Jurnal Agronomi Indonesia
(Indonesian Journal of Agronomy)

ISSN 2085-2916 | e-ISSN 2337-3652
December 2025, *53*(3), 356-365
DOI: https://dx.doi.org/10.24831/jai.v53i3.67153

Research Article

Determination of maturity stage, after ripening period, and seed storability of upland rice seeds at various phosphorus fertilizer doses

Irfan Firmansyah [1], Eny Widajati [2,*], Maryati Sari [2], and Heni Purnamawati [2]

[1] Seed Science and Technology Study Program, Graduate School of IPB University (Bogor Agricultural University), Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, INDONESIA

[2] Department of Agronomy and Horticulture, Faculty of Agriculture, IPB University (Bogor Agricultural University), Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, INDONESIA

* Corresponding author (✉ eny_widajati@apps.ipb.ac.id)

ABSTRACT

The increasing demand for rice makes upland rice a promising alternative. However, one major challenge in upland rice cultivation is the availability of high-quality seeds. This study aimed to determine the physiological seed maturity, after-ripening period, storage longevity, and optimal fertilizer dose to produce high-quality IPB 10G Tanimar. The research used a split-plot randomized complete block design with two factors and three replications. The main plot was phosphate fertilizer doses (50, 100, and 150 kg ha^{-1} SP-36), and the sub-plot was seed maturity stages (112, 116, 120, 124, and 128 days after planting(DAP). The results showed that fertilizer dose had no significant effect on vegetative and generative growth. The application of 100 kg ha^{-1} SP-36 fertilizer produced the best seed quality based on the initial vigor index. The best maturity stage was 124 DAS with a heat unit of 2,505 °Cd, as indicated by the parameters of initial vigor index, germination rate during storage, and storability. The shortest after-ripening period was also found at 124 DAS, with the minimum germination rate (>80%) achieved one week after storage (WAS). The best storage vigor at the end of the observation period (8 WAS) was at 124 DAS, with a germination rate of 79.67% and a vigor index of 21.89%.

Keywords: high-quality seed; heat unit; phosphate fertilizer; storage longevity; vigor index

Edited by:
Okti Syah Isyani Permatasari
IPB University

Received:
26 August 2025
Accepted:
31 December 2025
Published online:
31 December 2025

Citation:
Firmansyah, I., Widajati, E., Sari, M., Purnamawati, H. 2025. Determination of maturity stage, after ripening period, and seed storability of upland rice seeds at various phosphorus fertilizer doses. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 53*(3), 355-364. DOI: https://dx.doi.org/10.24831/jai.v53i3.67153

INTRODUCTION

The need for rice as a staple food continues to increase every year. Dryland rice is one of the alternative solutions to overcome the rice shortage for consumption. The problem that often arises related to the utilization of dry land for upland rice is the availability of quality seeds. Seed production is closely associated with the quantity and quality of seeds produced. High seed quality is determined by the right harvest time at physiological maturity. Physiological maturity is when seeds' viability, vigor, and dry weight reach their maximum (Ilyas, 2012). In various types of plants, the period from flowering to producing physiologically ripe seeds varies, so knowing the time of physiological maturity is crucial for determining the optimal harvest time.

The determination of physiological maturity can be carried out using various methods. According to the research by Puspaningrum et al. (2021), the optimal maturity stage of Inpari 42 rice was achieved at the late maturity phase (F3) with a germination rate of 97%, which showed a negative correlation (r = -0.414) with total seed chlorophyll content. The heat unit required for IPB 3S rice seeds to reach physiological maturity was

2,204.4 °Cd (Putri et al., 2023). The study by Fitrianingsih (2019) reported that the best maturity stage for Inpari Sidenuk rice was when the entire panicle turned yellow (110 days). Research on the IR64 rice variety showed that harvesting at 100 days after planting (DAP) produced the highest seed quality (Sugriana et al., 2023). Hybrid rice seeds (*Oryza sativa* L. subsp. *indica*) of the Qianyou No. 1 variety harvested between 19 and 28 days after pollination all had high seed vigor (Zhu et al., 2016).

The maturity stage can be influenced by input factors, one of which is fertilizer application. Application of 20 kg ha^{-1} FTE BR 12 (B: 2.5%; Cu: 7.5%; Mn: 12%; Zn: 5%; Fe: 6%), 10 kg ha^{-1} N, and 50 kg ha^{-1} K_2O affected the seed maturation process of sesame by increasing germination capacity, germination speed, and early germination percentage. Physiological maturity of sesame seeds is achieved between 52 and 54 days after anthesis(Ferreira et al., 2017). Delaying the timing of fertilizer application can increase rice seed viability. According to the study by Aliyah et al. (2023), rice fertilization at 7 DAP, 28 DAP, and 35 DAP resulted in a higher vigor index (11.67%) compared to the control treatment (7 DAP, 21 DAP, 35 DAP), which showed only 2.33%.

Application of the right dose of phosphorus fertilizer can maximize production and improve seed vigor. The study by Kartika et al. (2022) showed that the interaction between half-dose phosphate fertilizer and bacterial isolates optimized the seed vigor of PBM UBB 1 rice variety. The recommended dose for lowland rice according to the Ministry of Agriculture (2022c) is 50 kg ha^{-1} of SP-36, while for upland rice, the recommendation is not yet available, thus requiring further research. Proper fertilization is expected to maximize seed viability at harvest. Optimal seed viability at harvest will positively impact the longevity of seed storage.

Seed storability is closely related to the ability of seeds to maintain their viability during storage. In rice, seed storability is also related to the after-ripening period. The length of the after-ripening period depends on the ratio of ABA (abscisic acid) to GA (gibberellic acid) during storage. Research by Branco et al. (2022) showed that the after-ripening period varied among potential local rice landraces in Timor-Leste, with the ABA/GA_3 ratio decreasing over storage time, from 0.53–1.22 ppm at 2 weeks after storage (WAS) to 0.45–0.93 ppm at 4 WAS. In Bangka local upland rice (Balok accession), Wahyuni et al. (2023) reported that the after-ripening period occurred in the 9th week, and soaking the seeds in 3% KNO_3 solution for 24 hours increased seed viability.

Applying the appropriate phosphate fertilizer dose can influence the time required for seeds to reach physiological maturity with optimal physiological quality. This study aimed to determine the physiological maturity of rice seeds, the after-ripening period, and the storability of upland rice seeds of the IPB 10G Tanimar variety.

MATERIALS AND METHODS

The research was conducted from May 2024 to January 2025 at the Leuwikopo Experimental Field and the Seed Science and Technology Laboratory, IPB, Dramaga, Bogor. The planting material was upland rice seeds (IPB 10G Tanimar variety) and planted in a rainfed system.

The experiment was arranged using a split-plot randomized complete block design with three replications. The main plot was the phosphate fertilizer dose: 50 kg ha^{-1} SP-36 (P1) (Agustiansyah et al., 2013; Ministry of Agriculture, 2022c), 100 kg ha^{-1} SP-36 (P2), and 150 kg ha^{-1} SP-36 (P3). The sub-plots were the maturity stages: 112 days after planting (DAP) (T1), 116 DAP (T2), 120 DAP (T3)(Ministry of Agriculture, 2022b), 124 DAP (T4), and 128 DAP (T5). The treatment combination (plot) was repeated three times. SP-36 contained 36% P_2O_5.

Land preparation was carried out one week before planting. The application of manure at a dose of 1 ton ha^{-1} and agricultural lime at 500 kg ha^{-1} was conducted simultaneously at final soil preparation. Soil analysis was conducted before the final soil preparation. Soil sampling was performed using a composite sampling method. A total of five sampling points were used. Soil samples were taken in slices to a depth of 20 cm at each point, with 200 g collected per point. The soil samples from all points were mixed, and approximately 750 g of the mixed soil was taken for laboratory analysis.

The rice was planted using the direct seeding method. The planting distance was 40 cm x 15 cm (BP2TP, 2024). The size of each experimental plot was 2 m x 3.2 m, consisting of five rows of plants with 21 planting holes per row, total of 105 planting holes per plot. The distance between plots was 0.7 m, and the distance between replications was also 0.7 m. Planting was carried out at a depth of 3–5 cm, with 6–10 seeds per hole, along with the application of carbofuran. In each experimental plot, five sample clumps were selected for observation. Replanting was conducted 7 days after planting (DAP) until 14 DAP. After planting, a data logger (Temperature Data Logger RC 5) was installed.

The maintenance activities included roguing, watering, weed control, pest and disease management, and net installation. Roguing was carried out at 15 days after planting (DAP). Watering was performed based on weather conditions and rainfall. Weed control was done manually, following the weed growth stage. Pest and disease control was carried out selectively and in a limited manner using pesticides. Net installation was done when the plants started flowering to protect them from bird attacks.

Fertilization was carried out following the method of Arinta & Lubis (2018). The recommended fertilizer dose consisted of 150 kg ha^{-1} of Urea, 100 kg ha^{-1} of SP-36, and 100 kg ha^{-1} of KCl. The fertilizer application at planting: 60 kg ha^{-1} of Urea, SP-36 according to treatment, and 100 kg ha^{-1} of KCl. The second application was 45 kg ha^{-1} of Urea at 3 weeks after planting (WAP), and the third was 45 kg ha^{-1} of Urea at 6 WAP. Details of the fertilization activities are presented in Table 1.

Table 1. Fertilizers doses and applications.

No	Activity	Time	Type of fertilizer	Dose	Application method
1	Before land preparation	Before planting	Organic fertilizer/ compost	1,000 kg ha^{-1}	Applied along small furrows beside the planting row, ±10 cm apart
2	Initial fertilization	At planting	Urea	60 kg ha^{-1}	
			SP36	According to treatment	
			KCl	100 kg ha^{-1}	
3	First follow-up fertilization	3 weeks after planting (WAP)	Urea	45 kg ha^{-1}	
4	Second follow-up fertilization	6 WAP	Urea	45 kg ha^{-1}	

Harvesting occurred at 112, 116, 120, 124, and 128 days after planting (DAP). The harvest began by cutting the upper one-third portion of the stem using a sickle, with the stems and panicles kept upright. The harvested rice was immediately threshed using a mechanical thresher. The grains were then cleaned to remove impurities. Drying was performed using the sun-drying method on a drying floor until the moisture content reached 12% (maximum 13%) (Ministry of Agriculture, 2022a).

Experimental observations

Vegetative parameters were observed from 3 weeks after planting (WAP) to 9 WAP, including plant height and number of tillers. The analysis of P content in the leaves was carried out when the plants had entered the flowering stage, or 10 weeks after planting. Generative parameters were observed from the flowering stage to harvest, including the number of productive tillers, the number of grains per panicle (filled, unfilled, total), the percentage of filled and unfilled grains per panicle, and the 50% flowering age. Daily temperature monitoring and physical and physiological seed quality observations were conducted, including 1,000-grain weight, seed dry weight, moisture content at harvest, and initial seed viability and vigor (germination rate, maximum growth potential, and vigor index).

After-ripening period at several maturity stages was observed during storage. Harvested seeds were dried to a moisture content of 12% (maximum 13%) (Ministry of Agriculture, 2022a) and then packaged in plastic bags. The packaged seeds were stored in a room with a temperature of 20 °C. The seeds were stored for 8 weeks, with observations conducted weekly. The observed parameters included moisture content, germination rate, and accelerated aging test.

The observational data were analyzed using analysis of variance (ANOVA/F-test), and further testing was conducted using the Duncan Multiple Range Test (DMRT) at a 5% significance level. The software used for data analysis was Microsoft Excel and STAR (Statistical Tools for Agriculture Research).

RESULTS AND DISCUSSION

The soil pH status in this study was 5.44, which is classified as acidic; therefore, agricultural lime was applied at a dose of 500 kg ha^{-1} at the beginning of planting. The organic carbon (C-organic) content before planting was 1.28%, which is considered low according to ISRI (2023), likely due to continuous land use for cultivation. Organic fertilizer was applied at 1 ton ha^{-1} at the beginning of planting. Adding organic and inorganic fertilizers will increase the soil's organic carbon content. Research by Yuniarti et al. (2019) showed that applying organic and inorganic fertilizers significantly increased soil organic carbon percentage compared to the control.

The measurement results of available phosphorus (30.30 ppm P_2O_5) and available potassium (75.64 ppm K_2O) indicated that the soil's phosphorus and potassium content were classified as high (ISRI, 2023). Generally, the initial soil fertility status in the Leuwikopo Experimental Field was categorized as moderate to low. Therefore, adding fertilizers is expected to improve the seeds' quality.

Vegetative growth of rice

The analysis of variance results showed that applying different phosphorus fertilizer rates did not affect vegetative parameters, including plant height and number of tillers. Ye et al. (2019) showed that various phosphorus fertilizer rates (ranging from 0 to 180 kg ha^{-1}) had no significant effect on rice plant height. These research findings are, of course, influenced by the initial fertility of the soil used.

The results of the leaf P analysis showed that phosphorus status in the leaves increased with higher doses of SP-36 fertilizer. This suggests that P was well absorbed by the plants, except at 120 and 124 DAP, where the 150 kg ha^{-1} dose showed a significant decrease. Application rates higher than the recommended dose led to higher leaf phosphorus content. The 100 and 150 kg ha^{-1} rates resulted in the highest phosphorus status (Table 2). According to the study by Bustami et al. (2012), phosphorus fertilizer rates significantly affected plant phosphorus levels.

Table 2. Leaf phosphorus level (%) at different maturity stages and phosphorus fertilizer doses.

SP-36 fertilizer dose (kg ha^{-1})	Leaf phosphorus level (%)				
	112 DAP	116 DAP	120 DAP	124 DAP	128 DAP
50	0.12Bd	0.14Cc	0.21Ca	0.19Bb	0.15Cc
100	0.22Ac	0.17Bd	0.30Aa	0.24Ab	0.23Bbc
150	0.23Ac	0.25Ab	0.26Bb	0.14Cd	0.28Aa

Note: Values followed by the same uppercase letter in the same column or the same lowercase letter in the same row are not significantly different according to the 5% DMRT test; DAP-days after planting.

Generative growth of rice

The analysis of variance results showed that phosphate fertilizer dose at various maturity stages had no significant effect on generative growth parameters (Table 3). This result is presumed to be influenced by the sufficient availability of phosphorus in the soil, as the study by Tabar (2012) showed that a fertilizer rate of 90 kg ha^{-1} increased the number of productive tillers, the weight of 100 grains, and dry weight. Another explanation is found in the study by Massawe & Mrema (2017), which stated that phosphorus fertilizer was applied two weeks before planting to allow it to dissolve. In contrast, in the present study, phosphorus fertilizer was applied simultaneously with planting.

Table 3. Summary of ANOVA for generative parameters.

Generative parameters	SP-36 fertilizer dose	Maturity stage	Interaction
Number of productive tillers	ns	ns	ns
Number of grains (filled, unfilled, total)	ns	ns	ns
Percentage of filled grains per panicle	ns	ns	ns
Percentage of unfilled grains per panicle	ns	ns	ns
Flowering age	ns	ns	ns

Note: ns = not significant

Physical and physiological seed quality

The analysis of variance results showed that phosphate fertilizer dose at various maturity stages had no significant effect on several physical seed quality parameters, including 1,000-grain weight, seed dry weight, and seed moisture content at harvest. The results were observed for seed viability indicators such as germination rate, vigor index, and maximum growth potential, which were significantly affected. Both fertilizer dose and maturity stage significantly affected the vigor index parameter. The vigor index can be used to determine the optimal maturity stage. Physiological maturity is achieved when seeds reach maximum dry weight and vigor index (Ilyas, 2012).

The addition of phosphate fertilizer is expected to improve seed physiological quality. However, several studies have shown that increasing the phosphate dose does not affect generative parameters. Research by Agustiansyah et al. (2013) found that seeds treated with 50 and 100 kg ha^{-1} of SP-36, phosphate fertilizer, had no significant difference in viability and vigor compared to seeds without phosphate application. Similarly, Ridwansyah et al. (2010) reported that increasing fertilizer doses to the highest level (300 kg Urea + 150 kg SP-18 + 150 kg KCl) did not affect seed quality measurements. Maturity stage treatments also did not affect generative parameters such as 1,000-grain weight. Wang et al. (2018) found no significant differences in 1,000-grain weight when seeds were harvested within 17 to 23 days after artificial pollination. The study by Zhang et al. (2021b) showed that applying phosphorus fertilizer at 50 kg ha^{-1} resulted in the highest 100-grain weight when continuous flooding was applied.

The initial viability test results showed the seeds' dormancy, indicated by a germination rate below 80%. The maturity stage of 120 DAP produced the highest viability in terms of germination rate and maximum growth potential (Table 4). The germination rate and maximum growth potential were 66.33% and 68.33%, respectively. At this stage, all maturity stages were still experiencing dormancy. The maturity stage significantly affects seed viability and vigor. The seed maturity phase significantly affects seed viability and vigor, with the best germination percentage of 97% obtained from the Inpari-42 variety at the late maturity stage (Puspaningrum et al., 2021).

Table 4. Average seed viability at different maturity stages

Viability parameter	Seed viability				
	112 DAP	116 DAP	120 DAP	124 DAP	128 DAP
Germination rate (%)	43.78c	49.67bc	66.33a	55.56b	53.11b
Maximum growth potential (%)	49.00c	53.67bc	68.33a	56.67b	53.33bc

Note: Values followed by the same letter in the same row are not significantly different based on the 5% DMRT test; DAP-days after planting.

Table 5 shows that the best maturity stage was 124 DAP with a fertilizer dose of 100 kg ha^{-1} SP-36, based on the vigor index of the seeds. Physiological maturity significantly affects the vigor index at harvest. Seeds of the Inpari Sidenuk variety harvested at the recommended age (113 days after sowing) had the best vigor index of 24.82% compared to other maturity stages (Fitrianingsih, 2019). Seed vigor reaches its maximum at 50 days after flowering and continuously declines with delayed harvest time, indicating that a timely early harvest is effective for conventional japonica rice seed production(Zhu et al., 2022). Phosphorus and calcium fertilization can also affect germination rates. Germination increased by 5-6% with 100 kg ha^{-1} of calcium and 90 kg ha^{-1} of phosphorus compared to the control (without fertilization) (Bishnoi et al., 2007).

Table 5. The effect of the interaction between fertilizer dose and maturity stage on the vigor index

SP-36 dose (kg ha^{-1})	Seed vigor index (%)				
	112 DAP	116 DAP	120 DAP	124 DAP	128 DAP
50	10.33Aab	3.00Ac	5.33Abc	13.67Ba	14.33Aa
100	7.33Ab	2.67Ab	5.33Ab	22.67Aa	7.33Bb
150	9.67Ab	0Ac	7.00Ab	17.00ABa	11.67ABab

Note: Values followed by the same uppercase letter in the same column or the same lowercase letter in the same row are not significantly different based on the 5% DMRT test.

Heat unit

The IPB 10G rice variety requires a specific heat unit accumulation to determine its physiological maturity, which can help estimate the optimal harvest time. Daily temperature observations showed that the maturity stage at 112 DAP was reached at 2,266 °Cd, 116 DAP at 2,348 °Cd, 120 DAP at 2,428 °Cd, 124 DAP at 2,505 °Cd, and 128 DAP at 2,584 °Cd. Environmental conditions during planting affect the accumulation of heat units and the attainment of physiological maturity. The three rice varieties (Pathum Thani 1, Suphan Buri 1, and Chai Nat 1/CN1) reached physiological maturity at 106.8 days after sowing (1,912 °Cd) in 2018, whereas in 2019, physiological maturity was reached at 86.2 days after sowing (1,883.8 °Cd) (Sanwong et al., 2023). Rice variety Bg300 reached physiological maturity at 96 DAS (1,543 °Cd), Bg352 at 98 DAS (1,627 °Cd), and Bg358 at 104 DAS (1,698 °Cd), with no significant difference when grown during either the South-West Monsoon or the North-East Monsoon seasons (Suriyagoda et al., 2022).

The optimal maturity stage was at 124 days after planting (DAP). The parameters indicating that 124 DAP was the best harvest time were the initial vigor index, germination rate during storage, and seed vigor storability. Seed dry weight and vigor are commonly used to determine the maturity stage. Deepak et al. (2019) state that rice seeds mature 45 days after anthesis. Fu et al. (2016) reported that the ZLY06 rice variety was harvested 20 days after anthesis (DAA) and the CY84 variety at 25 DAA. Rodnuch et al. (2023) reported that harvesting at 20 days after anthesis resulted in the highest germination for the three varieties studied (Rice Berry, Tubtim Chumpae, and Sang Yod). Upland rice cv. Dawk Pa-Yawn reached physiological maturity at 28 days after flowering, with a maximum seed dry weight of 21.89 mg and a germination rate of 97% (Kwankaew et al., 2017). Harvest timing can also affect harvest quality. Zhang et al. (2021a) found that the percentage of head rice significantly increased with delayed harvest time. Yadav et al. (2019) reported that rice cultivars NDR 97, NDR 359, BPT 5204, and Swarna Sub 1 reached physiological maturity at 21, 28, 35, and 38 days after 50% anthesis, respectively, as indicated by the highest seed quality, including seed weight, germination rate, and vigor.

After-ripening period

Analysis of variance showed that the application of various phosphorus (P) fertilizer doses had no significant effect on the after-ripening period of upland rice seeds of the IPB 10G Tanimar variety, as indicated by the parameters of moisture content and germination rate during storage. Harvest time at different maturity stages significantly affected the moisture content parameters from the second to the eighth week of storage. Harvest time at different maturity stages also influenced the germination rate parameters from the initial week up to the eighth week of storage, except for the seventh week.

Based on the germination rate, the best maturity stage during storage was 124 DAP (Table 6), especially during the first week after storage. However, in the following weeks, the results were slightly similar to those of 120 DAP. This indicates that seeds harvested at 120 DAP require a marginally longer storage period to overcome dormancy. A similar trend was observed for the maximum growth potential parameter. Seeds harvested at 124 DAP had a shorter after-ripening period than other maturity stages. Research by Korotenko et al. (2023) showed that rice seeds from various varieties harvested at 35 days after anthesis had a 50% increase in germination rate after one month of storage and reached maximum germination after six months of storage.

Table 6. Moisture content and seed viability at several maturity stages and after-ripening periods.

Maturity stage (DAP)	Weeks after storage (WAS)								
	0	1	2	3	4	5	6	7	8
	Moisture content (%)								
112	14.18	15.12	14.96a	14.60a	15.08a	14.27a	14.51a	14.34a	15.20a
116	12.53	13.89	15.20a	14.28a	13.83b	14.02ab	14.44a	12.91b	14.25b
120	13.22	14.31	13.9ab	13.18b	13.28b	14.91a	13.01b	13.88a	14.00bc
124	13.03	14.51	13.21b	12.97b	13.05b	12.63b	13.09b	13.68a	13.45c
128	13.74	14.02	13.93ab	13.37b	13.60b	13.43ab	13.26b	13.81a	13.87bc
	Germination rate (%)								
112	43.78c	45.89c	50.22c	65.78b	69.67b	76.44ab	75.56cd	73.00	88.44a
116	49.67bc	49.78c	70.22b	79.22a	79.44a	81.67a	85.11ab	70.11	80.67b
120	66.33a	74.78b	78.11a	82.33a	79.89a	80.22a	86.33a	74.22	81.67b
124	55.56b	83.00a	74.89ab	80.11a	81.78a	78.44a	80.33bc	77.67	81.44b
128	53.11b	71.00b	72.67ab	69.44b	76.78a	70.44b	73.56d	73.78	72.44c

Note: Numbers followed by the same letters in the same column are not significantly different based on the 5% DMRT test; DAP-days after planting

After-ripening period is considered complete when the germination rate reaches 80%, by the minimum seed certification standard issued by the Ministry of Agriculture (Ministry of Agriculture, 2022a). Special treatments are needed to accelerate the after-ripening process if the germination rate does not reach this value during storage or harvest.

Germination rate for each maturity stage is presented in Table 6. The germination rate at 124 days after planting reached 83% in the first week, indicating that the after-ripening period had ended. This result shows that IPB 10G seeds have a short after-ripening period when harvested at 124 DAP. Meanwhile, when harvested at 120 DAP, the after-ripening period lasted for three weeks after storage, as indicated by a germination rate of 82.33%. The earlier the harvest time, the longer the tendency for the after-ripening period to be.

The other three maturity stages each showed different after-ripening periods. Seeds harvested at 116 days after planting (DAP) completed the after-ripening period after five weeks after storage (WAS) with a germination rate of 81.67%. Seeds harvested at 112 DAP completed the after-ripening period at eight weeks after storage with a germination rate of 88.44%. Meanwhile, seeds harvested at 128 DAP had not yet completed the after-ripening period even after eight weeks of storage.

Seed storability

Seeds that still have high viability after being tested with the Accelerated Aging Test are seeds that have high storage vigor (ISTA 2018). The results of the seed storability observation using vigor index and maximum growth potential parameters are presented in Table 7. At 4 weeks after storage (WAS), the best maturity stage was 116 days after planting (DAP) with a vigor index value of 23%. At 8 WAS, the best maturity stage was 128 DAP with a vigor index of 25.56%. However, it was not significantly different from 124 DAP, which had a vigor index of 21.89%. Meanwhile, for the maximum growth potential parameter, the best maturity stage was 112 DAP, although it was not significantly different from 116 DAP and 120 DAP. According to the study by Rao and Jackson (1997), physiological maturity affects seed storability. Seeds harvested too early or too late tend to have poor storability. Japonica cultivars are better harvested 35 days after flowering than 21, 28, or 42 days after flowering, indicating the best storability potential.

Table 7. Seed viability after accelerated aging test at several maturity stages.

Maturity stage (DAP)	Viability parameters during the storage period		
	Vigor index (%)	Germination rate (%)	Maximum growth potential (%)
		4 weeks after storage	
112	12.56b	80.78	83.67
116	23.00a	79.22	82.44
120	15.56b	75.11	82.00
124	16.11b	71.89	83.00
128	13.44b	71.33	79.00
		8 weeks after storage	
112	15.11b	80.11	89.78a
116	10.89c	85.00	86.22a
120	11.78bc	84.78	85.33ab
124	21.89a	79.67	80.78b
128	25.56a	78.78	80.22b

Note: Numbers followed by the same letters in the same column are not significantly different based on the 5% DMRT test.

CONCLUSIONS

The phosphorus fertilizer dose had no significant effect on vegetative or generative growth of upland rice. The application of 100 kg ha^{-1} SP36 produced the best seed quality based on the initial vigor index. The optimal maturity stage was at 124 days after planting (DAP) with a heat unit of 2,505 °Cd, according to the parameters of the initial vigor index, germination rate during storage, and seed vigor storability. The shortest after-ripening period was observed at 124 DAP, with a minimum germination rate above 80% achieved one week after storage (WAS). The best seed vigor storability at the end of observation (8 WAS) was also at 124 DAP, with a germination rate of 79.67% and a vigor index of 21.89%.

REFERENCES

Agustiansyah, A., Ilyas, S., Sudarsono, S., & Machmud, M. (2013). Seed treatment with biological agents and P fertilizer to increase plant growth, yield, and quality of rice seed. (In Indonesian.). *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 41*(2), 98–104.

Aliyah, T., Suhartanto, M. R., Surahman, M., & Setiawan, A. (2023). Effect of delaying fertilization time on production and quality or rice seeds (*Oryza sativa* L.) IPB 3S variety. (In Indonesian.). *Buletin Agrohorti, 10*(3), 468–476. https://doi.org/10.29244/agrob.v10i3.46450

Arinta, K., & Lubis, I. (2018). The Growth and production of some local rice cultivars from Kalimantan. (In Indonesian.). *Buletin Agrohorti, 6*(2), 270–280. https://doi.org/10.29244/agrob.6.2.260-270

Bishnoi, U. R., Kaur, G., & Khan, M. H. (2007). Calcium, phosphorus, and harvest stages effects soybean seed production and quality. *Journal of Plant Nutrition, 30*(12), 2119–2127. https://doi.org/10.1080/01904160701700608

BP2TP. (2024). *Upland Rice Cultivation*. (In Indonesian.). Institute for Agricultural Technology Assessment and Development.

Branco, L. M., Ilyas, S., Purwoko, B. S., Purwito, A., & Palupi, E. R. (2022). Agro-morphological traits and seed after-ripening period of potential rice landraces from Timor-Leste. (In Indonesian.). *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 50*(3), 249–256.

Bustami, B., Sufardi, S., & Bakhtiar, B. (2012). Nutrient uptake and phosphate fertilizer efficiency as well as growth of local rice varieties. (In Indonesian.). *Jurnal Manajemen Sumberdaya Lahan, 1*(2), 159–170.

Deepak, D., Yadav, S. S., Mahendrakar, M. D., Yadav, R. D. S., & Singh, R. B. (2019). Study of physiological maturity in Indian scented rice cultivars (*Oryza sativa* L.). *Journal of Pharmacognosy and Phytochemistry, 8*(1), 1036–1039.

Ferreira, E. I., Pereira, M. D., de Macedo, A. R., & Soares, E. R. (2017). Effect of fertilization on the physiological maturation of sesame seeds. *Pesquisa Agropecuária Tropical, 47*(2), 202–210. https://doi.org/10.1590/1983-40632016v4745715

Fitrianingsih, N. (2018). Effect of maturity stage on yield quantity and seed storability of rice (*Oryza sativa* L.) variety Inpari Sidenuk at PP Kerja. (In Indonesian.). *Vegetalika, 7*(4), 42–55. https://doi.org/10.22146/veg.34598

Fu, H., Cao, D. D., Hu, W. M., Guan, Y. J., Fu, Y. Y., Fang, Y. F., & Hu, J. (2016). Studies on optimum harvest time for hybrid rice seed. *Journal of the Science of Food and Agriculture, 97*(4), 1124–1133. https://doi.org/10.1002/jsfa.7838

Ilyas, S. (2012). *Seed and Science Technology.* (In Indonesian.). IPB Press.

ISRI. (2023). *Technical Guidelines for Soil, Plant, Water, and Fertilizer Chemical Analysis.* (In Indonesian.). Indonesian Soil Research Institute.

ISTA. (2018)*. International Rule for Seed Testing*. The International Seed Testing Association.

Kartika, K., Suhartanto, M. R., Munif, A., Palupi, E. R., & Ilyas, S. (2022). Optimization of production and quality brown rice seed PBM UBB 1 varieties with phosphate solubilizing bacteria and phosphate fertilizer. (In Indonesian.). *AGROSAINSTEK: Jurnal Ilmu dan Teknologi Pertanian, 6*(2), 9–18. https://doi.org/10.33019/agrosainstek.v6i2.402

Korotenko, T., Mukhina, Z., Garkusha, S., Savenko, E., & Yurchenko, S. (2023). Dynamics of moisture content and sowing qualities of seeds in rice varieties during post-harvest ripening and storage. *E3S Web of Conferences, 431*, 01053. https://doi.org/10.1051/e3sconf/202343101053

Kwankaew, T., Santipracha, Q., & Santipracha, W. (2017). Seed Development and maturation on seed quality of upland rice cv. Dawk Pa-yawm. *Walailak Journal of Science and Technology, 14*(7), 607–614.

Massawe, P., & Mrema, J. (2017). Effects of different phosphorus fertilizers on rice (*Oryza sativa* L.) yield components and grain yields. *Asian Journal of Advances in Agricultural Research, 3*(2), 1–13. https://doi.org/10.9734/ajaar/2017/37202

Ministry of Agriculture. (2022a). *Decree of the Minister of Agriculture Number 966 of 2022 concerning Technical Guidelines for the Certification of Food Crop Seeds.* (In Indonesian.). Ministry of Agriculture Republic of Indonesia.

Ministry of Agriculture. (2022b). *Decree of the Minister of Agriculture of the Republic of Indonesia Number 1830 of 2022 concerning the Release of the Candidate Inbred Rice Variety B-32 as a Superior Variety under the Name IPB 10G Tanimar.* (In Indonesian.). Ministry of Agriculture Republic of Indonesia.

Ministry of Agriculture. (2022c). *Regulation of the Minister of Agriculture of the Republic of Indonesia Number 13 of 2022 concerning the Application Rates of N, P, and K Fertilizers for Rice, Maize, and Soybeans on Lowland Fields.* (In Indonesian.). Ministry of Agriculture Republic of Indonesia.

Puspaningrum, W., Widiastuti, M. L., Azizah, E., & Saputro, N. W. (2021). Detection of Physiological maturity stage of pigmented rice (*Oryza sativa* L.) through chlorophyll analysis and its effect on seed viability and vigor. (In Indonesian.). *Jurnal Agrohita, 6*(2), 272-278.

Putri, A. A., Widajati, E., & Ilyas, S. (2023). Determination of physiological maturity and methods for breaking dormancy of rice seeds of IPB 3S variety. *IOP Conference Series: Earth and Environmental Science, 1133*, 012006. https://doi.org/10.1088/1755-1315/1133/1/012006

Rao, N. K., & Jackson, M. T. (1997). Effect of sowing date and harvest time on longevity of rice seeds. *Seed Science Research, 7*(1), 13–20. https://doi.org/10.1017/S0960258500003317

Ridwansyah, B., Basoeki, T. R., Timotiwu, P. B., & Agustiansyah, A. (2010). Effect of three dose nitrogen, phosphor, and potassium at seed rice production of mayang rice variety at three locations in North Lampung. (In Indonesian.). *Jurnal Agrotropika, 15*(2), 68–72.

Rodnuch, N., Aninbon, C., & Kaewtaphan, P. (2023). Harvesting time influences seed germination and vigour of some coloured rice varieties in Thailand. *International Journal of Agricultural Technology, 19*(2), 609–620.

Sanwong, P., Sanitchon, J., Dongsansuk, A., & Jothityangkoon, D. (2023). High temperature alters phenology, seed development and yield in three rice varieties. *Plants, 12*(3), 666. https://doi.org/10.3390/plants12030666

Sugriana, L. T., Rajiman, R., & Wartapa, A. (2023). Effect of harvesting age and threshing techniques on seed quality of variety IR64. (In Indonesian.). Prosiding Seminar Nasional, *5*(1), 132–137.

Suriyagoda, L., Illangakoon, T., Wijerathna, S., & Devasinghe, U. (2022). Degree-day requirement for heading and maturity of three most popular rice varieties in Sri Lanka as influenced by location and season. *Ceylon Journal of Science, 51*(3), 229-245. https://doi.org/10.4038/cjs.v51i3.8031

Tabar, S. Y. (2012). Effect of nitrogen and phosphorus fertilizer on growth and yield rice (*Oryza sativa* L.). *International Journal Agronomy and Plant Production, 3*(12), 579–584.

Wahyuni, W., Saputri, R., Yufikar, Y., & Kurniasari, L. (2023). After-ripening testing and effectiveness of dormancy breaking in local Bangka upland rice seeds, Balok accession. (In Indonesian.). *Fruitset Sains: Jurnal Pertanian Agroteknologi, 11*(2), 116–125.

Wang, X., Zheng, H., & Tang, Q. (2018). Early harvesting improves seed vigour of hybrid rice seeds. *Scientific Reports, 8*, 11092. https://doi.org/10.1038/s41598-018-29021-5

Yadav, R. D. S., Singh, R. K., Purshottam, P., Giri, S. P., & Rai, M. (2019). Studies on seed development and harvesting stages and their impact for the maintenance of seed vigour in rice (*Oryza sativa* L.). *International Journal of Chemical Studies, 7*(4), 1135–1138.

Ye, T., Li, Y., Zhang, J., Hou, W., Zhou, W., Lu, J., Xing, Y., & Li, X. (2019). Nitrogen, phosphorus, and potassium fertilization affects the flowering time of rice (*Oryza sativa* L.). *Global Ecology and Conservation, 20*, e00753. https://doi.org/10.1016/j.gecco.2019.e00753

Yuniarti, A., Damayani, M., & Nur, D. M. (2019). Effect of organic fertilizer and N, P, K fertilizer on organic C, total N, C/N ratio, N uptake, and black rice yield on Inceptisols. (In Indonesian.). *Jurnal Pertanian Presisi, 3*(2), 90–105.

Zhang, J., Tong, T., Potcho, P. M., Li, L., Huang, S., Yan, Q., & Tang, X. (2021a). Harvest time effects on yield, quality and aroma of fragrant rice. *Journal of Plant Growth Regulation, 40*, 2249–2257. https://doi.org/10.1007/s00344-020-10288-w

Zhang, Y., Zhang, W., Wu, M., Liu, G., Zhang, Z., & Yang, J. (2021b). Effects of irrigation schedules and phosphorus fertilizer rates on grain yield and quality of upland rice and paddy rice. *Environmental and Experimental Botany, 186*, 104465. https://doi.org/10.1016/j.envexpbot.2021.104465

Zhu, L. W., Cao, D. D., Hu, Q. J., Guan, Y. J., Hu, W. M., Nawaz, A., & Hu, J. (2016). Physiological changes and sHSPs genes relative transcription in relation to the acquisition of seed germination during maturation of hybrid rice seed. *Journal of the Science of Food and Agriculture, 96*(5), 1764–1771. https://doi.org/10.1002/jsfa.7283

Zhu, M., Yu, X., Zhao, G., & Wang, L. (2022). Effects of harvest time on seed vigor, enzyme activity and gene expression of conventional japonica rice. *Archives of Agronomy and Soil Science, 68*(4), 460–475. https://doi.org/10.1080/03650340.2020.1840558