INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 08 Issue 12 December 2025

DOI: 10.47191/ijmra/v8-i12-34, Impact Factor: 8.266

Page No. 6875-6887

Effectiveness of Germination Stimulants On the Viability and Vigor of Arabica Coffee Seeds of Kopyol Variety and Lini S 795 Variety

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ABSTRACT: This study is a laboratory-based experimental research aimed at evaluating the effectiveness of germination stimulants on the viability and vigor of Arabica coffee (Coffea arabica L.) seeds, specifically the Kopyol and Lini S 795 varieties, which are important plantation commodities in Bali Province. The decline in Arabica coffee production due to aging plants has increased the need for high-quality seeds, yet seed dormancy and hard seed coats remain major barriers to optimal germination. The objectives of this research were to determine the influence of various germination stimulants on seed physiological performance and to identify the most effective treatment for enhancing germination and early seedling growth. The experiment was conducted in December 2024 at the UPTD Laboratory of Seed Testing and Certification for Food Crops, Horticulture, and Plantation, Bali Province, using a Nested Design with two factors: coffee varieties (Kopyol and Lini S 795) and germination stimulants (water, 25% young coconut water, 100 ppm GA_3, 20% H_2SO_4, and 0.3% KNO_3). Observed parameters included germination rate, maximum growth potential, germination speed, uniformity, radicle length, shoot height, vigor index, fresh weight, and dry weight. The results showed that germination stimulants significantly improved both viability and vigor of Arabica coffee seeds. The 0.3% KNO_3 treatment applied for 24 hours produced the highest germination rate (92%), maximum growth potential (94%), and vigor index. The Kopyol variety exhibited superior physiological responses compared to Lini S 795. Based on these findings, the application of 0.3% KNO_3 is recommended as the most effective germination stimulant to enhance the physiological quality of Arabica coffee seeds, particularly the Kopyol variety, supporting rejuvenation programs for coffee cultivation in Bali Province.

KEYWORDS: Arabica coffee, Kopyol, Lini S 795, KNO_3, seed viability, seed vigor.

INTRODUCTION

Arabica coffee (*Coffea arabica* L.) is one of the most valuable plantation commodities because of its high economic importance and the increasing demand in both domestic and international markets. In Indonesia, coffee consumption continues to rise along with the growing coffee culture and the expansion of modern coffee shop industries. At the global level, the demand for Indonesian coffee remains strong, which is reflected in national coffee exports reaching approximately 206,700 tons in the first half of 2025 (Antara 2025). Arabica coffee contributes about 25 to 30 percent of the total coffee production in Indonesia, making it a strategic commodity that supports global market needs (BRMP Perkebunan 2025). This growing demand for high quality coffee highlights the need to improve farmer level productivity through the provision of high quality seeds that ensure sustainable production and consistent quality.

Bali Province is known as a producer of Arabica coffee with distinctive flavor characteristics that have gained international recognition. The Kopyol and Lini S 795 varieties are among the superior Arabica coffee varieties cultivated in Bali. The Kopyol variety is recognized for its strong adaptability in highland environments and its resistance to leaf rust, while the Lini S 795 variety is valued for its high yield potential and resistance to the same disease. Although both varieties have excellent production potential, the success of seed propagation is affected by several external factors, including seed physiological quality, storage conditions, and seedling management during the germination phase.

Data from the Central Statistics Agency of Bali Province show that Arabica coffee production has decreased from 3,983 tons in 2021 to 3,644 tons in 2023. One major factor behind this decline is the aging of coffee plants, which makes rejuvenation and replanting necessary. These efforts require high quality seeds that are capable of producing strong and productive plants (Abay, 2022). High quality seeds must have good viability and vigor, because seeds with high viability and vigor grow into normal plants that are able to germinate successfully and adapt well to diverse environmental conditions.

Seed provision is an essential first step in crop cultivation and greatly influences plant productivity (Bakri, 2019). According to the Indonesian Seed Law Number 22 of 2019, seeds are defined as plants or plant parts used for reproduction and multiplication. Coffee can be propagated through vegetative methods such as grafting and cuttings or through generative methods using seeds. Generative propagation offers several advantages, including the production of healthier plants with deeper taproots that provide better tolerance to drought, flooding, and lodging.

The Ministry of Agriculture Regulation Number 27 of 2021 states that certified coffee seeds must have a minimum germination rate of eighty percent. Germination is the early growth process of the embryo and seed structures that lead to the development of a new plant (Handi & Sari, 2018). The germination percentage is therefore used to determine seed viability and to describe seed vigor, which relates to the ability of a seed to grow rapidly and uniformly under a wide range of environmental conditions (Sutopo 2012).

Germination in Arabica coffee seeds often encounters constraints, especially seed dormancy. After fruits reach maturity and seeds are harvested, the seeds commonly enter a dormant state that prevents germination even under ideal environmental conditions (Idha et al. 2017). Dormancy functions as a survival mechanism, but it also prolongs the germination process and reduces the efficiency of seedling production (Wahyuni et al. 2021). The physical characteristics of coffee seeds, particularly their hard endocarp, slow down water absorption and further delay germination (Tefa, 2017).

Dormancy can be overcome through various techniques such as soaking seeds in water, reducing seed coat thickness, applying chemical treatments, or storing seeds in alternating warm and cool moist environments (Wicaksono, 2010). Scarification is commonly used to ease water penetration and activate dormant cells (Widajati et al. 2013). In coffee seeds, scarification can be performed manually by removing the hard endocarp or chemically through substances such as gibberellic acid, potassium nitrate, or sulfuric acid.

Research has shown that the application of germination stimulants can improve physiological seed quality. Nisa (2020) reported that soaking Arabica coffee seeds in gibberellic acid at five hundred parts per million for twenty four hours increased root length, hypocotyl height, and seedling biomass. Sulfuric acid at a concentration of twenty percent has been shown to soften the coffee seed coat and increase germination speed (Wardana et al. 2023). Potassium nitrate has also been effective in improving germination rate, speed, uniformity, and seedling growth in several plant species (Sela et al. 2018). These findings indicate that germination stimulants may enhance seed viability and vigor by accelerating germination and promoting early growth.

Germination stimulants such as potassium nitrate, growth promoting substances, and coconut water influence internal metabolic processes that trigger germination (Ardi. 2021). Their effectiveness is evaluated based on increases in germination percentage, germination speed, and early seedling development (Handi et al. 2018). However, studies evaluating the effectiveness of germination stimulants specifically on Kopyol and Lini S 795 Arabica coffee varieties are still limited.

For these reasons, this research aims to examine the effectiveness of germination stimulants on the viability and vigor of Arabica coffee seeds of the Kopyol variety and the Lini S 795 variety. The results of this study are expected to support seed quality improvement efforts and contribute to sustainable coffee production in Bali.

RESEARCH METHOD

Research Time and Location

The research was conducted in December two thousand twenty four at the Laboratory of the Seed Testing and Certification Unit for Food Crops, Horticulture, and Plantation under the Department of Agriculture and Food Security of Bali Province.

Research Tools and Materials

The tools used in this study included tweezers, basins, rulers, a digital scale, a hand sprayer, measuring cylinders, and writing instruments.

The materials consisted of Arabica coffee seeds of the Kopyol variety and the Lini S seven hundred ninety five variety obtained from the official seed source gardens of the Department of Agriculture and Food Security of Bali Province. Additional materials used were sand media, sand trays, distilled water, alcohol, gibberellin GA three, potassium nitrate K N O three, sulfuric acid H two S O four, and young coconut water.

Research Design

This study employed an experimental method using a Nested Design consisting of two factors.

The first factor was Arabica coffee variety coded as A with two levels:

A k = Arabica coffee Kopyol variety

A l = Arabica coffee Lini S seven hundred ninety-five variety

The second factor was germination stimulants coded as P with five levels:

P a = seed soaking in water control

P c = seed soaking in twenty-five percent young coconut water for twenty-four hours

P g = seed soaking in one hundred ppm gibberellin for twenty-four hours

P h = seed soaking in twenty percent sulfuric acid for twenty minutes

P k = seed soaking in zero point three percent potassium nitrate for twenty-four hours

Each treatment combination was repeated two times, resulting in thirty experimental units. Each replicate used twenty-five seeds.

Research Procedures

1. **Seed Preparation**

Arabica coffee seeds of the Kopyol variety were collected from the Kopyol Arabica coffee seed source garden in Kerta Village, Payangan Sub district, Gianyar Regency. The Lini S seven hundred ninety-five variety was sourced from the S seven hundred ninety-five Arabica coffee seed garden in Kembangsari Village, Kintamani Sub district, Bangli Regency. The seeds used were physiologically mature and free from pests and diseases.

2. **Seed Treatments**

Prepared coffee seeds were soaked according to the respective germination stimulant treatments. The treatments consisted of twenty-four hour soaking in young coconut water, twenty-four hour soaking in one hundred ppm gibberellin, twenty-minute soaking in twenty percent sulfuric acid, and twenty-four hour soaking in zero point three percent potassium nitrate. After soaking, the seeds were sown into trays filled with sand media.

3. **Observation Variables**

Observations were conducted at seven, fourteen, twenty-one, and twenty-eight days after sowing. The variables observed included seed viability and seed vigor using the following parameters:

a) **Germination Percentage**

Germination percentage described the seed quality in terms of viability and the ability to produce normal seedlings. This parameter was obtained by counting the number of normal seedlings at the first and final count based on the standard of the International Seed Testing Association two thousand twenty-one. The first count for coffee seeds was conducted on day seven and the final count on day fourteen.

b) **Maximum Growth Potential**

Maximum growth potential was measured at twenty-eight days after sowing and reflected the highest possible ability of the seed to germinate and develop under optimal conditions.

c) **Germination Speed**

Germination speed indicated the vigor level of seeds based on their ability to germinate rapidly. The calculation used the percentage of normally germinated seeds divided by the observation interval.

d) **Uniformity of Germination**

Germination uniformity was calculated using the percentage of strong normal seedlings at the final observation.

e) **Radicle Length**

Radicle length was measured using a ruler from the base of the root to its tip at twenty-eight days after sowing on normal seedlings.

f) **Shoot Height**

Shoot height was measured at twenty-eight days after sowing from the base of the stem to the tip of the shoot of normal seedlings.

g) **Seed Vigour Index**

The seed vigour index was calculated by multiplying the germination percentage by the average length of the hypocotyl and radicle.

h) **Fresh Weight**

Fresh weight was obtained by weighing all germinated seedlings in fresh condition for each treatment unit.

i) Dry Weight

Dry weight was obtained by oven drying seedling samples at one hundred five degrees Celsius for twenty-four hours until a constant weight was reached.

Data Analysis

All data were analyzed using Analysis of Variance ANOVA to determine the effects of treatments. When significant differences were detected, the analysis was continued with the Least Significant Difference test at five percent significance level.

RESULTS

Significance of Treatment Effects on Observation Variables

Based on Table 1, all germination-promoting substances (Pa, Pc, Pg, Ph, and Pk) show an asterisk (*) for every observed variable, indicating a significant effect on all viability and vigor parameters of Arabica coffee seeds. This demonstrates that each treatment successfully enhances the physiological responses of seeds, from the initiation of germination to early seedling growth.

For viability parameters (germination percentage, maximum growth potential, growth rate, and uniformity of germination), the treatments improved the seeds' ability to germinate faster and more uniformly. Vigor parameters (radicle length, shoot height, and Seed Vigour Index/SVI) also increased, indicating accelerated cell elongation and improved early biomass formation. The increase in fresh and dry weight further confirms that the treatments promote more optimal tissue development.

Overall, all germination-promoting materials proved effective in improving seed viability and vigor, producing stronger and more uniform seedlings that are better prepared for subsequent growth stages.

Table 1. Significance of the effectiveness of germination-promoting materials on seed viability and vigor of coffee

No	Plant Variable	Applied Treatment				
		Pa	Pc	Pg	Ph	Pk
1	Germination Percentage (%)	*	*	*	*	*
2	Maximum Growth Potential (%)	*	*	*	*	*
3	Growth Rate (%/day)	*	*	*	*	*
4	Germination Uniformity (%)	*	*	*	*	*
5	Radicle Length (cm)	*	*	*	*	*
6	Shoot Height (cm)	*	*	*	*	*
7	Seed Vigour Index (SVI)	*	*	*	*	*
8	Fresh Weight	*	*	*	*	*
9	Dry Weight	*	*	*	*	*

Notes: ns: not significant, *: significant, **: highly significant

Germination Percentage (%)

Germination percentage is a key parameter for assessing seed viability as it reflects the proportion of seeds capable of producing normal seedlings under optimal conditions. Statistical analysis (Table 2) indicates that germination-enhancing treatments significantly affect the germination percentage of Arabica coffee seeds, as shown by differing letters in the 5% LSD test. Each treatment displayed a distinct response, reflecting differences in their ability to stimulate early physiological processes of germination.

Table 2. Effectiveness of Germination-Enhancing Agents on Seed Viability and Vigour (Germination Percentage)

Parameter	Germination Percentage (%)					
Treatment	Pa	Pc	Pg	Ph	Pk	Mean
AL	44,00c (a)	64,00bc (a)	66,67b (a)	50,67c (a)	92,00a (a)	63,47 a (a)
AK	61,33b (a)	66,67b (a)	70,67ab (a)	58,67b (a)	92,00a (a)	69,87 a (a)
Mean	52,66a	65,33a	68,67a	54,67a	92,00a	

Note: Numbers followed by the same letters and letters in parentheses within the same column indicate non-significant differences based on the LSD test at 5% with an LSD value of 30.26.

Variety AL showed an average germination of 63.47%, ranging from the lowest value under Pa (44.00%) to the highest under Pk (92.00%). Pc and Pg moderately improved germination through increased enzymatic activity and dormancy release. Variety AK had a higher overall average (69.87%) with similarly strong responses to Pc, Pg, and especially Pk (92.00%). Overall, Pk consistently produced the highest germination (92.00%), indicating KNO_3 as the most effective stimulant for enhancing permeability, water uptake, and early metabolic activation.

Maximum Growth Potential (%)

Maximum growth potential reflects the highest possible proportion of seeds that can develop into normal seedlings under optimal conditions. Table 3 shows significant differences among treatments based on the 5% LSD test, with clear variations across both varieties.

Table 3. Effectiveness of Germination-Enhancing Agents on Maximum Growth Potential (%)

Parameter	Maximum Growth Potential (%)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	58,67c (a)	80,00b (a)	78,67bc (a)	66,67c (a)	94,67a (a)	75,73a (a)
AK	76,00b (a)	80,00b (a)	78,67b (a)	77,33b (a)	97,33a (a)	81,87 a
Mean	67,33a	80,00a	78,67a	72,00a	96,00a	

Note: Numbers followed by the same letters within the same column indicate non-significant differences based on the LSD test at 5% with an LSD value of 21.74.

Variety AL reached 75.73% on average with Pk (94.67%) as the most effective treatment, while Pa produced the lowest value. Variety AK performed better overall with a mean of 81.87%, and again Pk gave the highest value (97.33%). Although some treatments were statistically similar, the trend showed that KNO_3 consistently maximized growth potential in both varieties.

Growth Rate (%/etmal)

Growth rate represents seed vigour, indicating the speed and uniformity of germination. Table 4 shows varied responses, with some treatments differing significantly based on LSD 5% (2.86%/etmal).

Table 4. Effectiveness of Germination-Enhancing Agents on Growth Rate (%/etmal)

Parameter	Growth Rate (%/etmal)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	1,68c (a)	2,29bc (a)	2,83ab (a)	1,82c (a)	3,24a (a)	2,37a
AK	2,24c (a)	2,38c (a)	2,89bc (a)	2,14c (a)	3,78a (a)	2,68a
Mean	1,96a	2,33a	2,86a	1,98a	3,51a	

Note: Numbers followed by the same letters within the same column indicate non-significant differences based on the LSD test at 5% with an LSD value of 2.86.

Growth rate in AL ranged from 1.68–3.24%/etmal, while AK ranged from 2.24–3.78%/etmal, indicating stronger vigour in AK. In both varieties, Pk produced the fastest growth rate, demonstrating its ability to enhance early metabolic activity and accelerate seedling emergence.

Germination Uniformity (%)

Germination uniformity reflects the synchrony of seedling emergence. Variations among treatments were observed; however, many were statistically similar (LSD 5% = 29.89).

Table 5. Effectiveness of Germination-Enhancing Agents on Germination Uniformity (%)

Parameter	Uniformity of Germination (%)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	45,33b (a)	64,00ab (a)	66,67ab (a)	50,67b (a)	92,00a (a)	63,73a

AK	61,33a (a)	66,67a (a)	70,67a (a)	58,67a (a)	92,00a (a)	69,87a
Mean	53,33a	65,33a	68,67a	54.67a	92,00a	

Note: Numbers followed by the same letters within the same column indicate non-significant differences based on the LSD test at 5%, with an LSD value of 29.89.

Variety AK had higher uniformity (69.87%) than AL (63.73%). Pk provided the highest uniformity (92.00%) for both varieties, confirming its strong ability to accelerate germination initiation and reduce emergence variability. Lower uniformity in Pa and Ph treatments indicates suboptimal support for early metabolic activation.

Radicle Length (cm)

Radicle length reflects the initial vigor of the seedlings and the seed's ability to initiate primary root formation. The results showed variation among treatments; however, most differences were statistically non-significant based on the 5% LSD (2.14). The AK variety exhibited longer radicles than AL, and the Pk treatment consistently produced the longest radicle length in both varieties. This indicates that Pk was the most effective in stimulating root cell elongation and enhancing early seed vigor.

Table 6. Effectiveness of Germination-Enhancing Substances on Radicle Length (cm)

Parameter	Radicle Length (cm)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	4,69b (a)	4,53b (a)	4,67b (a)	4,34b (a)	5,45a (a)	4,73a
AK	4,56b (a)	4,76b (a)	4,98ab (a)	4,85ab (a)	5,55a (a)	4,94a
Mean	4,62a	4,60a	4,82a	4,59a	5,50a	

Note: Numbers followed by the same letters in the same column indicate non-significant differences based on the 5% LSD test, with an LSD value of 2.14.

The radicle length of both varieties showed variation in response to the treatments, although the differences were not statistically significant based on the 5% LSD test. The AK variety exhibited slightly longer radicles than AL, indicating better initial vigor. The Pk treatment consistently produced the longest radicles in both varieties, reflecting its effectiveness in promoting root elongation through enhanced metabolism and cell expansion activity. In contrast, the lowest values were recorded under the Ph treatment for AL and the Pa treatment for AK, suggesting less optimal physiological stimulation. Overall, the response pattern indicates that although not statistically significant, the Pk treatment tended to improve primary root growth vigor during the early germination phase.

Shoot Height (cm)

Shoot height represents the vertical vigor of the seedlings. Although differences among treatments were not significant (LSD 5% = 1.55), a consistent pattern was observed in which Pk produced the highest values in both varieties. The Ph treatment resulted in the lowest shoot height, indicating a less optimal physiological response to the stimulant compound. The consistent responses in AL and AK suggest that Pk performs reliably across both genotypes.

Table 7. Effectiveness of Germination-Enhancing Substances on Shoot Height (cm)

Parameter	Shoot Height (cm)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	12,63ab (a)	12,85ab (a)	11,36b (a)	11,24b (a)	13,51a (a)	12,32a
AK	12,69ab (a)	13,04ab (a)	12,33ab (a)	11,97b (a)	13,56a (a)	12,72a
Mean	12,66a	12,94a	11,84a	11,60a	13,53a	

Note: Numbers followed by the same letters in the same column indicate non-significant differences according to the 5% LSD test, with an LSD value of 1.55.

Shoot height exhibited a similar response pattern in both varieties, with the Pk treatment producing the highest values and the Ph treatment the lowest. Nevertheless, all treatments fell within the same significance group, indicating no statistically significant differences. The consistently higher values under the Pk treatment suggest a stronger physiological stimulation of vertical shoot growth, likely through enhanced mobilization of stored reserves and increased activity of hydrolytic enzymes. The parallel response patterns in AL and AK demonstrate that the effect of Pk is stable across both genotypes, making it more promising for improving the early shoot vigor of coffee seedlings.

Seed Vigour Index (SVI)

The seed vigour index integrates seedling growth and the percentage of normal seedlings. All treatments fell within the same significance group (LSD 5% = 365.10); however, numerically, Pk produced the highest SVI values in both varieties. This indicates that Pk enhances seed vigour by accelerating the mobilization of stored reserves.

Table 8. Effectiveness of Germination-Enhancing Substances on Seed Vigour Index (SVI)

Parameter	Seed Vigour Index (S.V.I)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	557,50b (a)	823,73ab (a)	758,00ab (a)	574,53b (a)	1.052,90a (a)	753,33a
AK	779,60b (a)	871,73ab (a)	895,87ab (a)	778,67b (a)	1.226,00a (a)	910,37a
Mean	668,55a	847,73a	826,93a	676,60	1139,45a	

Note: Numbers followed by the same letters in the same column indicate non-significant differences according to the 5% LSD test, with an LSD value of 365.10.

The seed vigour index (SVI) showed a clear increasing pattern under the Pk treatment, although statistically the treatments did not differ significantly. Pk produced the highest SVI values in both AL and AK, demonstrating its effectiveness in enhancing the seeds' ability to grow rapidly and uniformly. The Ph treatment resulted in the lowest SVI values for both varieties, indicating a less optimal physiological response. The relatively wide variation in values suggests that each variety exhibits a different level of sensitivity to the growth-promoting substances. The consistent upward trend observed under Pk further confirms that this treatment is more capable of optimizing metabolic activity, carbohydrate mobilization, and cellular respiration—processes that underpin seedling vigor.

Fresh Weight (g)

Fresh weight reflects the initial biomass accumulation of the seedlings. Although the differences were not statistically significant (LSD 5% = 3.59), the response pattern indicated that Pk produced the highest fresh weight in both varieties. The AK variety showed a higher mean fresh weight than AL, suggesting a stronger physiological capacity for early biomass formation.

Table 9. Effectiveness of Germination-Enhancing Substances on Fresh Weight (g)

Parameter	Fresh Weight (g)					
Treatment	**Pa**	**Pc**	**Pg**	**Ph**	**Pk**	**Mean**
AL	5,16b (a)	6,70b (a)	7,20ab (a)	6,06b (a)	10,47a (a)	7,12b
AK	8,90b (a)	9,60ab (a)	9,47ab (a)	7,99b (a)	12,72a (a)	9,74a
Mean	7,03a	8,15a	8,33a	7,02a	11,59a	

Note: Numbers followed by the same letters in the same column indicate **non-significant differences**, based on the **5% LSD test** with an LSD value of **3.59**.

Fresh seedling weight increased the most under the Pk treatment for both varieties, indicating this treatment's ability to accelerate early biomass formation through enhanced imbibition, hydrolysis of stored reserves, and cell division. The AK variety exhibited higher fresh weight than AL, reflecting stronger early vigor potential. Although the lowest values differed between the two varieties, the shared letter groupings among treatments indicate that these differences were not statistically significant.

Nevertheless, the consistent numerical pattern shows that the Pk treatment remains the most effective in promoting early biomass growth in coffee seedlings.

Dry Weight (g)

Dry weight reflects the accumulation of structural biomass. The response pattern showed that Pk produced the highest dry weight in both varieties, although the differences were not statistically significant (LSD 5% = 0.83). The AK variety again exhibited a higher average value than AL, reinforcing its superior physiological efficiency.

Table 10. Effectiveness of Germination-Enhancing Substances on Dry Weight (g)

Parameter	Dry Weight (g)					
Treatment	Pa	Pc	Pg	Ph	Pk	Mean
AL	1,06b (a)	1,34ab (a)	1,77ab (a)	1,38ab (a)	2,15ab (a)	1,54b
AK	1,87b (a)	2,08ab (a)	2,18ab (a)	1,74c (a)	2,91a (a)	2,16a
Mean	1,46a	1,71a	1,97a	1,56a	2,53a	

Note: Numbers followed by the same letters in the same column indicate **non-significant differences**, based on the **5% LSD test** with an LSD value of **0.83**.

Dry seedling weight showed that the Pk treatment consistently produced the highest values in both varieties, reflecting its effectiveness in enhancing the accumulation of structural biomass independent of water content. Although differences among treatments were not statistically significant according to the LSD test, the upward trend under Pk indicates improved efficiency in reserve mobilization and tissue formation. The AK variety produced higher dry weight than AL, demonstrating a stronger physiological capacity for building dry biomass during the early germination phase. The similar response patterns observed in both varieties indicate that the effect of the Pk treatment is stable and effective.

DISCUSSION

This study aims to elucidate the effects of various germination-promoting agents, including KNO_3 (Pk), gibberellin (Pg), young coconut water (Pc), plain water (Pa), and H_2SO_4 (Ph), on enhancing the viability and vigor of Arabica coffee seeds, considering both the genetic characteristics of the varieties and their physiological responses as key determining factors (Sitanggang et al., 2021). Successful germination of coffee seeds highly depends on the initial physiological condition and the surrounding environment, as both influence imbibition, metabolic activation, and embryonic cell division (Lestari et al., 2016). Arabica varieties Lini S 795 (AL) and Kopyol (AK) were selected due to their genetic differences, which affect the seeds' responsiveness to germination-promoting treatments. Optimal environmental conditions, including humidity, temperature, and water availability, support early metabolic activities such as respiration, membrane stabilization, and activation of reserve-breaking enzymes, thereby improving seedling vigor (Lolo et al., 2025).

Germination percentage is used as the primary indicator of seed viability because it reflects the proportion of seeds capable of normal growth. Analysis shown in Table 2 indicates that germination-promoting treatments significantly affect the germination percentage in both varieties, as evidenced by the differences in letters according to the 5% BNT test. Arabica Lini S 795 (AL) had an average germination percentage of 63.47%, with plain water (Pa) yielding the lowest at 44.00% and KNO_3 (Pk) the highest at 92.00%. Gibberellin/GA_3 (Pg) and young coconut water (Pc) treatments produced 66.67% and 64.00%, respectively, demonstrating the ability of these bioactive compounds to accelerate enzymatic activity and break physiological dormancy, consistent with the findings of Lolo et al. (2022) and Sirait (2020). Soaking in KNO_3 enhances seed coat permeability and accelerates imbibition, optimizing early respiration, membrane stabilization, and the activity of reserve-degrading enzymes, as reported by Sitanggang et al. (2021).

Maximum germination potential reflects the seed's capacity to produce normal seedlings under optimal conditions. Data in Table 3 show variation in responses between treatments and varieties, indicated by differences in letters according to the 5% BNT test. Arabica Lini S 795 (AL) had an average maximum germination potential of 75.73%, with plain water (Pa) as the lowest at 58% and KNO_3 (Pk) showing the highest response at 94.67%. Young coconut water (Pc) and GA_3 (Pg) treatments yielded 80.00% and 78.67%, respectively, indicating that these compounds optimally support early seed metabolism. This aligns with Sirait (2020), who reported that soaking Arabica seeds in KNO_3 increases germination percentage.

Arabica Kopyol (AK) exhibited a higher average maximum germination potential of 81.87%. Pa treatment produced 76.00%, while Pk reached 97.33%, confirming KNO_3 as the most consistently effective promoter. This is also supported by Wijaya et al. (2022) in Robusta coffee, showing a similar effect of KNO_3 in enhancing germination. Physiologically, the increase in maximum germination potential is associated with faster water imbibition, metabolic activation, cell membrane stabilization, and cell division and elongation. GA_3 application also demonstrated a positive effect on Arabica seed germination, as reported by Lolo et al. (2025).

Growth rate is an important indicator of seed vigor because it reflects the ability of seeds to germinate rapidly and uniformly within a given period. According to Table 4, statistical analysis revealed variation in response to germination-promoting treatments across both Arabica varieties, with differences in letters according to the 5% BNT test of 2.86%/etmal. Arabica Lini S 795 (AL) showed a growth rate ranging from 1.68–3.24%/etmal, with an average of 2.37%/etmal. Pa treatment produced the lowest growth rate at 1.68%/etmal, followed by H_2SO_4 (Ph) at 1.82%/etmal, while Pc and Pg yielded intermediate responses of 2.29–2.83%/etmal. KNO_3 (Pk) treatment produced the highest value of 3.24%/etmal, highlighting KNO_3's ability to accelerate early seed metabolism, including imbibition, respiration, and enzyme synthesis such as α-amylase, which mobilizes food reserves for cell division and elongation.

Arabica Kopyol (AK) showed a higher growth rate of 2.24–3.78%/etmal with an average of 2.68%/etmal. Pk treatment again proved most effective at 3.78%/etmal, whereas Pa and Ph produced the lowest growth rates of 2.24–2.14%/etmal. This indicates that AK is more responsive to promoting agents, reflecting higher genetic vigor and superior physiological ability to utilize stimulants for rapid seedling emergence. Physiologically, increased growth rate is associated with early metabolic activation, including rapid imbibition, membrane stabilization, and enhanced activity of enzymes that degrade carbohydrate and protein reserves. KNO_3 synergistically accelerates cell division and embryonic cell elongation. Inter-varietal differences reflect physiological traits and genetic capacity to respond to chemical stimuli, similar to GA_3 mechanisms that stimulate cell division and tissue expansion in fruit crops (Ruttanaruangboworn et al., 2017). Overall, KNO_3 was the most effective treatment for increasing growth rate, while Pa showed the lowest response, underscoring the role of promoting agents in enhancing initial seed vigor.

Uniformity of germination is a crucial indicator of viability and vigor as it reflects the seeds' ability to emerge synchronously within a short period, indicating consistent physiological response to early metabolic activation. Table 5 shows statistical analysis with variations among treatments, most of which were not significantly different, BNT = 29.89. Arabica Lini S 795 (AL) had uniformity ranging from 45.33–92.00%, with an average of 63.73%. KNO_3 (Pk) produced the highest uniformity at 92.00%, whereas Pa was the lowest at 45.33%. Pc and Pg showed intermediate uniformity of 64.00–66.67%, indicating that KNO_3 can accelerate synchronous germination initiation, minimize time gaps between seed emergence, and support early physiological stability. Arabica Kopyol (AK) exhibited higher uniformity, 58.67–92.00% with an average of 69.87%. Pk again proved most effective at 92.00%, while Ph was the lowest at 58.67%. This variation reflects AK's genetic responsiveness to promoting agents and better physiological capacity to stabilize hydration and enzymatic activation during germination.

Physiologically, increased germination uniformity is related to efficient hydration, activation of early metabolic enzymes, and uniform mobilization of food reserves. Seed priming with KNO_3 supports synchronized emergence by regulating osmotic balance and enhancing α-amylase, protease, and lipase activities, enabling all embryos to initiate growth simultaneously, as reported in tomato seeds (Ali et al., 2020), tomato seeds treated with KNO_3 plus aeration (Santika et al., 2022), and macadamia seeds (Nyasasi et al., 2025). Inter-varietal differences highlight the influence of physiological traits on responsiveness to chemical stimuli, similar to GA_3's effect in improving organ growth uniformity in certain plant seeds (Hernández et al., 2024). Overall, Pk treatment demonstrated the highest effectiveness in improving germination uniformity, contributing positively to the production of uniform and ready-to-plant seedlings.

Radicle Length is an early indicator of seedling vigor as it reflects the growth strength of the embryo after imbibition. This parameter indicates the seed's ability to form an initial root system, which is essential for supporting subsequent growth stages. Based on Table 6, there was variation in radicle length responses among the germination-promoting treatments, although most differences were not statistically significant according to the 5% BNT test with a value of 2.14 cm. Arabica Lini S 795 exhibited radicle lengths ranging from 4.34 to 5.45 cm, with an average of 4.73 cm. KNO_3 treatment produced the highest value of 5.45 cm, while H_2SO_4 yielded the shortest radicle at 4.34 cm. Treatments with plain water, young coconut water, and gibberellin showed intermediate values of 4.53–4.69 cm, reflecting the varying effectiveness of the promoting agents on primary root cell elongation.

Arabica Kopyol showed longer radicles with an average of 4.94 cm, where KNO_3 produced 5.55 cm and plain water the lowest at 4.56 cm. This indicates that Arabica Kopyol has a better physiological response to promoting agents, particularly in stimulating radicle cell division and elongation. Physiologically, increased radicle length is associated with the activation of early metabolism, including imbibition, respiration, and the synthesis of hydrolytic enzymes that break down food reserves for embryonic cell division. Seed priming with KNO_3 consistently accelerates this process, supporting optimal radicle elongation and enhancing seedling vigor (Kundu & Bordolui, 2025). Similar findings have been reported in tomato, where KNO_3 priming increased root length and seedling vigor (Ali et al., 2020), as well as in macadamia seeds, which showed improvements in root length and seedling vigor after KNO_3 treatment (Nyasasi et al., 2025).

Inter-varietal variation highlights the genetic and physiological differences in responding to chemical stimuli, similar to gibberellin's role in stimulating early organ growth in plants (Hs et al., 2025). Overall, the results confirm that KNO_3 treatment enhances early seed vigor by promoting longer radicle growth, supporting the development of robust coffee seedlings with better growth potential in later stages.

Shoot Height serves as an indicator of early vigor, reflecting the seedling's ability to grow vertically, efficiently utilize food reserves, and respond physiologically to promoting agents. Based on Table 7, the germination-promoting treatments had different effects on shoot height, with a 5% BNT value of 1.55 cm. Arabica Lini S 795 had shoot heights ranging from 11.24 to 13.51 cm, with KNO_3 yielding the highest shoot height of 13.51 cm and H_2SO_4 the lowest at 11.24 cm. Treatments with plain water, young coconut water, and gibberellin showed intermediate values of 11.36–12.85 cm, indicating a specific varietal response of Lini S 795 to certain promoting agents.

Arabica Kopyol exhibited a similar pattern, with shoot heights of 11.97–13.56 cm. KNO_3 again proved most effective at 13.56 cm, while H_2SO_4 produced the lowest value of 11.97 cm. The consistent response across both varieties suggests that the physiological mechanisms stimulated by KNO_3 operate similarly in both genotypes. Physiologically, increased shoot height is associated with optimized mobilization of endosperm reserves, enhanced hydrolytic enzyme activity, accelerated cellular metabolism, and stimulated stem elongation. Seed priming with KNO_3 consistently supports these processes, strengthening early shoot growth and seedling vigor, as reported in various horticultural crops (Kundu & Bordolui, 2025; Ali et al., 2020). Although differences among treatments were below the 5% BNT threshold and not statistically significant, the consistent pattern indicates that KNO_3 provides superior growth stimulation. Overall, KNO_3 proved to be the most effective treatment for increasing shoot height, supporting early vigor and preparing seedlings for subsequent growth stages.

Seed Vigour Index (SVI) quantitatively describes seedling growth strength by considering both germination percentage and initial seedling growth. SVI values reflect the seed's ability to grow rapidly, uniformly, and robustly under optimal conditions. Based on Table 8, variation existed among promoting treatments, though most differences were not statistically significant (BNT = 365.10). Arabica Lini S 795 had SVI values ranging from 557.50 to 1,052.90, with KNO_3 producing the highest SVI (1,052.90) and H_2SO_4 the lowest (574.53). Plain water, young coconut water, and gibberellin showed intermediate values of 557.50–823.73, indicating specific varietal responses of Lini S 795 to the treatments.

Arabica Kopyol showed SVI values from 778.67 to 1,226.00, with KNO_3 highest at 1,226.00 and H_2SO_4 lowest at 778.67. The response patterns of both varieties were consistent, indicating KNO_3's effectiveness across genotypes. Physiologically, increased SVI is linked to optimized germination enzyme activity, faster carbohydrate mobilization, and enhanced cellular respiration, resulting in faster and more uniform seedling growth. KNO_3 treatment had a strong positive physiological effect, enhancing overall seed vigor in both Lini S 795 and Arabica Kopyol (Kumar et al., 2024; Lainufar et al., 2025).

Fresh Seedling Weight reflects early biomass accumulation achieved through mobilization of food reserves during germination. High values indicate the seedling's capacity to absorb water, elongate tissues, and perform active cell division. Based on Table 9, variation among treatments existed but was not statistically significant (BNT = 3.59). Arabica Lini S 795 had fresh weights of 5.16–10.47 g, with KNO_3 yielding the highest value (10.47 g) and plain water the lowest (5.16 g). Young coconut water, gibberellin, and H_2SO_4 showed intermediate values (6.06–7.20 g), reflecting treatment-specific responses.

Arabica Kopyol showed a similar pattern, ranging from 7.99 to 12.72 g, with KNO_3 again producing the highest fresh weight and H_2SO_4 the lowest. The higher mean in Kopyol indicates better early vigor and biomass formation efficiency in this variety. Physiologically, increased fresh weight under KNO_3 treatment is associated with optimized imbibition, accelerated hydrolysis of reserves, and stimulation of cell division and elongation, resulting in thicker, heavier, and more vigorous seedlings. Similar results have been reported in tomato, where KNO_3 priming significantly increased root length and seedling fresh weight (Ali et al., 2020).

Dry Weight reflects structural biomass accumulation independent of water content. High values indicate efficient reserve mobilization and the seedling's capacity to form optimal tissues. Based on Table 10, variation existed among treatments but was not statistically significant (BNT = 0.83). Arabica Lini S 795 had dry weights of 1.06–2.15 g, with KNO_3 producing the highest value and plain water the lowest. Young coconut water, gibberellin, and H_2SO_4 showed intermediate values (1.34–1.77 g).

Arabica Kopyol exhibited a similar trend, with KNO_3 highest at 2.91 g and H_2SO_4 lowest at 1.74 g. The higher average in Kopyol (2.16 g) compared to Lini S 795 (1.54 g) indicates superior physiological capacity for forming dry biomass (Lestari et al., 2016). Physiologically, increased dry weight under KNO_3 is associated with intensive respiration, active cell division, and efficient use of reserves. Higher dry biomass reflects better seedling vigor, and the consistent response across varieties shows optimal physiological stimulation via KNO_3 treatment (Da Rocha et al., 2025; Hernández et al., 2024).

Figures 1 and 2 illustrate Arabica coffee seedling growth under different germination-promoting treatments—KNO_3 (Pk), gibberellin (Pg), young coconut water (Pc), plain water (Pa), and H_2SO_4 (Ph)—for Arabica Lini S 795 (AL) and Kopyol (AK).

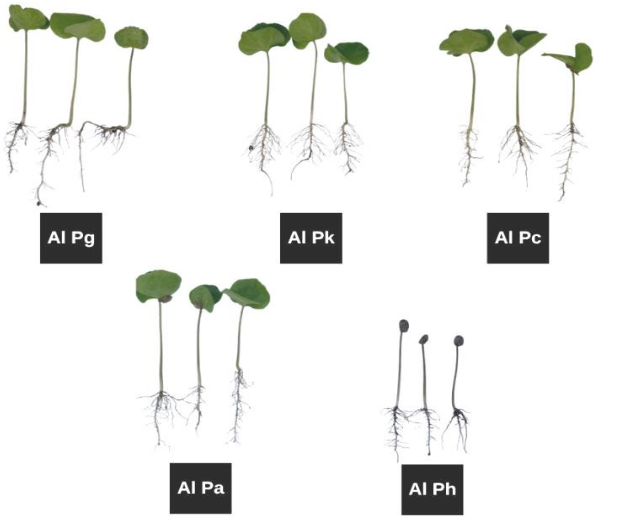

Figure 1. Seedling growth of Arabica coffee under various germination-promoting treatments, namely KNO_3 (Pk), gibberellin (Pg), young coconut water (Pc), plain water (Pa), and H_2SO_4 (Ph), for the Arabica Lini S 795 (AL) variety.

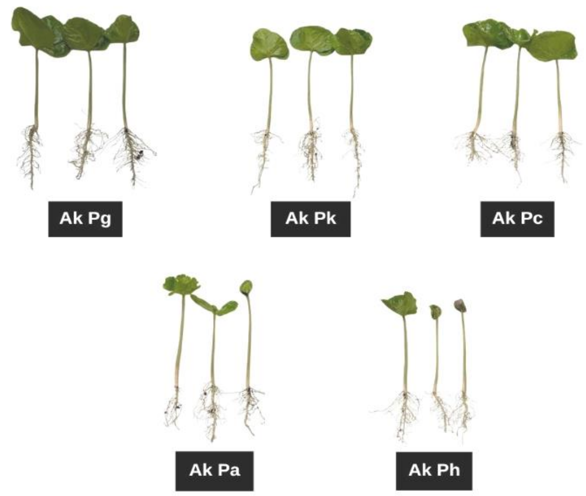

Figure 2. Seedling growth of Arabica coffee under various germination-promoting treatments, namely KNO_3 (Pk), gibberellin (Pg), young coconut water (Pc), plain water (Pa), and H_2SO_4 (Ph), for the Arabica Kopyol (AK) variety.

Figure 1 shows Arabica Lini S 795 seedlings, with KNO_3 treatment producing the best growth, indicated by more branched primary and lateral roots, fully expanded leaves, and upright, long stems. This demonstrates KNO_3's effectiveness in enhancing early metabolism, accelerating imbibition, and stimulating cell division and elongation, thus increasing seedling vigor (Sitanggang et al., 2021; Da Rocha et al., 2025). Gibberellin also promoted healthy growth, especially in stem elongation and root development, but root growth was less pronounced than with KNO_3 (Lolo et al., 2025; Hernández et al., 2024). Young coconut water had moderate effects due to natural hormones like auxins and cytokinins (Ali et al., 2020; Nyasasi et al., 2025), while plain water showed baseline growth. H_2SO_4 caused the poorest growth, with underdeveloped leaves, thin stems, and limited roots due to chemical stress (Santika et al., 2022).

Figure 2 shows Arabica Kopyol seedlings, with the best responses to gibberellin and KNO_3. Pg treatment led to broad green leaves, well-developed primary and lateral roots, and upright stems, indicating high vigor and physiological activity (Lolo et al., 2025). KNO_3 also produced healthy, uniform seedlings with balanced root-to-shoot ratios. Young coconut water had moderate effects, plain water showed basic growth, and H_2SO_4, although detrimental, had less negative impact than in Lini S 795, suggesting higher tolerance of Kopyol to chemical stress (Santika et al., 2022). Overall, KNO_3 was the most consistent germination promoter across both varieties, supporting the development of healthy, vigorous seedlings (Hernández et al., 2024).

CONCLUSION

The findings of this study demonstrate that germination-promoting treatments significantly influence the viability and vigor of Arabica coffee seeds. All tested treatments, including KNO_3, GA_3, H_2SO_4, and young coconut water, effectively enhanced germination percentage, maximum germination potential, and overall seed vigor compared to the control.

Among the treatments, 0.3% KNO_3 applied for 24 hours produced the most favorable results across all measured parameters. Seeds treated with KNO_3 achieved the highest germination rate of 92%, maximum germination potential of 94%, and showed more uniform germination speed and synchronicity. Additionally, KNO_3 treatment resulted in the greatest radicle length, shoot height, and seed vigor index, indicating its superior effectiveness in stimulating early seedling growth.

Varietal differences were also observed, with the Arabica Kopyol variety demonstrating better physiological performance compared to Lini S 795. Kopyol seeds exhibited higher germination rates, maximum germination potential, and vigor, reflecting superior adaptability and physiological responsiveness to germination-promoting treatments. Overall, the study confirms that the application of KNO_3 is the most effective strategy to enhance Arabica coffee seed viability and vigor, and that varietal selection plays a key role in optimizing seedling performance for early growth stages.

ADVICE

It is recommended that 0.3% KNO_3 applied for 24 hours be used as the most effective method to enhance the viability and vigor of Arabica coffee seeds, particularly for the Kopyol and Lini S 795 varieties, prior to sowing.

For farmers and nursery operators, the use of germination-promoting substances can be applied practically to accelerate the nursery process and produce healthier, more uniform coffee seedlings.

For further research, it is advised to evaluate combinations of chemical and natural germination-promoting agents, such as KNO_3 combined with young coconut water, to develop treatments that are more environmentally friendly while remaining effective.

ACKNOWLEDGMENTS

The author would like to express sincere gratitude to the Master's Program in Dryland Agriculture, Faculty of Agriculture, Udayana University, for the academic guidance, facilities, and continuous support provided throughout the completion of this research. Special thanks are also extended to colleagues, friends, and supervisors who offered valuable insights, advice, and constructive suggestions that greatly improved the quality of this study. Finally, the author acknowledges all personal and institutional support that made it possible to successfully complete this research.

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