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RESPON VIABILITAS BENIH KEDELAI (*Glycine max* [L.] *Merril*) VARIETAS DETAP-1 TERHADAP PROPORSI KAPUR TOHOR SELAMA PENYIMPANAN SEMBILAN BELAS BULAN

VIABILITY RESPONSE OF SOYBEAN SEEDS (Glycine max [L.] Merril) VARIETY DETAP-1 TO THE PROPORTION OF QUICKLIME DURING NINETEEN MONTHS OF STORAGE

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ABSTRACT

Soybean seed storage using quicklime aims to maintain the quality of soybean seeds during a long storage period until the soybean seeds are ready to plant. This study aims to determine the optimal proportion of lime in maintaining the highest seed viability after being stored for nineteen months. This study was conducted from May to November 2023 at the Seed and Plant Breeding Laboratory, Faculty of Agriculture, University of Lampung. This study used a single factor, namely the proportion of quicklime. The proportion of lime weight used in this study was 0.0% (P0); 7.5% (P1); 15.0% (P2); 22.5% (P3); and 30.0% (P4) per 100g of seeds with a storage container volume of three liter volume. This study was arranged in a randomized block design (RAK) with five treatments and five replications to obtain 25 experimental units. The homogeneity test of variance was carried out using the Barlett test and the additivity of the data was tested using the Tukey test. The assumption of the analysis of variance was met, the separation of the mean value of the treatment used a polynomial comparison at the α level of 5%. The results of the study revealed that the addition of the proportion of quicklime increased the germination rate, strong normal sprouts, hypocotyl length, normal dry weight of sprouts, and decreased seed water content linearly, but the increase in germination power decreased with increasing proportion of lime. Seed viability after 17 and 19 months showed a relatively low seed germination power, which was 77.80% per 30 g of lime.

KATA KUNCI:

Kapur tohor, penyimpanan benih, proporsi kapur tohor, dan viabilitas benih kedelai (32:10:10)

ABSTRAK

Penyimpanan benih kedelai menggunakan kapur tohor bertujuan untuk mempertahankan mutu benih kedelai selama periode simpan yang lama hingga benih kedelai siap tanam. Penelitian ini bertujuan untuk menentukan proporsi kapur yang optimal dalam menjaga viabilitas benih tertinggi setelah disimpan selama sembilan belas bulan. Penelitian ini dilakukan pada Mei sampai Nopember 2023 di Laboratorium Benih dan Pemuliaan Tanaman, Fakultas Pertanian, Universitas Lampung. Penelitian ini menggunakan faktor tunggal yaitu proporsi kapur tohor. Proporsi bobot kapur yang digunakan pada penelitian ini 0,0% (P0); 7,5% (P1); 15,0% (P2); 22,5% (P3); dan 30,0% (P4) per 100g benih dengan volume wadah penyimpanan tiga liter. Penelitian ini disusun dalam rancangan acak kelompok (RAK) dengan lima perlakuan dan lima ulangan sehingga diperoleh 25 satuan percobaan. Uji Homogenitas ragam dilakukan dengan uji Barlett dan aditivitas data diuji menggunakan uji Tukey. Asumsi analisis varians terpenuhi, pemisahan nilai tengah perlakuan menggunakan perbandingan polinomial pada taraf α 5%. Hasil penelitian mengungkapkan bahwa penambahan proporsi kapur tohor meningkatkan kecepatan perkecambahan, kecambah normal kuat, panjang hipokotil, bobot kering kecambah normal, dan menurunkan kadar air benih secara linear, namun peningkatan daya berkecambah menurun seiring dengan bertambahnya proporsi kapur. Viabilitas benih setelah 17 dan 19 bulan menunjukkan daya berkecambah benih yang relatif rendah, yaitu 77,80% per 30 g kapur.

1. INTRODUCTION

Soybean constitutes one of Indonesia's primary food crops, serving as a fundamental ingredient in the production of various food items, including tofu, tempeh, tauco (fermented soybean paste), snacks, soy milk, and livestock feed. Not only are soybeans safe for consumption, but they are also nutrient-dense, with a particularly high protein content that offers significant health benefits (Ningsih, 2017; Nurrahman, 2015). In 2022, the national demand for soybeans reached approximately 2.84 million tons, while the local supply for less than 10% of this demand, necessitating reliance on imports as the main source. The low production of soybeans can be partially attributed to a reduction in harvested areas, which decreased from 660.8 thousand hectares in 2010 to 285.3 thousand hectares in 2019. In addition, the insufficient availability of high-quality soybean seeds further exacerbates the low yields experienced by Indonesian farmers (Badan Pusat Statistik, 2021). The Detap-1 soybean variety has been developed to support the national demand for soybeans, exhibiting advantageous characteristics such as a large seed size, resistance to pod shattering, early maturity (78 days), high yield potential, and tolerance to acidic dryland conditions (Adinurani, 2022; DPKP, 2023; Tanjung *et al*., 2022).

However, soybean seeds, including the Detap-1 variety, are recognized for their relatively short storage life, lasting between 1 to 6 months, which results in seed deterioration occurring more rapidly. This deterioration poses a significant challenge in the storage of soybean seeds, characterized by a more rapid loss of viability compared to other agricultural seeds. The decline in viability is heavily influenced by various internal and external factors, particularly temperature. In tropical regions such as Indonesia, the shelf life of soybean seeds is notably reduced due to high temperatures and humidity, which, in conjunction with the protein and fat content, accelerates deterioration. Under controlled room temperature conditions, the viability of soybean seeds can be maintained at 88% for two months, whereas at lower temperatures, it can persist at 85% for four months. Implementing treatments that establish optimal environmental conditions can mitigate or even prevent seed deterioration during storage (Rahman *et al*., 2024; Tatipata *et al*., 2004; Wahyuni & Kartika, 2022).

One effective strategy for preserving seed quality involves the incorporation of quicklime (calcium oxide) as an air-drying agent. Research on the use of quicklime in liming processes has been conducted for several years (Soebijarso, 1996). In the field of seed storage, quicklime for the storage of soybean seeds can effectively manage humidity levels and sustain seed viability. Achieving successful seed storage necessitates the establishment of appropriate conditions, which include the correct proportion of quicklime, optimal seed moisture content, and regulated air humidity. The hygroscopic characteristics of quicklime enable it to absorb water vapor effectively (Danaprianta, 2012). Employing varying proportions of quicklime during soybean seed storage can enhance its efficacy in moisture absorption. Higher proportions of quicklime correspond to increased moisture absorption capacity, thereby fostering optimal storage conditions that better preserve seed viability compared to storage without quicklime treatment (Adha, 2018; Pramono, 2011).

Additionally, the selection of storage containers plays a crucial role; the use of sealed containers helps maintain low air humidity and regulates the atmospheric conditions surrounding the seeds according to their requirements. The employment of quicklime is also considered a cost-effective method for seed storage, as lower relative humidity extends storage life and inhibits the growth of pathogenic fungi (Dewi, 2015). This study aims to assess the effectiveness of quicklime as an air-drying agent in sealed storage containers to optimize air conditions throughout the storage duration.

2. MATERIALS AND METHODS

The instruments employed in this research comprised the IPB 75-1 paper compressor, a ruler, three-liter plastic storage containers, an EC conductivity meter, a digital balance, a Memmert-type oven, an HTC-1 thermometer-hygrometer for assessing temperature and humidity, an IPB 73-2A/2B germinator, scissors, plastic trays, glass cups, hygro-thermometers, wire, a binocular microscope, and standard office supplies. The materials employed included Detap-1 soybean seeds, purified water, an air-drying agent (quicklime), brown paper envelopes, distilled water (aquades), labels, rubber bands, polyethylene (PE) plastic, and blotting paper serving as the germination substrate.

This research was designed based on a single-factor treatment, specifically focusing on the weight proportion of quicklime. The applied proportions were as follows: 0,0 g quicklime/100 g seeds (p_0), 7,5 g quicklime/100 g seeds (p_1), 15,0 g quicklime/100 g seeds (p_2), 22,5 g quicklime/100 g seeds (p_3) dan 30,0 g quicklime/100 g seeds (p_4). The treatments were organized according to a Randomized Block Design (RBD), including five treatments and five replications, leading to a total of 25 experimental units. Bartlett's test was utilized to assess variance homogeneity, while Tukey's test was employed to evaluate data additivity. Once the underlying assumptions were confirmed, treatment means were separated through polynomial comparisons at the 5% significance threshold (Figure 1).

The seed storage containers utilized were airtight, transparent white plastic boxes in polyethylene (PE) plastic. The seed groups were stored in containers of varying colors—orange, green, and blue—illustrated. The seeds were maintained over a duration of six months. The variables monitored included daily temperature (°C) and relative humidity (%), observations were conducted bi-monthly, from the fourteenth month through the nineteenth month of storage, resulting in three distinct observation periods.

Germination uniformity assessments were performed utilizing the UKDdP (Uniformity of Germination Based on Seedling Performance) method, which measured criteria such as primary root length, shoot length, the count of strong normal seedlings, and the dry weight of normal seedlings. Quicklime was replenished monthly, with changes in color, form, and weight documented over the nineteen-month storage period (Prabhandaru & Saputro, 2017). Germination percentage (%) was calculated by the number of normal seedlings at 3 days and 5 days post-planting. The Germination Rate Index (GRI) was derived from the observed increase in the percentage of normal seedlings emerging throughout the germination timeframe. Observations were carried out from day 2 to day 5 following planting. Vigorous normal seedlings were identified as those meeting the criteria for normal growth at 5 × 24 hours post-planting.

I	II	III	IV	V
P_2	P_3	P_0	P_1	P_4
P_4	P_0	P_2	P_3	P_1
P_0	P_1	P_3	P_0	P_0
P_3	P_4	P_1	P_4	P_2
P_1	P_2	P_4	P_2	P_3

Figure 1. Experimental layout

Hypocotyl length measurements were taken from five randomly selected normal seedlings per experimental unit, yielding 20 samples for each treatment. Seedling dry weight was obtained by oven-drying five normal seedlings from each experimental unit (totalling 20 seedlings) at 80 °C for 3 days in paper envelopes, subsequently weighing them. Seed moisture content was assessed by oven-drying 5.00 g of soybean seeds from each experimental unit at 80 °C for 3 × 24 hours, followed by weighing. Electrical conductivity (EC) was measured via a conductivity meter to evaluate seed leakage levels. The EC value of the seed soak water was noted, and a control solution (devoid of seeds) was analyzed for comparative purposes.

3. RESULTS AND DISCUSSION

The findings indicated that the proportion of quicklime adversely affected seed viability, as evidenced by metrics such as germination rate (after 17 and 19 months of storage), germination rate index (after both 17 and 19 months), the quantity of vigorous normal seedlings (observed after 19 months), hypocotyl length (measured after 15, 17, and 19 months), normal seedling dry weight (assessed after 17 and 19 months), and seed moisture content (evaluated after 15, 17, and 19 months).

3.1 Germination Percentage (%)

The data collected after 15 months of storage revealed no significant differences in germination percentages across the various treatments. However, by 17 and 19 months, there was a linear increase in germination percentages corresponding to higher proportions of quicklime (Table 1). Notably, enhanced seed viability was recorded with the quicklime treatment after 15 months, while the control seeds, which lacked quicklime, exhibited a decline in viability. After 17 and 19 months of storage, viability fell below 80%. As noted by Copeland and McDonald (2001), sealed storage maintained at a constant temperature of 25 °C permits hygroscopic equilibrium at seed moisture contents of 8–14% and relative humidity (RH) levels of 55–75%, conditions deemed secure for seed storage. In this investigation, after 15 months, the control treatment (0.0% quicklime) was characterized by a temperature of 27.33 °C, RH of 54.47%, and seed moisture at 7.64%. In contrast, treatments incorporating 7.5–30.0% quicklime yielded a temperature of 27.28 °C, RH of 47.38%, and seed moisture content of 6.96%, all of which remain within acceptable storage parameters. Such conditions likely contributed to the maintenance of viability over 80% after 15 months.

A rise of 1% in the weight of quicklime correlates with a 1.88% increase in the germination percentage (GP) of soybean seeds following 17 months of storage, and a 2.34% increase after 19 months. Nonetheless, the germination percentages at both the 17-month and 19-month marks fall below 80%. Figure 2 illustrates the reduction in seed viability over extended storage durations, while Table 2 presents the mean value of germination percentages for soybean seeds stored for 15, 17, and 19 months.

Table 1. Results of the Polynomial Comparison Test for Seed Germination Rate (%) at 15, 17, and 19 Months of Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime-linear	-23,00	tn	69,00	*	117,00	*
P_2: quicklime-kuadratik	15,00	tn	-25,00	tn	21,00	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

Table 2. Mean Value of Seed Germination Rate (%) at 15, 17, and 19 Months of Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	85,80	70,40	68,20
7,5	87,60	72,00	71,00
15,0	81,60	74,20	72,80
22,5	86,20	76,00	75,20
30,0	84,20	77,80	77,80
Mean	85,08	74,08	73,00

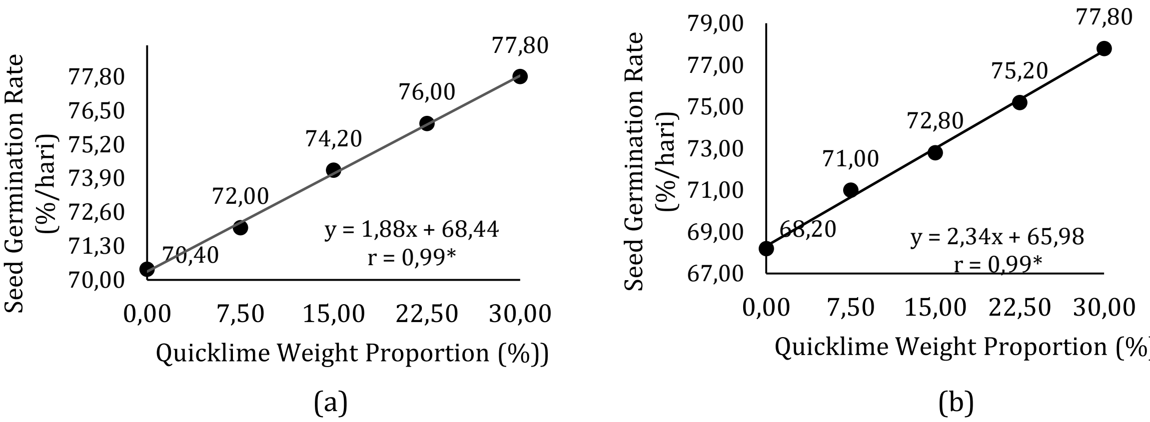


Figure 2. Relationship Between Seed Germination Rate and Quicklime Weight Proportion at 17 Months (a) and 19 Months (b) of Seed Storage.

Table 3. Results of the Polynomial Comparison Test for Germination Rate Index (%/day) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime-linear	-6,42	tn	24,20	*	49,3	*
P_2: quicklime-kuadratik	15,65	tn	-3,93	tn	-8,0	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

3.2 Germination Rate Index (GRI)

The results from a 15-month storage period of soybean seeds indicated no significant variation in germination rates. However, a linear increase in germination rate index was observed after 17 and 19 months of storage, as illustrated in Table 3. Specifically, each 1% rise in the weight of quicklime corresponded to an enhancement in germination rate index of 0.48% after 17 months and 0.99% after 19 months, as depicted in Figure 3. The mean germination rates following 15, 17, and 19 months of storage are detailed in Table 4.

3.3 Vigorous Normal Seedlings

The percentage of vigorous normal seedlings were not significantly different after 15 and 17 months of storage (Table 5). However, after 19 months, there was a linear increase with higher proportions of quicklime. Each 1% increase in quicklime improved the percentage of vigorous normal seedlings by 4.38% Figure 4. The mean germination rates following 15, 17, and 19 months of storage are detailed in Table 6.

Table 4. Mean Value of Germination Rate Index (%/day) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	30,91	24,01	24,50
7,5	32,04	25,01	26,55
15,0	28,42	25,24	26,82
22,5	31,19	25,58	27,90
30,0	30,69	26,14	28,75
Mean	30,65	25,20	26,90

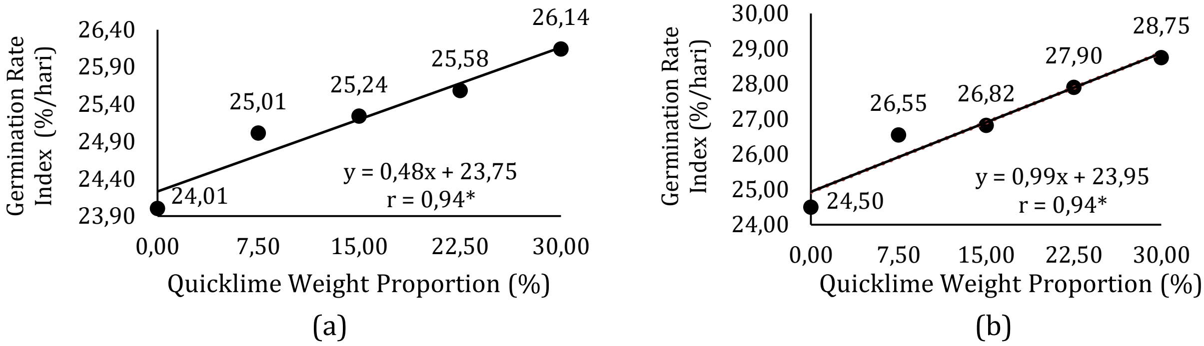


Figure 3. Relationship Between Germination Rate Index and Quicklime Weight Proportion at 17 Months (a) and 19 Months (b) of Seed Storage

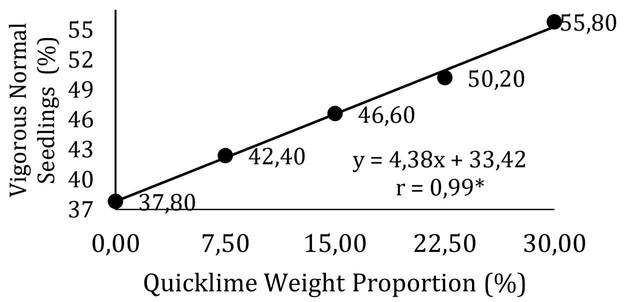


Figure 4. Relationship Between Vigorous Normal Seedlings and Quicklime Weight Proportion at 19 Months of Seed Storage.

Table 5. Results of the Polynomial Comparison Test for Vigorous Normal Seedlings (%/day) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime-linear	15,00	tn	-49,00	tn	219,0	*
P_2: quicklime -kuadratik	49,00	tn	87,00	tn	7,0	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

Table 6. Mean Value of Vigorous Normal Seedlings (%/day) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	71,60	66,80	37,80
7,5	69,20	64,00	42,40
15,0	70,80	59,40	46,60
22,5	69,00	60,60	50,20
30,0	73,20	63,60	55,80
Mean	70,76	62,88	46,56

Table 7. Results of the Polynomial Comparison Test for Hypocotyl Length at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime-linear	17,76	*	19,91	*	28,31	*
P_2: quicklime--kuadratik	4,66	tn	2,10	tn	9,74	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

Table 8. Mean Value of Hypocotyl Length (cm) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	B		
	15	17	19
0,0	8,41	10,40	9,40
7,5	8,53	10,51	9,74
15,0	8,61	10,98	9,96
22,5	9,53	11,59	10,69
30,0	9,69	11,85	11,75
Mean	8,95	11,07	10,31

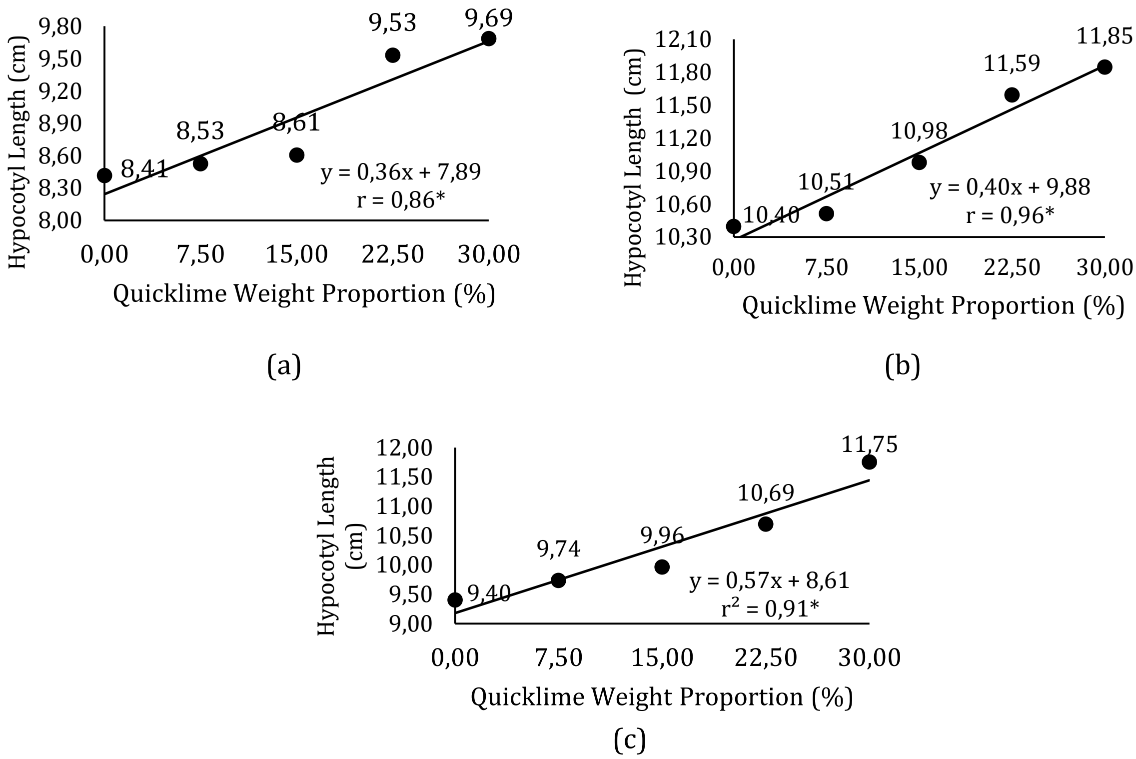


Figure 5. Relationship Between Hypocotyl Length and Quicklime Weight Proportion at 15 Months (a), 17 Months (b), and 19 Months (c) of Storage.

3.4 Hypocotyl Length

The results regarding the storage of soybean seeds indicated a linear increase in hypocotyl length after 15, 17, and 19 months, as demonstrated in Table 7. Specifically, every 1% rise in the weight of quicklime corresponded to increases in hypocotyl length of 0.36%, 0.40%, and 0.57% for the respective storage durations of 15, 17, and 19 months, as illustrated in Figure 5. These results were derived from the mean value of hypocotyl lengths outlined in Table 8.

3.5 Seedling Dry Weight (NSDW)

The results regarding the storage of soybean seeds indicate that the normal seedling dry weight (NSDW) observed after 15 months did not significant variations across the different treatment conditions. However, after 17 and 19 months of storage, a linear increase in NSDW was observed, as illustrated in Table 9. Specifically, a 1% rise in the weight of quicklime corresponded to an increase in NSDW of 1.90% following 17 months and 1.16% after 19 months, as shown in Figure 6, The average NSDW values at 15, 17, and 19 months of storage are detailed in Table 10. Notably, a higher NSDW after 15 months was indicated of considerable seed viability when compared to the NSDW at 17 and 19 months. This phenomenon suggests that after 15 months of storage, hygroscopic equilibrium was achieved between external environmental factors and the internal factors, specifically the nutrient reserves within the seeds. The substantial nutrient reserves facilitated enhanced metabolic activity during the germination phase, thereby aiding embryo development into viable seedlings (Ochandio *et al*., 2017).

Table 9. Results of the Polynomial Comparison Test for Dry Weight of Normal Seedlings (mg) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime-linear	3,00	tn	95,00	*	58,22	*
P_2: quicklime-kuadratik	2,00	tn	-43,00	tn	18,35	tn

Table 10. Mean Value of Dry Weight of Normal Seedlings (mg) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	41,60	33,50	31,16
7,5	42,20	36,00	32,23
15,0	42,30	40,20	32,56
22,5	41,00	40,60	33,75
30,0	42,50	40,70	36,23
Mean	41,92	38,20	33,19

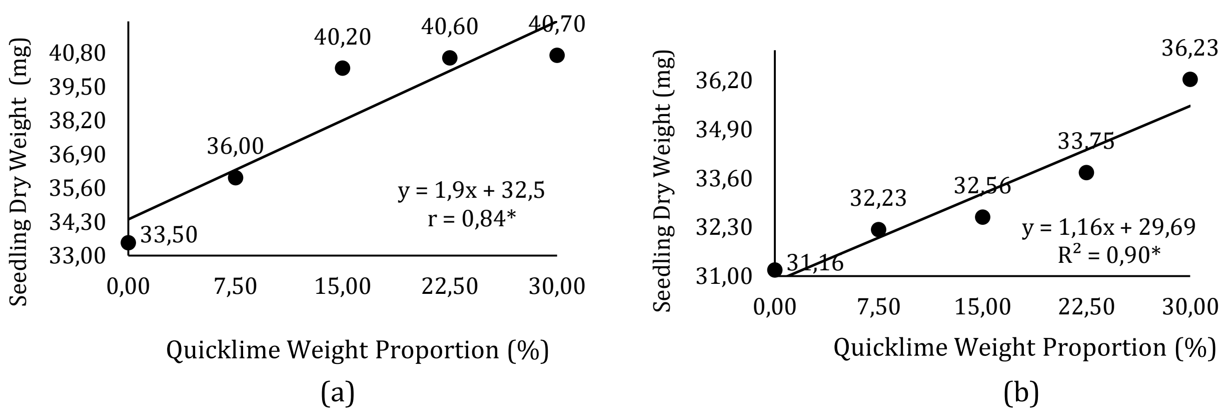


Figure 6. Relationship Between Dry Weight of Normal Seedlings and Quicklime Weight Proportion at 17 Months (a) and 19 Months (b) of Seed Storage.

3.6 Seed Moisture Content (SsMC)

The results regarding the storage of soybean seeds indicate a linear decrease in seed moisture content after 15, 17, and 19 months of storage, as illustrated in Table 11. The viability of the seeds at 17 and 19 months was indicated to be of low quality, with germination rates falling below 80%.

Table 11. Results of the Polynomial Comparison Test for Moisture Content (%/day) at 15, 17, and 19 Months of Seed Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime -linear	-12,93	*	-15,29	*	-16,31	*
P_2: quicklime -kuadratik	2,40	tn	3,87	tn	4,44	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

Table 12. Results of the Polynomial Comparison Test for Moisture Content (%/day) at 15, 17, and 19 Months of Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	7,63	7,75	7,74
7,5	7,44	7,30	7,25
15,0	6,93	6,88	6,79
22,5	6,81	6,70	6,61
30,0	6,66	6,52	6,43
Mean	7,09	7,03	6,96

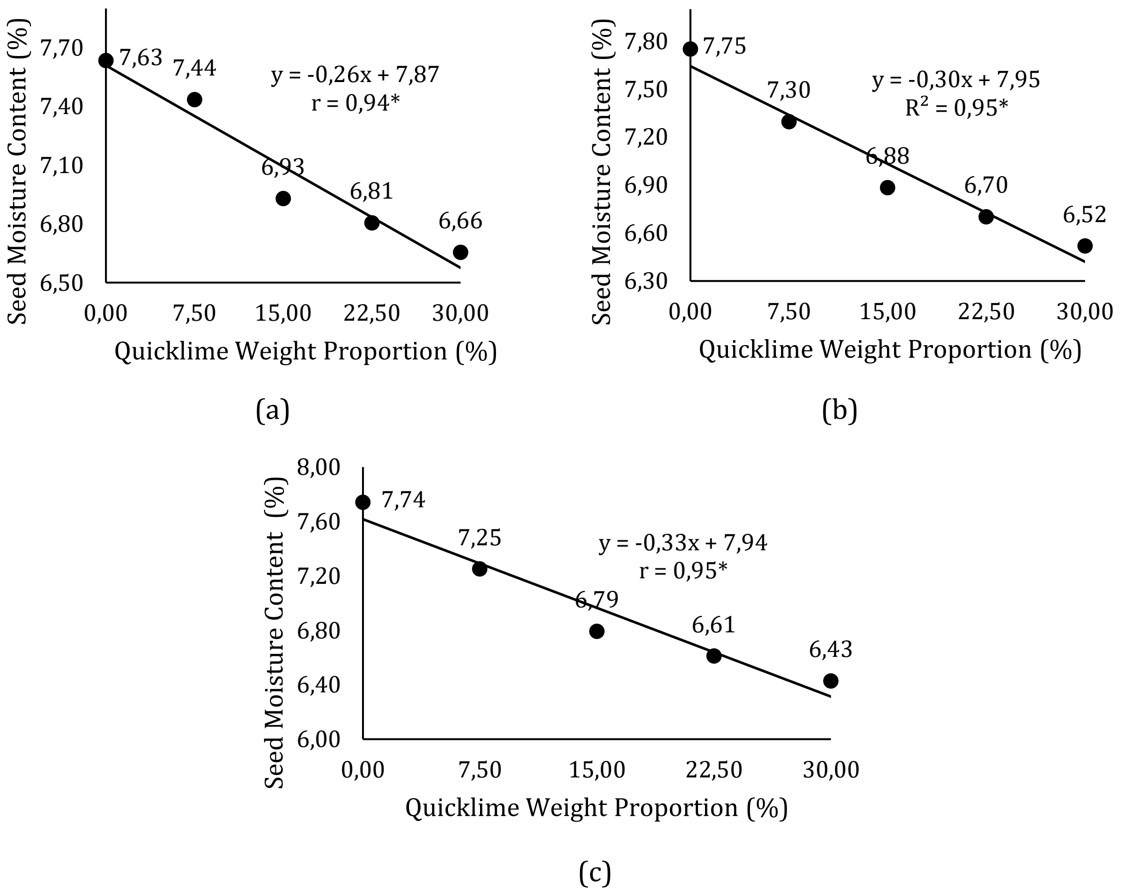


Figure 7. Relationship Between Seed Moisture Content and Quicklime Weight Proportion at 15 Months (a), 17 Months (b), and 19 Months (c) of Storage.

The role of quicklime in sustaining low water vapor levels within the storage container is demonstrated by the moisture readings: 7.75% for the control group, and 7.30%, 6.88%, 6.70%, and 6.52% for quicklime concentrations of 7.5%, 15.0%, 22.5%, and 30.0%, respectively, after 17 months of storage. After 19 months, the moisture content recorded was 7.74% in the control group, while those with quicklime had values of 7.25%, 6.79%, 6.61%, and 6.43% corresponding to the quicklime proportions. Incremental increases of 1% in quicklime weight were associated with reductions in seed moisture content of 0.26%, 0.30%, and 0.32% after 15, 17, and 19 months of storage, respectively, as depicted in Figure 7. Mean value of moisture contents for the seeds after 15, 17, and 19 months are detailed in Table 12. The moisture content of seeds is influenced by the relative humidity of the storage environment; seeds stored in open conditions are susceptible to variable humidity levels, complicating environmental management. In contrast, sealed containers tend to maintain lower internal humidity levels when temperatures rise, due to decreased water activity in the air. Elevated temperatures coupled with low relative humidity (RH) can prolong the lifespan of stored seeds (Hadi, 2013; Staden *et al*., 1975). Results from moisture tests confirmed percentages below 10% (Table 12). According to Yulyatin (2015) it advises that soybean seeds should be preserved at a moisture content below 10% to retain viability for up to one year. As moisture content increases, concern related to seed storage becomes more intricate, higher moisture levels accelerate seed deterioration and enhance the risk of fungal proliferation (Tefa, 2017).

3.7 Electrical Conductivity (EC)

The results from the electrical conductivity (EC) assessments conducted on various quicklime weight proportions after 15, 17, and 19 months of storage revealed no statistically significant differences among the treatments: 0.0% (P0), 7.5% (P1), 15.0% (P2), 22.5% (P3), and 30.0% (P4) relative to every 100 g of seeds, as illustrated in Table 13. Table 14 presents the mean EC values corresponding to the 15, 17, and 19 months of storage. The presence of low EC values which corresponded with high seed viability suggests the preservation of seed coat membrane quality. According to Iswara (2022), that low EC values indicate that seeds have not undergone deterioration or leakage during the four-month storage period. In contrast, an increase in EC is associated with a reduction in seed vigor, as the deterioration process leads to the release of electrolytes from the seed (Sukowardojo, 2013; Pamungkas, 2020).

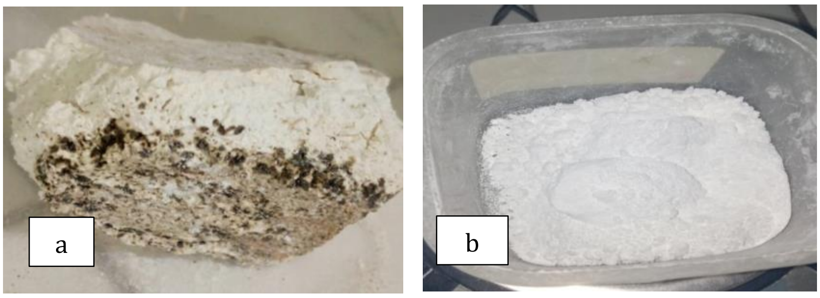
Table 13. Results of the Polynomial Comparison Test for Electrical Conductivity (mS/cm·g) at 15, 17, and 19 Months of Storage

Quicklime Weight Proportion (%)	Months					
	15		17		19	
	Q	F-value	Q	F-value	Q	F-value
P_1: quicklime -linear	0,33	tn	0,22	tn	0,18	tn
P_2: quicklime -kuadratik	0,29	tn	0,06	tn	0,20	tn

Note: * = Significantly different at α = 5%, tn = Not significantly different at α = 5%.

Table 14. Mean Value of Electrical Conductivity (mS/cm·g) at 15, 17, and 19 Months of Storage

Quicklime Weight Proportion (%)	Months		
	15	17	19
0,0	0,251	0,241	0,244
7,5	0,248	0,260	0,239
15,0	0,257	0,239	0,267
22,5	0,249	0,260	0,259
30,0	0,283	0,264	0,252
Mean	0,258	0,253	0,252



Gambar 8. Quicklime Before Storage (a) and After Storage (b).

After 15, 17, and 19 months of storage, the electrical conductivity values observed were consistently low, measured at 0.277 ms/cm, 0.252 ms/cm, and 0.252 ms/cm, respectively. According to Andini *et al.* (2021), low electrical conductivity values in seeds are indicative of a reduced likelihood of electrolyte leakage. A lower electrical conductivity (EC) value is correlated with a greater potential for germination. However, Taliroso (2008) highlighted that a compromised seed membrane structure leads to increased cellular leakage, which is significantly linked to diminished seed vigor. Thus, a greater release of amino acids and inorganic ions from the seeds corresponds to an elevated EC measurement.

3.8 Quicklime (CaO)

The results of seed storage over 15, 17, and 19 months indicated that the use of quicklime in its solid form for one month caused notable alterations in both the physical characteristics and color of the lime, as illustrated in Figure 8. These physical transformations encompassed the conversion of quicklime from solid clumps to a powdered form, alongside a color transition from gray to white. According to Muhsin and Tomo (2011), quicklime is generated from limestone through a high-temperature calcination procedure that results in the release of CO_2 gas from $CaCO_3$, ultimately leaving behind solid CaO. The efficacy of quicklime in moisture absorption from the atmosphere is demonstrated by these physical alterations; notably, the initial solid form converts to powder upon the absorption of water vapor. An increase in the proportion of quicklime following 17 and 19 months of storage led to a corresponding linear enhancement in germination percentage, germination velocity, the prevalence of robust normal seedlings, hypocotyl length, and dry weight of normal seedlings.

However, seed viability assessments after 17 and 19 months indicated low quality, as germination percentages fell below 80% across all tested quicklime proportions. The utilization of closed storage with quicklime managed hygroscopic equilibrium, regulating both internal moisture content and external relative humidity (RH) and oxygen levels (O_2), thereby establishing optimal storage temperatures. The vigorous seed deterioration depends on air humidity levels and ambient temperature, consequently, seeds should be packed and preserved in conditions that are conducive to maintaining quality, such as lower temperatures (Purwanti, 2004; Purwanti, 2015). While these parameters allowed for the retention of high seed quality after 15 months of storage, quality deterioration was evident at both 17 and 19 months. This degradation is likely a consequence of quicklime's moisture-absorbing properties, which resulted in a drier microenvironment for the seeds, facilitating moisture loss from the seeds to the surrounding air within the storage container. This phenomenon was evidenced by the reduction in moisture content observed after 17 and 19 months compared to the 15-month period. Low moisture levels are a significant factor in the acceleration of seed deterioration. Another potential contributing factor is that the seeds may have entered Period III, or the critical phase, within the seed viability model.

According to this concept, seeds stored for durations of 17 and 19 months were situated in this critical phase, where seed longevity declines rapidly, even under conditions deemed safe for storage. The findings indicated that after 17 months in airtight containers, the germination percentage exhibited a linear increase from 70.40% in the control group (0.0%) to 72.00%, 76.20%, 74.20%, and 76.00% for quicklime concentrations of 7.5%, 15.0%, 22.5%, and 30.0%, respectively. Concomitantly, germination rate index (GRI) increased from 24.01% in the control to 25.01%, 25.24%, 25.58%, and 26.14% for the same quicklime proportions. The proportion of strong normal seedlings rose from 66.80% in the control group to 64.00%, 59.40%, 60.60%, and 63.60%, while hypocotyl length increased from 10.40% to 10.51%, 10.98%, 11.59%, and 11.85%. Normal seedling dry weight showed an increase from 33.50 mg to 36.00 mg, 40.20 mg, 40.60 mg, and 40.70 mg. Moisture content decreased from 7.71% in the control to 7.30%, 6.88%, 6.70%, and 6.52% at the respective quicklime concentrations.

Following 19 months of storage, the germination percentage rose from 68.20% in the control to 71.00%, 72.80%, 75.20%, and 77.80% for quicklime proportions of 7.5%, 15.0%, 22.5%, and 30.0%, respectively. Furthermore, the germination speed grew from 24.50% in control to 26.55%, 26.82%, 27.90%, and 28.75%. The number of strong normal seedlings increased from 37.80% to 42.40%, 46.60%, 50.20%, and 55.80%, while hypocotyl length showed growth from 9.40% to 9.74%, 9.96%, 10.69%, and 11.75%. Normal seedling dry weight augmented from 31.16 mg to 32.23 mg, 32.56 mg, 33.75 mg, and 36.23 mg. Meanwhile, moisture content declined from 7.76% in the control to 7.25%, 6.79%, 6.61%, and 6.43% for the respective quicklime concentrations.

5. CONCLUSION

The conclusion of this study demonstrates that an increase in the proportion of quicklime leads to a linear enhancement in germination speed, the robustness of normal seedlings, hypocotyl length, and normal seedling dry weight, while concurrently decreasing seed moisture content. However, it is noteworthy that the increase in germination percentage diminishes with higher quicklime proportions. After 17 and 19 months of storage, seed viability was relatively low, with the germination percentage falling to 77.80% at a quicklime proportion of 30 g.

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