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Persistence of Seed Dormancy in Superior Rice Varieties across Different Storage Durations

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ABSTRACT

Varietal differences in dormancy persistence often delay germination, complicating seed quality certification and distribution. This study analyzes the dormancy characteristics and physiological readiness of two superior rice varieties, Inpari 32 and Memberamo, across storage intervals of 2, 3, 4, and 5 weeks post-harvest. The research employed a completely randomized design with eight treatment combinations and three replications. Core methods included standardized testing for germination rate, maximum growth potential, vigor index, and dormancy intensity, along with moisture content analysis. Quantitative results revealed a significant interaction between variety and storage duration: Inpari 32 dissipated dormancy faster, reaching an 88% germination rate by the third week, whereas Memberamo required five weeks to meet the national standard at 87%. Dormancy intensity significantly declined from 29.0% to 2.7% for Inpari 32 and from 66.0% to 8.0% for Memberamo over the five-week period. These findings indicate that Inpari 32 reaches optimal physiological maturity earlier than Memberamo, providing a critical basis for variety-specific storage management and quality testing schedules.

1. Introduction

Seed quality is a primary determinant of rice (*Oryza sativa* L.) productivity, and seed dormancy is a critical physiological attribute that regulates germination timing and early seedling establishment. Rice seed dormancy is a complex trait governed by genetic regulation and environmental conditions during seed maturation (Zhang *et al*., 2020; Park *et al*., 2024). As a temporary physiological state, dormancy gradually declines during after-ripening during storage; however, its persistence varies considerably among rice varieties, reflecting differences in genetic background and transcriptional regulation during seed development (Park *et al*., 2024).

In seed production systems, dormancy persistence poses a dual challenge: excessively long dormancy may delay germination and disrupt planting schedules, whereas insufficient dormancy increases susceptibility to pre-harvest sprouting (PHS), potentially leading to yield losses (Sohn *et al*., 2021). Recent studies have reported substantial variation in dormancy duration across varieties. Vishwanath *et al*. (2023) demonstrated significant differences in the longevity of dormancy dissipation among rice genotypes, while Wijaya *et al*. (2025) observed persistent dormancy in certain varieties, such as Sintanur, for several weeks after harvest. These findings indicate that dormancy persistence is a varietal-specific trait that does not dissipate uniformly during storage.

However, empirical studies systematically comparing the natural persistence of dormancy across multiple superior rice varieties at different storage times remain limited. Consequently, the dynamics of dormancy dissipation during storage in widely cultivated superior varieties remain poorly characterized. Addressing this research gap is essential for optimizing storage duration, improving seed distribution timing, and maintaining seed quality. Accordingly, this study aims to analyze the persistence of dormancy in several superior rice varieties across different storage time intervals to provide practical guidance for rice seed quality management.

2. Methodology

This research was conducted at the Laboratory of the Seed Supervision and Certification Unit (*UPT Pengawasan dan Sertifikasi Benih Tanaman Pangan dan Hortikultura*), East Java Province, Working Area V Jember, located at Jalan Pondok Curah Lele No. 66, Gumelar Village, Balung, Jember. The experiment was carried out from April to May 2025.

The tools used in this study included sample plastic bags, permanent markers, staplers, a moisture meter (Kett PM650), CD paper, tweezers, a seed germinator, and watercolor pencils. The materials consisted of two superior rice seed varieties, *Inpari 32* and *Memberamo,* and distilled water. This study employed a *Factorial Completely Randomized Design (CRD)* with two factors:

a. Factor I (Variety): V_1 = *Inpari 32*, V_2 = *Memberamo*
b. Factor II (Storage Time Interval): P_1 = 2 weeks, P_2 = 3 weeks, P_3 = 4 weeks, P_4 = 5 weeks after harvest

The combination of treatments resulted in eight treatment codes, such as V_1P_1 (Inpari 32 with 2-week storage) and V_2P_4 (Memberamo with 5-week storage), totaling 8 treatment combinations (2 × 4).

The number of replications was determined using the formula:

$$t(n-1) \geq 15$$

Where t is the number of treatments and n is the number of replications. Based on the calculation showing that n ≥ 2.88, each treatment was assigned 3 replications (3 per treatment), resulting in 24 experimental units in total. This design allows for the observation of the interaction between rice varieties and storage time intervals on dormancy-persistence parameters with statistical accuracy.

Seed samples of *Inpari 32* and *Memberamo* (Foundation Seed Class/BP) were taken from the seed storage warehouse. The samples were homogenized, and 1400 g were taken as representative samples for laboratory analysis. Initial moisture content was measured before treatment using a Kett PM650 moisture meter.

The seeds were stored at 25 °C and 50–60% relative humidity in the dark prior to testing, as dormancy is strongly influenced by temperature, humidity, and light exposure. Germination testing was conducted using the Between Paper (BP) method, in which 100 seeds were placed between moistened paper sheets and rolled into four analytical replicates per treatment. Germination persistence was observed weekly for four weeks. The parameters observed included germination rate, maximum growth potential, vigor index, dormancy intensity, and seed moisture content.

Moisture content was measured weekly using the Kett PM650 moisture meter, utilizing the remaining sample seeds. The observation procedures and formulas for each parameter are as follows (Tefa, 2017):

1. Germination Rate (DB)

   Observation was conducted on days 5 and 7 by counting normal seedlings.

$$DB(\%) = \frac{KN_1 + KKN_2}{seeds\ planted} \times 100\%$$

   Where:

   DB = Germination rate (%);

   $KN_1 + KN_2$ = Number of normal seedlings on first and second counts.

2. Maximum Growth Potential (PTM)

   Calculated based on the total number of normal and abnormal seedlings on day 7.

$$PTM(\%) = \frac{germinated\ seeds}{seeds\ planted} \times 100$$

   Where:

   PTM = Maximum growth potential (%).

3. Vigor Index (IV)

   Observed based on the number of normal seedlings on day 5.

$$IV(\%) = \frac{normal\ seedlings\ on\ day\ 5}{seeds\ planted} \times 100$$

   Where:

   IV = Vigor index (%)

4. Dormancy Intensity (ID)

   Measured based on the number of fresh but ungerminated seeds on day 7.

$$ID(\%) = \frac{fresh\ ungerminated\ seeds}{seeds\ planted} \times 100$$

   Where:

   ID = Dormancy intensity (%).

5. Seed Moisture Content (KA)

   Moisture content was determined with two replications using the formula (ISTA, 2021):

$$KA(\%) = \frac{M_1 + M_2}{2}$$

   Where:

   KA = Seed moisture content (%);

   M_1 = First replication;

   M_2 = Second replication.

   The difference between two replications must not exceed 0.2%.

Data obtained from observations were analyzed using analysis of variance (ANOVA) to determine the effect of varieties and storage intervals on all measured parameters. When significant differences were detected, mean comparisons were conducted using the Least Significant Difference (LSD) test at the 5% significance level. All statistical analyses were performed using SPSS version 26 to ensure transparency and reproducibility.

3. Results and Discussion

3.1. Germination Rate

Germination rate is the ability of seeds to germinate normally under optimal environmental conditions. A high germination rate is one of the key indicators of seed quality. According to Regulation No. 966 of the Minister of Agriculture (2022), seed quality testing includes examination of moisture content, purity, and germination rate.

Based on analysis of variance (ANOVA), the germination rates of Inpari 32 and Memberamo rice seed varieties at storage times of 2, 3, 4, and 5 weeks after harvest were significantly different. Therefore, a further Least Significant Difference (LSD) test at a 5% significance level was conducted. The results of the LSD 5% test are presented in Table 1.

Table 1. Results of the LSD 5% Test on the Average Germination Rate of Rice Seeds

Treatment	Germination Rate (%)
Rice Variety	
Inpari 32 (V1)	85.75 a
Memberamo (V2)	59.75 b
Storage Time Interval	
2 weeks (P1)	49.00 d
3 weeks (P2)	68.00 c
4 weeks (P3)	82.83 b
5 weeks (P4)	91.17 a

Note: Values followed by different letters indicate significant differences based on the LSD test at the 5% significance level.

Based on Table 1, treatment V1 showed a significantly different result compared to V2. Similarly, the storage interval treatments P1, P2, P3, and P4 also exhibited significant differences. The germination percentage that met the seed standard according to the Ministry of Agriculture Regulation (Kepmentan) No. 996 of 2022 was observed in treatments V1 (85.75%), P3 (82.83%), and P4 (91.17%). The minimum germination standard for inbred rice seeds of Foundation Seed (Benih Pokok/BP) class, as stipulated in Kepmentan No. 996 of 2022, is 80%. These results indicate that the germination rate of Inpari 32 rice seeds at 4 to 5 weeks after harvest still meets the established national seed quality standard.

Based on the analysis of variance (ANOVA), the interaction between the germination rate of the Inpari 32 (V1) and Memberamo (V2) rice varieties at different storage intervals of 2 weeks (P1), 3 weeks (P2), 4 weeks (P3), and 5 weeks (P4) showed a significant effect. Therefore, a further Least Significant Difference (LSD) test at the 5% significance level was performed. The results of the LSD 5% test are presented in Table 2 and Figure 1.

Table 1. Average Interaction of Germination Rate (%) Between Inpari 32 and Memberamo Varieties at Different Storage Time Intervals

Storage Time Interval	Germination Rate (%) by Variety	
	Inpari 32 (V1)	Membramo (V2)
2 weeks (P1)	68 b	30 d
3 weeks (P2)	88 a	48 c
4 weeks (P3)	91 a	74 b
5 weeks (P4)	95,33 a	87 a

Note: Values followed by different letters indicate significant differences based on the LSD test at the 5% significance level.

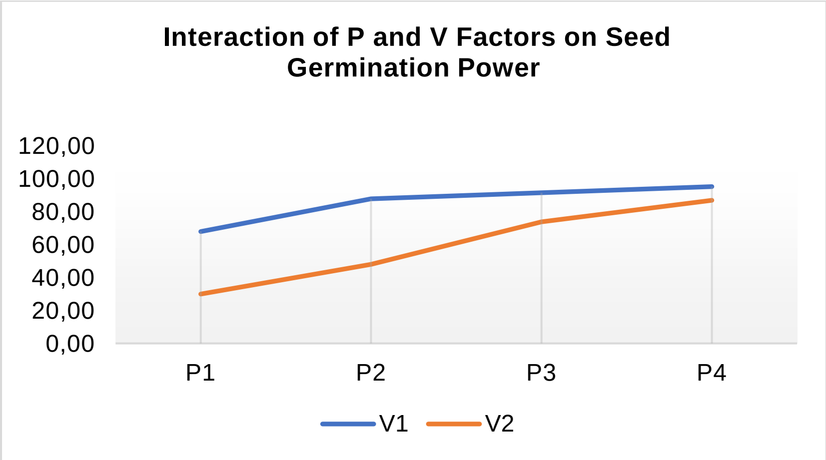

Figure 1. Interaction of P and V Factors on Seed Germination Power

3.2 Vigor Index

The analysis of variance (ANOVA) revealed a significant interaction between the superior rice varieties (Inpari 32 and Memberamo) and storage duration (2, 3, 4, and 5 weeks post-harvest) for the seed vigor index. To further determine the specific differences between treatment combinations, a Least Significant Difference (LSD) test at the 5% level was performed. The detailed distribution of vigor index values across different storage intervals is presented in Table 3 and Figure 2.

Table 2. Average Vigor Index of Interaction between V and P Treatments

Storage Interval	% Vigor Index by Variety	
	Inpari 32 (V1)	Membramo (V2)
2 weeks (P1)	66.00 c	28.67 d
3 weeks (P2)	88.00 b	46.33 c
4 weeks (P3)	90.00 b	74.00 b
5 weeks (P4)	95.00 a	86.67 a

Note: Numbers followed by different letters indicate significant differences based on the LSD test at the 5% level.

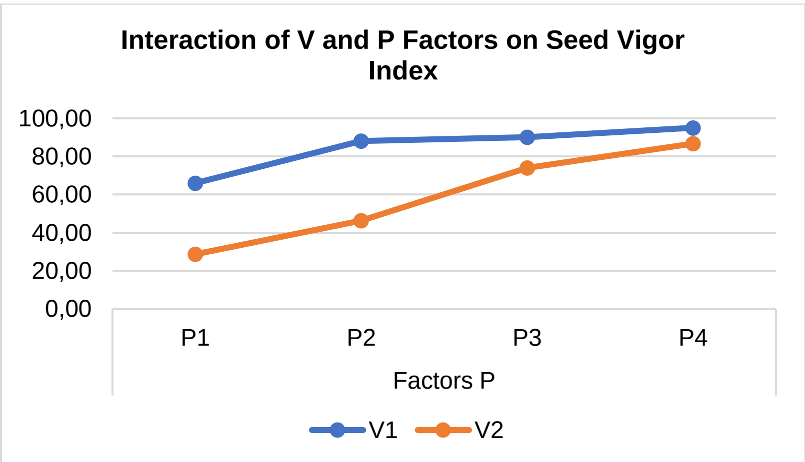

Figure 2. Interaction of V and P Factors on Seed Vigor Index

Based on the data presented in Table 3 and Figure 2, which show a significant interaction between variety and storage duration, it is evident that seed vigor response is influenced not only by the genetic characteristics of the varieties but also by physiological dynamics during the postharvest period. The increasing vigor pattern from the 2nd to the 5th week in both varieties indicates the presence of an after-ripening phase, a physiological process in which seeds undergo metabolic refinement and membrane stabilization, enhancing rapid and uniform germination. The pronounced differences between Inpari 32 and Membramo across storage intervals demonstrate that each variety has a distinct physiological sensitivity to postharvest maturation, where Inpari 32 tends to exhibit a faster recovery of vigor. This explains why certain treatments (such as V1P2 and V1P3) did not show significant differences, as the variety may have entered a physiologically stable phase during that time frame.

The finding that treatment V1P4 produced the highest vigor (95%) indicates that five weeks after harvest is the optimal time for Inpari 32 to achieve maximum physiological stability before vigor declines due to seed deterioration. The increase in vigor up to this optimum period may be associated with improved membrane integrity and more efficient activation of early germination enzymes, while the subsequent decline is typically caused by the accumulation of free radicals and lipid degradation. In practice, these results have important implications for seed management: storage intervals must be adjusted to the characteristics of each variety so that seeds are distributed at their peak vigor stage. Moreover, the observed interaction pattern reinforces that storage treatments cannot be generalized across varieties, making variety-specific storage strategies increasingly relevant for maintaining high-quality seed performance.

3.3 Maximum Growth Potential

The analysis of variance (ANOVA) for the maximum growth potential of Inpari 32 and Memberamo varieties showed significant differences across storage intervals of 2, 3, 4, and 5 weeks post-harvest. This parameter, which accounts for both normal and abnormal seedlings, exhibited distinct variations as storage duration progressed. To identify specific mean differences, a Least Significant Difference (LSD) test at the 5% level was conducted; the results are detailed in Table 4 and Figure 3.

Table 4. Mean Values of Maximum Growth Potential from the Interaction between Variety (V) and Storage Interval (P)

Storage interval	% Maximum growth potential by variety	
	Inpari 32 (V1)	Membramo (V2)
2 weeks (P1)	71.0 d	34.0 d
3 weeks (P2)	88.0 c	50.3 c
4 weeks (P3)	91.7 b	75.0 b
5 weeks (P4)	97.3 a	92.0 a

Note: Numbers followed by different letters indicate significant differences according to the 5% LSD test.

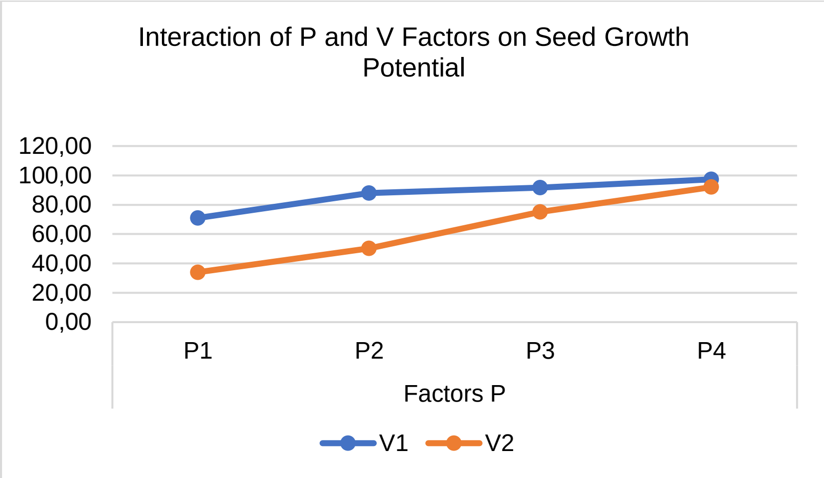

Figure 3. Interaction of P and V Factors on Seed Growth Potential

Based on Table 4 and Figure 3, the significant interaction between rice variety and storage interval indicates that maximum growth potential is strongly shaped by both genetic factors and physiological adjustments during the early postharvest phase. The consistent increase in maximum growth potential from week 2 to week 5 in both varieties reflects a progressive improvement in physiological readiness, particularly due to after-ripening processes such as membrane repair, enzymatic activation, and stabilization of metabolic pathways. These physiological upgrades allow seeds to express greater growth potential once germination begins. The distinct patterns observed between Inpari 32 and Membramo indicate that each variety responds differently to storage-induced physiological conditioning, where Inpari 32 appears to reach metabolic stabilization earlier than Membramo. This physiological sensitivity explains why every interaction combination showed significant differences, as each storage interval represents a different stage of metabolic refinement within each variety.

The finding that the five-week storage interval (P4) produced the highest maximum growth potential in both varieties, 97.3% for Inpari 32 and 92.0% for Membramo, indicates that this period corresponds to the peak of physiological optimization before seed aging processes begin to dominate. During this interval, the seeds likely reach a balance between decreased moisture content, improved membrane integrity, and heightened activity of early germination enzymes, all of which contribute to robust early seedling growth. Beyond this optimal phase, physiological deterioration, such as oxidative stress and lipid peroxidation, would gradually reduce growth potential. In practice, these results highlight that determining the optimal storage duration is essential to ensure seeds are distributed when their metabolic condition is most favorable. Storage intervals should therefore be tailored to each variety's physiological behavior to maximize the effectiveness of seed production and certification programs.

3.4 Dormancy Intensity

The analysis of variance (ANOVA) revealed a significant interaction between the superior rice varieties (Inpari 32 and Memberamo) and the storage intervals of 2, 3, 4, and 5 weeks post-harvest regarding dormancy intensity. This parameter was measured as the percentage of viable seeds that remained ungerminated at the end of the observation period. To identify specific mean differences among treatment combinations, a Least Significant

Difference (LSD) test at the 5% level was conducted. The results of the dormancy intensity test are summarized in Table 5 and Figure 4.

Table 5. Mean Dormancy Intensity in the Interaction Between Variety (V) and Storage Interval (P)

Storage Interval	% Dormancy Intensity by Variety	
	Inpari 32 (V1)	Membramo (V2)
2 weeks (P1)	29.0 a	66.0 a
3 weeks (P2)	12.0 b	49.7 b
4 weeks (P3)	8.3 c	25.0 c
5 weeks (P4)	2.7 d	8.0 d

Note: Values followed by different letters indicate significant differences based on the 5% LSD test

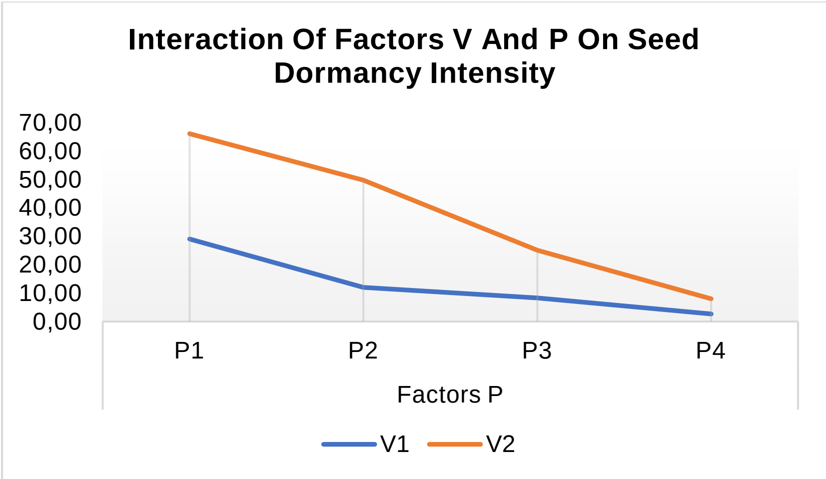

Figure 4. Interaction Of Factors V And P On Seed Dormancy Intensity

Based on Table 5 and Figure 4, the significant interaction between rice varieties and storage intervals indicates that dormancy intensity is closely influenced by both genetic differences and the physiological transitions that occur during the early postharvest period. The consistent decline in dormancy from week 2 to week 5 reflects the natural after-ripening process, during which seeds undergo enzymatic activation, hormonal rebalancing, particularly the reduction of abscisic acid (ABA), and gradual improvement of membrane permeability. These physiological adjustments reduce barriers to germination over time. The sharper decline observed in Inpari 32 compared to Membramo highlights varietal differences in the rate of after-ripening, suggesting that Inpari 32 may have a faster rate of hormonal degradation or membrane repair. The presence of significant differences across all treatment combinations confirms that each storage interval represents a distinct physiological stage that affects dormancy release.

The data show a clear reduction in dormancy intensity with increasing storage duration, with Inpari 32 decreasing from 29.0% at 2 weeks after harvest to 2.7% at 5 weeks, while Membramo decreased from 66.0% to 8.0% over the same period. This pattern demonstrates that extended storage provides sufficient time for seeds to complete key physiological processes necessary to overcome innate dormancy, including degradation of germination-inhibiting metabolites and activation of growth-promoting metabolic pathways. These findings imply that each variety requires a minimum storage period to reach an optimal physiological state that supports uniform, rapid germination. In practice, this reinforces the importance of adjusting storage intervals based on varietal characteristics to ensure seeds are released from dormancy before distribution, thereby improving field performance and seed lot uniformity.

3.5 Moisture Content

Analysis of variance (ANOVA) for the moisture content of the Inpari 32 and Memberamo varieties at storage intervals of 2, 3, 4, and 5 weeks post-harvest revealed significant differences. This parameter reflects the moisture levels maintained in the seeds during storage. To identify specific mean differences between treatment combinations, a Least Significant Difference (LSD) test at the 5% level was conducted. The results of the moisture content measurements are presented in Table 6 and Figure 5.

Table 6. Average Percentage of Moisture Content Measurement

Storage Time Interval	% Moisture Content by Variety	
	Inpari 32 (V1)	Membramo (V2)
2 weeks (P1)	12.8 b	13.0 ab
3 weeks (P2)	12.7 b	12.9 b
4 weeks (P3)	12.8 b	13.0 ab
5 weeks (P4)	13.1 a	13.1 a

Note: Numbers followed by the same letter indicate no significant difference according to the LSD 5% test.

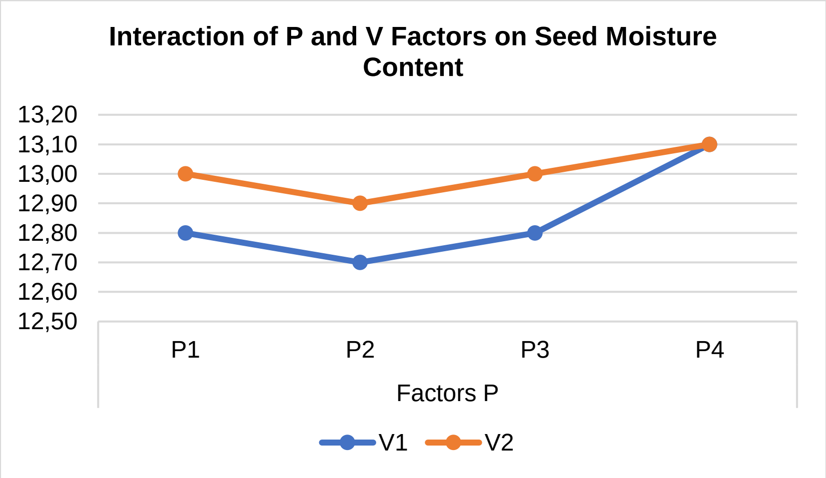

Figure 5. Interaction of P and V Factors on Seed Moisture Content

The results in Table 6 and Figure 5 show that moisture content in both rice varieties was significantly affected by the interaction between variety and storage duration, indicating that even short-term postharvest storage can alter seed water dynamics. The significantly higher moisture level in treatment V1P4 compared to other V1 treatments, as well as the variation observed among treatments in Membramo (notably the difference between V2P2 and V2P4), reflect the natural hygroscopic behavior of seeds during storage, in which seeds gradually equilibrate with ambient humidity and undergo slow physiological stabilization. The increase in moisture content at five weeks after harvest, reaching 13.1% in both varieties, suggests a shift in the seed's equilibrium moisture level, which, if exceeding the BP seed standard threshold of 13.0%, may heighten the risk of accelerated deterioration due to increased respiration and microbial susceptibility. Meanwhile, moisture values at earlier intervals (2–4 weeks) remained within the acceptable range (12.7–13.0%), indicating that storage before the fifth week better maintains physiological stability and reduces the likelihood of quality decline.

3.6. Discussion

The research findings revealed that both rice variety and storage interval significantly affected germination rate. Inpari 32 exhibited a higher germination percentage than Memberamo, indicating that genetic factors and physiological structure play a crucial role in maintaining seed viability. This aligns with Setiawan (2023), Badalliah *et al*. (2025), and Dwipa *et al*. (2018) who emphasize germination as a fundamental indicator of seed quality. However, the superior performance of Inpari 32 is not merely a phenotypic coincidence; according to Park *et al*. (2024), it is governed by a complex transcriptome-miRNAome network during seed maturation. This genetic predisposition allows Inpari 32 to have a shorter "biological clock" for after-ripening than Memberamo, consistent with Vishwanath *et al*. (2023), who found that the longevity of dormancy dissipation is a variety-specific trait.

The increase in germination and vigor index observed from week two to five suggests the transition from a dormant to a metabolically active state. Ardaniah (2024), Diyoprakuso *et al*. (2022), and ISTA (2021) define this as the seed’s ability to overcome innate barriers. Biologically, this is driven by a hormonal shift; as explained by Yustisia & Arham (2022), prolonged storage decreases Abscisic Acid (ABA) levels. This reduction in ABA, combined with an increase in sensitivity to Gibberellic Acid (GA), triggers alpha-amylase activity for starch mobilization (Sohn *et al*., 2021). The steeper improvement curve in Inpari 32 confirms that this variety reaches "metabolic stabilization" and hormonal rebalancing faster than Memberamo.

Regarding maximum growth potential, the findings demonstrate that longer storage intervals enhance physiological maturity. Wahab *et al*. (2025) and Wahyudi *et al*. (2025) noted that seeds require a storage period to allow enzymatic processes to stabilize. This process involves repairing cellular membranes damaged during desiccation. As Hadiyanti (2018) highlighted, this initial readiness determines subsequent plant vigor. The faster recovery in Inpari 32 compared to Memberamo indicates a more efficient membrane repair mechanism, allowing it to meet the national standard of 80% germination much earlier (Kepmentan 996, 2022).

Regarding dormancy intensity, the progressive decline reflects natural after-ripening. Wahab *et al*. (2023) Bristy *et al*. (2025), and Wina *et al*. (2023) describe this as a breakdown of germination inhibitors. The sharper decline in Inpari 32 suggests a faster rate of degradation of inhibitory metabolites. This varietal uniqueness is supported by Kamila (2021), Barokah & Susanto (2020) and Wijaya *et al*. (2025), who observed that varieties such as Sintanur and Inpari have distinct persistence periods. Without this understanding, as Tefa (2017) noted, seed distribution might occur while seeds are still in a deep dormant state, leading to planting failure.

Finally, the moisture content analysis showed a critical increase to 13.1% at five weeks. While Muis & Firmansyah (2021) and Gunawan *et al*. (2022) emphasize moisture control to prevent deterioration, this study finds that approaching the 13% threshold increases respiration rates. Higher respiration triggers the accumulation of Reactive Oxygen Species (ROS), leading to lipid peroxidation and membrane degradation. This explains why, although germination is high at week 5, the risk of rapid quality decline becomes imminent if storage is extended further under high humidity.

Limitations of the Study: This study focused on phenotypic observations under controlled laboratory conditions. While it addresses the "enzymatic and hormonal" mechanisms through existing literature, direct biochemical quantification of ABA/GA levels and ROS activity was not conducted. Future research should include these molecular assays to provide a more granular map of dormancy dissipation in Indonesian superior varieties.

4. Conclusion

This study establishes that seed dormancy persistence is a variety-specific physiological trait, providing a novel basis for differentiated post-harvest management in superior rice varieties. The findings reveal a distinct mechanistic synchronization between after-ripening duration and metabolic stabilization; Inpari 32 undergoes faster dormancy dissipation, achieving optimal germination and vigor (meeting national standards of >80%) as early as three to four weeks post-harvest. In contrast, Memberamo exhibits a more persistent dormancy, requiring a full five-week storage interval to achieve comparable physiological readiness. These results affirm that Inpari 32 is genetically predisposed for rapid after-ripening, making it more suitable for high-turnover seed production systems. Consequently, this study underscores that rice seed distribution and quality certification schedules cannot be generalized, but must be tailored to the specific after-ripening "biological clock" of each genotype to ensure peak field performance.

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