishment, uniformity, and productivity of the crop (Matilla, 2024). Technologies that promote seed vigor are important in improving yields, especially in areas with unstable weather or substandard land. For example, seed priming and seed coating the well-known methods in seed enhancement technologies aimed at preconditioning seeds to ultimately improve germination rates and seedling emergence (Lu *et al.*, 2024). Seed technology in agriculture is not confined to seed germination and vigor improvement only. In recent years, seed technology has embraced several technological advancements to respond to the emerging issues that affect agriculture all over the world including climate change, pest resistance, and increased global food demand (Rajamuthuramalingam *et al.*, 2024). Another highly beneficial factor of seed technology is the combination of GM and biotechnology for seeds. GM seeds have been produced to reduce vulnerability to pests, diseases, and abiotic factors including drought and salinity hence enhancing crop yields (Raza *et al.*, 2024). For instance, Bt cotton and herbicide-tolerant soybeans have been adopted on a large scale since they enable, improved control over pests and better yields. In addition, the technological improvement and implementation of molecular breeding and genomics have enhanced the opportunities of having higher-yielding stress-tolerant varieties through MAS and gene editing technologies (Bunjkar *et al.*, 2024). These technologies use traits that enhance germination, vigor, and performing ability to enhance crops that would better fit changing conditions (Gunadasa *et al.*, 2024). The other area of seed technology is seed coatings and treatments. Seeding with a layer of fertilizers, pesticides or growth promoters enhances seed germination and seed protection from diseases and pests (Janbandhu *et al.*, 2024). New-generation seed treatment, including nano seed treatment, is under consideration for better germination and seedling vigor, especially under stress conditions (Shelar *et al.*, 2024). Precision agriculture has also affected seed technology given the growing use of digital technologies. These technologies include remote sensing, artificial intelligence, and machine learning to enable proper seed choices, planting, and handling, increasing productivity and efficiency (Singh & Rai, 2024). For instance, precision agriculture tools that include sensors can detect the moisture and temperature of the soil and other environmental factors within a crop field to help farmers determine when and where to plant the seed and manage irrigation so that seeds get the best atmospheric conditions they need for germination and growth (Barrows *et al.*, 2014). The need for seed technology is underlined by the fact that it is used in food security all over the world. It is for this reason that with the increase in the world's population, the world is likely to face a huge demand for food (Margay & Hassan, 2024). In response, seed technology provides solutions for making crops more resistant, productive, and sustainable (Ganie *et al.*, 2024). Technologies like drought-resistant seeds, hybrid seeds, and efficient seed distribution mechanisms help in attaining food security goals with the least harm to the environment (Kolur *et al.*, 2024).

### Objective of the Study

1. The purpose of this study is to determine the effect of advanced seed technologies, including genetic modifications, seed priming, and seed coating, on germination potential and seed vigor under different environments.
2. To assess the effectiveness of new seed-applied technologies and precision farming technologies in promoting establishment, yield, and abiotic and biotic stress resistance in crops.

## MATERIALS AND METHODS

### Seed Selection and Treatment

Seeds employed in the work were chosen depending on their size, shape, and physical characteristics to reduce variability. Samples of seeds used in the study were healthy and mature seeds from certified seeds to enhance the accuracy of results. The seeds were washed with distilled water and debris was removed, then the seeds were treated with 1 % sodium hypochlorite for 10 minutes to eliminate microbial growth. The prepared seeds were left to air dry at room temperature before proceeding with other tests.

### Germination Testing Procedures

Germination tests were done according to the ISTA rules. One hundred seeds were taken at random and sown on moist filter paper in Petri dishes. The petri dishes were kept in a controlled incubator at  $25 \pm 2^\circ\text{C}$  and a light/dark cycle was maintained at 12/12 hrs. During the testing, the filter papers were moistened with distilled water whenever they appeared to be dry. Radical emergence was observed daily for 7 days, and seeds were considered germinated once the radical grew to a length of 2mm or more. The percentage of germination in the final experiment was obtained by using the formula:

### Vigor Testing Methods

Seed vigor was assessed using two methods the accelerated aging test as well as seedling growth assessment. In the accelerated aging test, seeds were kept in high humidity (100%) and at a temperature of  $42^\circ\text{C}$  for 72 hours. After

aging, the seeds were tested for germination as explained above, and the germination percentage was noted. Evaluation of seedling growth included determination of root and shoot lengths of seedlings developed from germinated seeds after 7 days. The vigor index was calculated using the formula:

$$\text{Vigor Index} = (\text{Root Length} + \text{Shoot Length}) \times \text{Germination Percentage}$$

### Statistical Analysis

The results of germination and vigor tests were statistically processed with the help of special programs. Mean and standard deviations were used as a measure of descriptive statistics. Inter-group comparisons were done using one-way ANOVA and intra-group comparisons were done using Tukey’s post-test. Statistical significance was set at  $p < 0.05$ . Data was analyzed using mean  $\pm$  standard deviation and graphical analysis was done to enable a better understanding of the trends.

## RESULTS

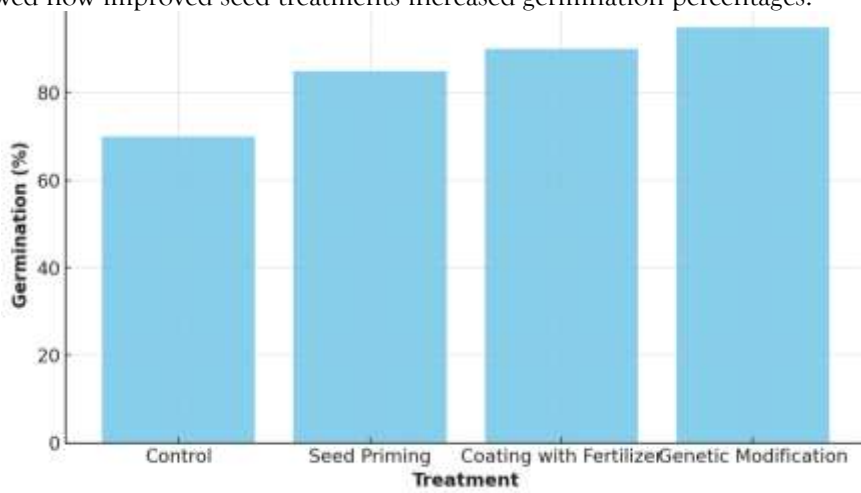
### Seed Germination Rates

The advanced seed treatments enhanced germination percentages as compared to the control group had a minimum germination rate that was 70 percent in Table 1. Among the treatments, genetic modification gave the highest percentage germination of at 95% while the second best method was coating with fertilizer with 90% and seed priming with 85%. These findings also pointed to the fact that modern seed technologies have the potential to improve germination performance.

**Table 1:** Germination Percentages Across Treatments

Treatment	Germination (%)
Control	70
Seed Priming	85
Coating with Fertilizer	90
Genetic Modification	95

The germination percentages are presented in Figure 1, by seed treatments. The mean germination rate of the control group was the lowest at seventy percent while through genetic modification it was the highest at ninety-five percent. Seed priming and coating with fertilizer also enhanced with 85% and 90% germination, respectively. These results showed how improved seed treatments increased germination percentages.



**Figure 1:** Germination Percentages Across Treatments

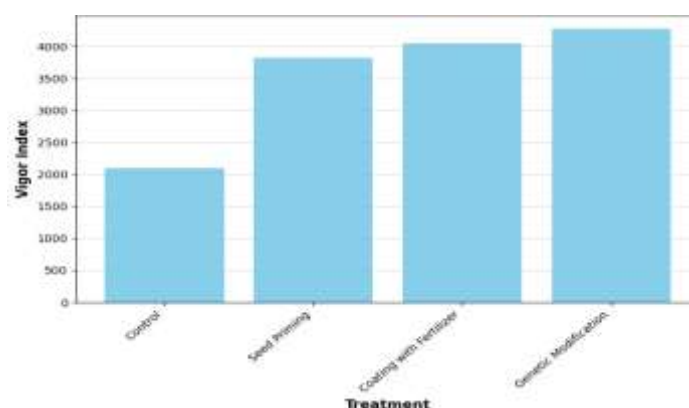
### Seed Vigor Assessment

The seed vigor index on different treatments were shown in Table 2. The control group had the lowest vigor index of 2100 implying that there was poor seedling vigor. The vigor was improved by the advanced treatments, with genetic modification scoring the highest at 4275, coating with fertilizer at 4050, and seed priming at 3825. These studies drew attention to the use of modern seed technologies in enhancing seedling strength and growth capacity.

**Table 2: Seed Vigor Index Across Treatments**

Treatment	Vigor Index
Control	2100
Seed Priming	3825
Coating with Fertilizer	4050
Genetic Modification	4275

The seed vigor index was illustrated in Figure 2, showing the result of the various treatments. The control group underwent the lowest vigor index of 2100, which was an indication of poor seedling growth. Genetic modification on the other hand gave the highest vigor index of 4275, fertilizer coating 4050, and seed priming 3825. These results showed that advanced seed treatments can be used to improve seedling vigor and potential for emergence.



**Figure 2: Seed Vigor Index Across Treatments**

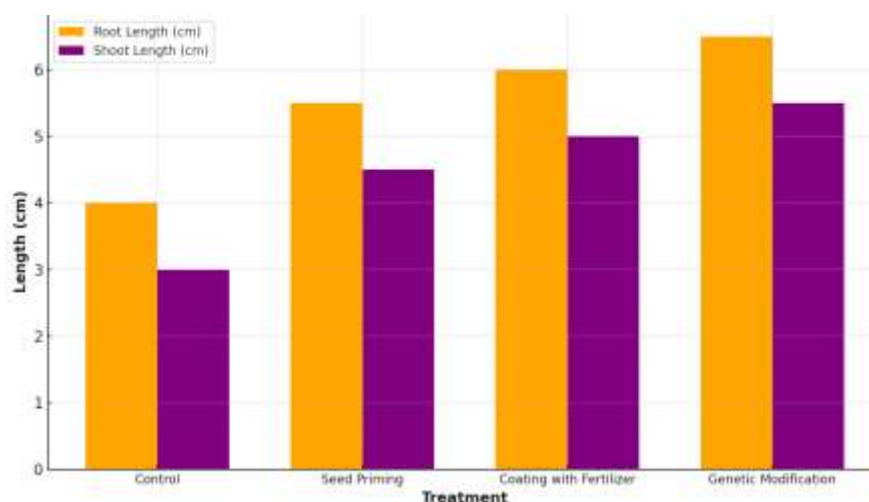
### Comparative Analysis of Different Seed Treatments

The seedling growth indicators of the treatments for root and shoot growth was shown in Table 3. The control group was seen to have the shortest root length of 4.0cm and shoot length of 3.0cm showing the least growth. Data on root and shoot lengths showed that genetic modification produced the longest root (6.5 cm) and shoot (5.5 cm) lengths and this was closely followed by coating with fertilizer and seed priming. These results therefore supported the hypothesis that advanced treatments had a better effect on seedling growth parameters.

**Table 3: Seedling Growth Metrics Across Treatments**

Treatment	Root Length (cm)	Shoot Length (cm)
Control	4.0	3.0
Seed Priming	5.5	4.5
Coating with Fertilizer	6.0	5.0
Genetic Modification	6.5	5.5

The seedling growth parameters, namely the root and shoot length, were shown in Figure 3 under different treatments. Genetic modification was found to increase the longest root (6.5 cm) and shoot (5.5 cm) lengths and these were enhanced by coating with fertilizer and seed priming. The untreated control had the least growth with roots having an average length of 4.0 cm and shoots of 3.0 cm.



**Figure 3:** Seedling Growth Metrics Across Treatments

## DISCUSSION

The germination data show that seeds treated with the advanced methods have a higher germination rate than the seeds of the control group. The results showed that seeds genetically modified had the highest germination percentage (95%), seeds coated with fertilizer (90%), and seeds that underwent priming techniques (85%). These observations support the role of technological measures in increasing seed performance, which may be attributed to better water imbibition, nutrient access, and enzymatic action required for germination (ISTA, 2020). Seed vigor indices also support the enhanced treatments with a vigor index of 4275 for the genetically modified seeds and 4050 for the seeds treated with fertilizer coating. The vigor index is an index of seedling growth and germination, which shows an improved ability to establish good-quality crops. More vigor therefore leads to improved resistance of crops to environmental stresses thereby boosting agricultural yield (Rosbakh *et al.*, 2024). The application of priming and fertilizer coating on the seeds has shown a lot of potential in enhancing both germination and seedling vigor. Seed priming enhances an initial metabolic activity before germination, while fertilizer coating provides nutrients that are required immediately after germination (Pieraccini *et al.*, 2024). These technologies are inexpensive approaches to enhancing crop productivity without radical genetic modifications, meaning that smallholder farmers can practice them (Farooq *et al.*, 2019). The results reported here were determined under a controlled environment and therefore there can be variations under field conditions concerning factors such as temperature, moisture, and light about soil. Some of these environmental issues can be managed by advanced seed technologies. For instance, coated seeds are preferred in that they do not easily crack under drought stress because they can hold water. Nonetheless, the effectiveness of these technologies could be different under extreme weather conditions, which makes the need for field testing of the technologies in different environments for agriculture (Gazzarrini & Song, 2024). There are still barriers to the use of advanced seed technologies for agricultural development. This is because genetic modification may be very expensive to undertake and the development of standard seed treatments may not be very straightforward. Moreover, the legal constraints that have been put in place for the production and use of genetically modified seeds. The opportunities are significantly large. Precision agriculture and automation are two fields that can work hand in hand with seed technologies, producing positive interactions that increase crop productivity and durability. Reductions in costs and acceptability of seed treatment could be achieved by continued research into environmentally sound methods of seed treatment.

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