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Physical and Physiological Quality of Rice Seeds of Inpari 32 Variety Under Different Harvest Ages, Packaging Types, and Storage Durations

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ABSTRACT

This study aimed to determine the optimal harvest time and packaging type to preserve the quality of Inpari 32 rice seeds during storage. Conducted at the Food and Horticultural Plant Seed Supervision and Certification Unit in East Java from November 2023 to April 2024, the research used a factorial experiment in a completely randomized design (CRD) with three replications. Harvest age treatments were 110, 120, 130, and 140 days after seedling (DAS), while packaging types included plastic sacks, polyethylene (PE) sacks, polypropylene (PP) sacks, and aluminium foil. Data were analyzed using ANOVA and Duncan's Multiple Range Test (DMRT) at a 5% significance level. Results showed that harvesting at 120 DAS with PP sacks yielded the highest starch content, while 140 DAS with aluminium foil resulted in the lowest reducing sugar content. Optimal germination and growth speed were achieved at 130 DAS, which also minimized electrical conductivity. Harvesting at 140 DAS produced the highest 1000-grain weight. Aluminium foil packaging maintained the lowest moisture content and significantly improved germination and growth speed compared to other packaging types. These findings suggest that optimizing harvest age and packaging type can significantly improve seed viability and storage performance.

1. INTRODUCTION

Rice production in Indonesia has experienced a notable decline over the past decade, with production levels dropping from 59.02 million tons in 2018 to between 54.41 and 54.74 million tons from 2019 to 2022 (BPS Indonesia, 2023). To address this downturn, it is essential to utilize superior seeds that exhibit resistance to pests and diseases. In East Java, the Inpari 32 Bacterial Leaf Blight (BLB) variety has emerged as the most produced rice variety, representing 33.02% of total rice seed production, amounting to 48,885,292 tons, and covering a planting area of 530,609 hectares (31.60%) in 2023 (BPS Jawa Timur, 2024). This variety is characterized by its tolerance to Bacterial Leaf Blight (BLB), high yield potential of 8.42 tons per hectare of harvested grain, and a fluffy texture similar to Ciherang rice. The effective use of certified quality seeds, combined with proper irrigation and cultivation techniques, can significantly enhance productivity, contributing approximately 75% to overall increases in rice production. However, the quality of seeds can deteriorate rapidly if harvested at inappropriate times or stored in unsuitable packaging.

One of the primary challenges in boosting rice production in Indonesia is ensuring the availability of high-quality seeds. High-quality seeds possess good genetic, physiological, and physical attributes. Factors that can diminish seed quality include improper harvesting times; harvesting before physiological maturity results in low levels of maturity and germination, while delaying harvest beyond physiological maturity can lead to yield losses exceeding 5%. To improve seed quality, it is crucial to harvest at the physiological maturity stage, which correlates with maximum dry weight accumulation, seed vigor, and optimal yield. Seed quality peaks when the yellow panicles and leaves have dried, ensuring maximum germination and growth potential. Identifying the correct harvest time is vital for achieving optimal physical and physiological seed quality. New high-yielding varieties often produce numerous productive tillers, leading to non-uniform harvesting times due to varying flowering periods in each panicle, complicating the determination of the right harvest age.

Research indicates that the physiological quality of rice seeds—including traits such as germination rate, seed vigor, and overall viability—can vary significantly based on harvest age. Seeds harvested too early or too late may show reduced germination rates and lower vigor, negatively impacting crop establishment and yield potential (Feyem *et al*., 2017; Hussain *et al*., 2014). Studies have highlighted that optimal harvest timing is critical for maximizing seed quality, as seeds harvested at the appropriate physiological maturity demonstrate superior germination and growth characteristics. In addition, storage conditions, including the type of packaging, play a significant role in maintaining seed quality over time. Various packaging materials can affect moisture retention, gas exchange, and exposure to pests, all of which are essential for preserving seed viability (Raja & Sasikala, 2018; Tejakhod & Ellis, 2018).

Environmental factors such as temperature and humidity also influence the physiological responses of rice seeds to storage conditions. High temperatures and humidity levels can accelerate seed quality deterioration, resulting in decreased germination rates and increased susceptibility to diseases (Raja & Sasikala, 2018). Conversely, appropriate storage conditions can enhance seed longevity and maintain vigor, which is crucial for successful crop establishment. Understanding these dynamics is essential for optimizing seed quality and ensuring effective crop production. Moreover, the physical quality of rice seeds encompassing attributes such as size, shape, and weight is influenced by harvest age and storage practices. Seeds that are uniform in size and optimal in shape are more likely to germinate successfully and yield robust seedlings (Li *et al*., 2022; Scariot *et al*., 2021). Overall, these findings emphasize the importance of high-quality seeds, as they not only enhance agricultural productivity but also improve economic viability through better yields and market prices (Ilangathilaka *et al*., 2021; Sarkar *et al*., 2024).

Despite previous studies on seed storage and physiological maturity, limited research has explored the combined effects of harvest age and packaging types on the long-term viability of rice seeds. The physical and physiological quality of Inpari 32 rice seeds is intricately linked to the age at which they are harvested and the types of packaging used during storage. Understanding these relationships is crucial for developing effective seed management strategies that enhance seed quality and, consequently, agricultural productivity. This study aims to obtain the best combination of harvest age treatment and packaging type to maintain the physical and physiological quality of Inpari 32 Bacterial Leaf Blight (BLB) during different storage. The results of this study by seed producers to choose the right harvest time and type of packaging.

2. MATERIALS AND METHODS

2.1. Research Location

The research was conducted at the Seed Certification and Quality Testing Laboratory of the Food and Horticultural Plant Seed Supervision and Certification Unit (UPT. PSBTPH) of East Java Province in Surabaya. The research took place from November 2023 to April 2024. The tools utilized were stationery, a sealer, a germinator, a grinder, an oven, tweezers, an Eutech Cyberscan Con 11 Conductivity Meter, a temperature & humidity data logger Elitech GSP-6, analytical scale, a container, a bucket, and a handsprayer. Materials used in the research included rice seeds of the Inpari 32 Bacterial Leaf Blight (BLB) variety harvested at different ages.

2.2. Design of Experiment

This research is a factorial study with two factors arranged in a complete randomized design (CRD). The first factor was the harvest age treatment consisting of four levels: 110, 120, 130, and 140 days after seedling (DAS). The second factor was the type of rice seed packaging, which included four types: Plastic Sacks, Polyethylene (PE) Sacks, Polypropylene (PP) Sacks, and Aluminum Foil. The combination of the two factors resulted in 16 treatment combinations, each repeated three times, leading to a total of 48 experimental units. The seeds were cleaned and dried before being packed into the specified packaging types, each containing 2 kg of rice seeds. They were then stored at room temperature in the storage warehouse of the seed producer (PT Sri Ayu Agro) for 2 and 4 months, placed on pallets according to the experimental layout. Storage conditions were monitored using the Elitech GSP-6 Temperature & Humidity Data Logger, maintaining a temperature range of 20-25°C and relative humidity (RH) between 50-60%. These specified conditions ensure that the method can be reproduced and retested effectively.

2.3. Parameters and Measurements

Laboratory testing was conducted at 0, 2, and 4 months of storage, while initial growth parameters were measured in the field after 4 months. Observations during laboratory testing included moisture content, weight of 1000-grain, germination rate, growth speed, electrical conductivity, starch (amylum) content, and reducing sugar content. Field testing involved measuring plant height and the number of tillers.

2.4. Analysis

The results of the observations were analyzed using variance analysis (ANOVA) with the F test. Prior to ANOVA, normality and homogeneity tests were conducted to ensure the data met the assumptions required for parametric analysis. Normality was assessed using the Shapiro-Wilk test, while homogeneity of variance was evaluated using Levene's test. If significant differences were found in the ANOVA, the analysis continued with Duncan's Multiple Range Test (DMRT) at the 5% level to determine which specific treatments differed from each other. Additionally, to identify the optimal harvest age for the physical and physiological quality of the seeds, quadratic regression analysis was employed, allowing for a more nuanced understanding of the relationship between harvest age and seed quality parameters. This comprehensive approach ensured the robustness and reliability of the statistical analysis.

3. RESULTS AND DISCUSSION

3.1. Water Content

Table 1 details the effect of harvesting age and packaging types on the moisture content of rice seeds following storage for 0, 2, and 4 months. Analysis of variance (ANOVA) shows that the interaction between harvest age and type of packaging has no significant effect on seed moisture content with F-count = 0.80, 0.47, and 2.06 at storage for respectively 0, 2, and 4 months. These F-count values are lower than the F-table value of 2.33 at significant level α = 0.05. The harvesting age factor is not significant to moisture content for seeds stored for 0 and 2 months (F-count = 1.37 and 2.79), which lower than F-table 2.83. The harvesting age, however, has a significant effect at 4 months storage with F-count = 4.20. Meanwhile, the type of packaging factor has no significant effect under storage 0 month (F-count = 2.79), but has a very significant effect with storage for 2 months (F-count = 9.26) and 4 months (F-count = 37.28). These results indicate that the type of packaging has a more dominant role in maintaining seed moisture content as compared to harvesting age, especially over a longer storage time.

Table 1. Effect of harvesting age and packaging type on the moisture content (%) of rice seeds stored for 0, 2 and 4 months.

Treatment	Shelf life (month)		
	0	2	4
Harvest Age (DAS)			
110	11.7 a	12.8 a	13.0 b
120	11.7 a	12.7 a	12.8 a
130	11.8 a	12.8 a	12.8 a
140	11.7 a	12.8 a	13.0 b
DMRT (α = 0.05)			
Packaging Type			
Plastic sack	11.8 a	13.0 c	13.2 c
PE plastic	11.7 a	12.8 b	13.0 b
PP plastic	11.8 a	12.8 b	12.8 a
Aluminum Foil	11.7 a	12.6 a	12.7 a

Note: Mean numbers followed by the same letter in the same treatment and column showed no significant difference in the DMRT test at α = 0.05.

Harvest ages 110 DAS and 140 DAS produced the highest moisture content, significantly different from harvest ages 120 DAS and 130 DAS. The type of rice grain packaging also showed significant differences in moisture content at 2 and 4 months of storage. At 2 months, Aluminum Foil packaging produced the lowest moisture content and was significantly different from plastic bag packaging, but not significantly different from PE and PP plastic packaging. At the shelf life of 4 months, Aluminum Foil and PP plastic packaging produced the lowest moisture which was significantly different from PP plastic packaging and plastic bags. This is in line with the research of Wibawa *et al*. (2019), which showed the highest germination power in aluminum foil packaging compared to PP plastic for IR 64 rice varieties, and aluminum foil packaging maintains moisture and germination of rice during the storage period of 45 DAH (day after harvest) (Suparto *et al*., 2021). After 4 months storage period, there was an increase in the moisture content of rice seeds in all treatments, but it still met the moisture standard based on the decree of Agriculture Minister on the technical guideline for seed certification (Menteri Pertanian, 2022), which sets a maximum limit of 13.0%.

The analysis of moisture content trends revealed that harvest ages 110 DAS and 140 DAS consistently resulted in higher moisture levels compared to 120 DAS and 130 DAS, indicating that earlier and later harvests may lead to increased moisture retention. Among the packaging types, Aluminum Foil consistently maintained the lowest moisture content across both the 2-month and 4-month storage periods, followed closely by PP plastic packaging, while plastic bags exhibited the highest moisture levels. Overall, moisture content increased over the 4-month storage duration for all treatments; however, all values remained within the acceptable limit set by Ministerial Decree 966 of 2022, underscoring the effectiveness of Aluminum Foil and PP packaging in preserving seed quality during storage.

The increase in seed moisture was influenced by environmental temperature and humidity, with an average storage temperature of 27.30°C and an average humidity of 68.50%. Fluctuations in temperature and humidity greatly affect the rate of seed damage (Pamungkas *et al*., 2022; Perdana *et al*., 2023). The absorption rate of water vapor is influenced by the type of packaging material; permeable packaging has a higher absorption rate (Lastriyanto *et al*., 2016; Manurung *et al*., 2023). Aluminum foil packaging has a high ability to retain water vapor, characterized by a slower increase in water content compared to the other three types of packaging. This is in accordance with the properties of aluminum foil which is not easily penetrated by water vapor and gas, with water protection of 0.0914 cc/m²/h better than polyethylene which is 0.2472 cc/m²/h (Rahayu & Widajati, 2007; Setiawan *et al*., 2021).

Table 2. Effect of harvesting age and packaging type on 1000-grain weight (g) of rice seeds stored for 0, 2 and 4 months

Treatment	**Shelf life (month)**		
	0	**2**	**4**
Harvest Age (DAS)			
110	25.62 a	25.72 a	25.82 a
120	26.55 b	26.69 b	26.87 b
130	27.67 c	27.79 c	27.86 c
140	27.81 d	27.84 c	27.94 c
DMRT 5%	n	n	n
Packaging Type			
Plastic sack	26.91	27.06	27.25
PE plastic	26.91	27.02	27.13
PP plastic	26.91	27.06	27.08
Aluminum Foil	26.92	26.91	27.02
DMRT 5%	tn	tn	tn

Notes: Mean numbers followed by the same letter in the same treatment and column showed no significant difference in the DMRT test (0.05).

3.2. Weight of 1000 Grains

The weight of 1000 grains of rice seeds stored at the ages of 0, 2, and 4 months after harvest was showed in Table 2. The results of the analysis of variance on the variable weight of 1000 grains of rice seeds stored at the age of 0, 2, and 4 months showed that there was no real interaction, but the harvest age treatment factor had a very significant effect. Analysis of variance (ANOVA) shows that the harvest age factor has a very significant effect on the weight of 1000 seeds at all storage periods, with F-count of 848.85; 281.97; and 223.85, respectively for 0, 2, and 4 months storage period. On the other hand, the type of packaging and the interaction between harvest age and type of packaging had no significant effect on all storage periods (F-count = 2.26). These results indicate that harvest age is the dominant factor determining the weight of 1000-grain, while the type of packaging has no significant effect on this parameter during storage. Harvesting age 140 DAS produced the highest 1000-grain weight and was significantly different from harvesting age 110 DAS, 120 DAS and 130 DAS at the age of 0 months. At 2 and 4 months of storage, harvesting age 130 DAS and 140 DAS produced the highest 1000-grain weight and significantly different from harvesting age 110 DAS and 120 DAS. The harvest age of 140 DAS gave the highest 1000-grain weight so that at that harvest age physiological maturity was achieved. At the time of seed or seed enlargement, at the same time there is a change in seed or seed size, the addition of seed dry weight and then reaches the largest size. The closer to physiological maturity, the higher the level of seed maturity. There was an increase in 1000-grain weight along with an increase in seed moisture content in all treatments (Kamsurya, 2018; Sudrajat *et al*., 2017).

3.3. Electrical Conductivity (EC)

The results of the analysis of variance on the electrical conductivity (EC) of rice seeds stored for 0, 2 and 4 months showed that there was no real interaction, but the single factor of harvest age had a very significant effect. Analysis of variance (ANOVA) shows that type of packaging and the interaction of harvest age and packaging type have no significant effect on the EC of seeds at all storage time. The harvest age is, however, significant to seed EC under storage of 2 months (F-count < 6.14), and 4 months (F-count < 4.40). These results indicate that the variation in harvest age have a significant effect on the EC value of seeds during the storage period. Thus, the DHL parameter tends to be stable and is not influenced by the treatments given in this study. Table 3 shows the electrical conductivity of seeds stored at the ages of 0, 2, and 4 months.

Table 3. Effect of harvesting age and packaging type on the EC (μS $cm^{-1}g^{-1}$) of rice seeds stored for 0, 2, and 4 months

Treatment	**Shelf life (month)**		
	0	**2**	**4**
Harvest Age (DAS)			
110	21.43	23.12 b	23.61 b
120	21.28	22.17 ab	23.10 b
130	21.23	21.40 a	21.51 a
140	21.25	21.05 a	21.86 ab
DMRT 5%	tn	n	n
Packaging Type			
Plastic sack	21.16	22.04	23.07
PE plastic	21.45	22.19	22.28
PP plastic	21.45	21.61	22.29
Aluminum Foil	21.13	21.90	22.44
DMRT 5%	tn	tn	tn

Notes: Mean numbers followed by the same letter in the same treatment and column showed no significant difference in the DMRT test (0.05).

Table 3 shows that harvesting age treatments resulted in significant differences in the electrical conductivity (EC) of rice seeds stored for 2 and 4 months. At 2 months of storage, rice seeds harvested at 110 DAS produced the highest electrical conductivity, significantly different from those harvested at 130 and 140 DAS, but not significantly different from those harvested at 120 DAS. At 4 months of storage, rice seeds harvested at 110 DAS also showed the highest electrical conductivity, significantly different from seeds harvested at 130 DAS. This indicates that at harvest age 110 DAS there was a higher membrane leakage compared to other harvest ages, as the seeds at that age had not reached physiological maturity and thus the membrane structure was still weak. Leakage of solution in seeds is caused by a decrease in membrane integrity due to damage to phospholipids and proteins which are the main components of cell membranes (Noviana *et al*., 2016; Nuraini *et al*., 2018; Tatipata, 2008). According to Abdiani *et al*. (2024); Begum *et al*. (2013), the content of carbohydrates, proteins, and lipids decreased during storage, while free amino acids, free fatty acids, and electrical conductivity increased. There was an increase in electrical conductivity values as the storage period increased. EC values measured using an electrical conductivity meter indicate the amount of electrolyte solutions containing dissolved electrical charges in the seed soaking water such as sugars, amino acids, fatty acids, proteins, enzymes, and organic ions (K^+, Ca_2^+, Mg_2^+, Na^+, and Mn_2^+). During imbibition, seeds with damaged membrane structures will release solutes from the cytoplasm into the imbibition medium (Dewa *et al*., 2018; Tatipata, 2008). According to Sinurat *et al*. (2023), the EC test is considered more effective and efficient in testing seed vigor. This is in line with the statement of Prayitno *et al*. (2017), that the EC test can be done quickly and simply and has been proven to be able to estimate the level of vigor and correlate with seed germination in the field. Seeds with high vigor are able to withstand the negative impact of various environmental conditions during production and processing (Finch-Savage & Bassel, 2016; Reed *et al*., 2022).

3.4. Germination Power

The results of the analysis of variance on the germination of rice seeds stored for 0, 2 and 4 months showed no real interaction, but the harvest age factor had a very significant effect on the germination of seeds stored at the age of 0, 2 and 4 months. Likewise, the type of packaging factor has a very significant effect on the germination of seeds stored at the age of 0, 2 and 4 months. Analysis of variance (ANOVA) shows that the harvest age factor has a very significant effect on seed germination at all storage periods, with F-count of 2950.53; 34.62; and 27.20, after storage periods of 0, 2, and 4 monts, respectively. The type of packaging factor has no significant effect on the shelf life of 0 months (F-count = 1.75), but has a significant effect at 2 months (F-count = 4.22) and a very significant effect at 4 months (F-count = 4.82). The interaction between harvest age and type of packaging has no significant effect on all storage periods (F-count < 2.08). These results indicate that harvest age is the dominant factor in determining germination capacity, while the type of packaging begins to have a significant effect on longer shelf life.

Table 4. Effect of harvesting age and type of packaging on the germination rate (%) of rice seeds stored at 0, 2 and 4 months.

Treatment	**Shelf life (month)**		
	0	**2**	**4**
Harvest Age (DAS)			
110	88.58 a	88.06 a	86.98 a
120	89.31 b	87.23 a	86.08 a
130	95.00 d	92.06 c	91.58 c
140	93.02 c	89.88 b	89.25 b
DMRT 5%	n	n	n
Packaging Type			
Plastic sack	91.58	88.46 a	87.27 a
PE plastic	91.44	88.92 a	87.98 ab
PP plastic	91.42	89.79 ab	89.10 b
Aluminum Foil	91.07	90.06 b	89.54 b
DMRT 5 %	tn	n	n

Description: Means followed by the same letter in the same treatment and column showed no significant difference in the DMRT test (0.05).

Table 4 shows that rice seeds with a harvest age of 130 DAS produce the highest germination and significantly different from other harvest ages both 0, 2, and 4 months of storage. This shows that at the physiological age of 130 DAS physiological maturity is reached, in accordance with the research of (Fitrianingsih, 2019), that when physiological maturity is characterized by a single panicle packing level, the production of IR Sidenuk rice seeds varieties reaches the highest 1000-grain seed weight, germination and optimum vigor index. The germination yield of the old phase of the Inpari-42 variety and the growth rate of the old phase of the Inpago-13 variety (Puspaningrum *et al*., 2021). Potential germination and maximum growth potential are achieved at the level of dry yellow panicle maturity (Sudrajat *et al*., 2017). 110 DAS harvest age displays the lowest germination power. This shows a negative relationship between germination and Durability of Harvest Life (DHL). High DHL values indicate low seed vigor, which is reflected by low germination values. Germination and growth rate at harvest ages 110 DAS and 120 DAS are lower than at harvest age 130 DAS because before reaching physiological maturity, seeds have not accumulated sufficient nutrient reserves so that the germination process take place unoptimally. In case of 140 DAS, germination power and growth speed decreased compared to 130 DAS. This is because the seeds at harvest age 140 DAS experience an aging process (decrease in seed condition) due to field weather stress during the delay in harvest time after physiological maturity (Kolo & Tefa, 2016; Sutopo, 2010). Delays in harvesting cause seed losses or even difficult to fall fruits because they are damaged (Firmansyah *et al*., 2023). Research by Ramadhani *et al*. (2018), stated that the percentage and speed of germination of plastic seeds were lower than PE packaging. Rice seeds stored using aluminum foil type packaging produced the highest germination rate both 2 months and 4 months storage. In accordance with the research of Lastriyanto *et al*. (2016), impermiable aluminum foil packaging can hold moisture better so that endosperm nutrient reserves are not quickly depleted so that germination reaches optima. The germination power produced by all treatments for 4 months still meets the minimum germination standard based on Ministerial Decree 966 of 2022 as much as at least 80%. The process of seed damage cannot be stopped but can be prevented (Ashar *et al*., 2024; Suryawan *et al*., 2019).

3.5. Growth Speed

The results of the analysis of variance on the variable growth speed of rice seeds stored at the age of 0, 2 and 4 months showed that there was no real interaction, but the harvest age factor had a very significant effect on the growth speed of seeds stored at the age of 0, 2 and 4 months. Analysis of variance (ANOVA) shows that the harvest age factor has a very significant effect on the speed of seed growth at all shelf lives, namely 0 months (F-count = 440.85), 2 months (F-count = 98.67), and 4 months (F-count = 72.32). The type of packaging factor has no significant effect on the shelf life of 0 months (F-count = 1.22), but has a very significant effect on 2 months (F-count = 5.80,) and 4 months (F-count = 5.39). The interaction between harvest age and type of packaging has no significant effect on all storage periods (F-count < 1.53). These results indicate that harvest age is the dominant factor in determining growth rate, while the type of packaging begins to have a significant effect on longer shelf life.

Table 5 shows that rice seeds with 130 DAS harvest age treatment produced the highest growth rate and was significantly different from other harvest ages, whether stored for 0, 2, or 4 months. There was an increase in the growth rate of rice seeds due to the treatment of harvest age 130 DAS stored for 4 months by 1.4%/gallon compared to rice seeds harvested at the age of 110 DAT. The type of rice seed packaging showed that rice seeds stored using aluminium aluminum foil packaging produced the highest growth rate, both stored for 2 and 4 months. At 2 and 4 months of storage, rice seeds in aluminum foil packaging had the highest growth rate and were significantly different from plastic bag packaging. There was an increase in the growth rate of rice seeds due to aluminum foil packaging stored for 4 months by 0.5%/gallon compared to the germination of rice seeds stored in plastic bags. The decrease in germination in plastic bag packaging at a shelf life of 4 months as much as 87.27% still meets the quality standards of physiological quality components according to Ministerial Decree 996 of 2022. Growth velocity is one indicator of seed vigor. This is in accordance with the statement of Syaranamual *et al*. (2024), that when physiological maturity, seed viability and vigor reach the highest level. Based on these results, it is believed that at the age of 130 DAS has reached physiological maturity. The physical indicator of seed maturity is the maximum 1000-grain seed weight, while the non-physical or physiological signs of seed maturity are seed viability and vigor. The more mature the seed, the higher the seed viability and vigor. Here, viability is reflected by germination power while vigor is reflected by growth

Table 5. Effect of harvesting age and type of packaging on the growth speed of rice seeds **(%/ethmal)** stored for 0, 2 and 4 months.

Treatment	**Shelf life (month)**		
	0	**2**	**4**
Harvest Age (DAS)			
110	15.38 a	15.35 a	15.32 a
120	15.58 a	15.20 a	15.10 a
130	16.94 c	16.83 c	16.72 b
140	16.63 b	16.24 b	16.19 b
DMRT 5%	n	n	n
Packaging Type			
Plastic sack	16.17	15.71 a	15.61 a
PE plastic	16.08	15.79 ab	15.74 ab
PP plastic	16.15	16.00 b	15.90 b
Aluminum Foil	16.14	16.12 b	16.09 b
DMRT 5 %	tn	n	n

Description: Mean followed by the same letter in the same treatment and column showed no significant difference in the DMRT test (0.05).

speed. According to Kamsurya (2018), when seed or seed dilation occurs, at the same time there is a change in seed or seed size, an increase in seed or seed dry weight, an increase in germination ability, an increase in growth vigor.

3.6. Starch Content (Amylum)

Table 6 shows that the highest starch content (70.32%) of rice seeds at a storage period of 2 months was produced by a combination of harvest age 120 DAS and PP plastic packaging. The higher starch content at 120 DAS suggests that seeds harvested at this stage have accumulated optimal reserves, leading to improved vigor and longevity. The same pattern is also shown at the 4-month shelf life of rice seed starch content implying that the treatment combination produces the highest starch content and is significantly different from other treatment combinations.

Table 6. Effect of harvesting age and packaging type on starch content (amylum) of rice seeds at 2 and 4 months after harvesting

Shelf Life (month)	Harvest Age (DAT)	Starch Content (%)			
		Packaging Type			
		Plastic sack	PE plastic	PP plastic	Aluminum Foil
2 Month	110	51.38 a	54.22 ab	52.09 a	53.87 ab
	120	58.94 b	65.40 bc	**70.32 c**	67.98 c
	130	69.60 c	68.40 c	64.25 bc	54.67 ab
	140	54.40 ab	55.44 ab	53.98 ab	55.11 ab
4 Month	110	48.04 a	49.29 ab	51.99 bc	47.63 a
	120	51.40 b	55.25 c	**56.58 c**	55.39 c
	130	55.01 c	55.73 c	53.94 bc	53.96 bc
	140	53.72 bc	49.07 ab	49.30 ab	48.60 ab

Notes: Mean numbers followed by the same letter at the same storage age showed no significant difference in the DMRT test (0.05).

The results of the analysis of variance on the variable starch content of rice seeds stored for 2 and 4 months showed that there was a real interaction at the storage age of 2 and 4 months. Likewise, the age factor of rice harvest shows a significant. Analysis of variance (ANOVA) shows that the harvest age factor has a very significant effect on seed starch (amylum) content at a shelf life of 2 months (F-count = 39.93) and 4 months (F-count = 34.97). The type of packaging factor had no significant effect on both storage periods (F-count < 1.77), but the interaction between harvest age and type of packaging had a very significant effect at 2 months (F-count = 5.10) and 4 months (F-count = 4.80). These results indicate that harvest age is the dominant factor in determining starch content, while the interaction between the two factors has a significant effect on these parameters during storage. However, the treatment of packaging type did not have a significant effect. While the relationship of harvest age to the starch content of rice seeds in each type of packaging stored for 2 and 4 months was done by quadratic regression analysis and the results are presented in Figure 1 and Figure 2.

The results of the quadratic regression analysis of the relationship between harvest age and starch content of rice seeds stored for 2 months resulted in a line equation for the type of plastic sack packaging, namely: $Y = -0.0569x^2 + 14.4222x - 848.0200$ ($R^2 = 0.781$). For PE plastic packaging type with the line equation $Y = -0.0604x^2 + 15.1541x - 882.8850$ ($R^2 = 0.980$). For PP plastic with the line equation $Y = -0.0713x^2 + 17.8085x - 1,043.7150$ ($R^2 = 0.910$) and for the type of aluminum foil packaging with the line equation $Y = -0.0342x^2 + 8.4479x - 459.82$ ($R^2 = 0.380$). Based on the line equation at a shelf life of 2 months, the highest harvest age was obtained at the best rice seed harvest age to produce the highest starch content ($Y1 = 0$) for the type of plastic sack packaging, PE plastic, PP plastic and aluminum foil, respectively 127, 126, 125 and 124 DAT. The starch content increased with the age of rice and reached a maximum at a certain age, then slowly decreased due to the packaging type factor.

The quadratic regression analysis of the relationship between harvest age and starch content in rice seeds stored for 4 months yielded distinct equations for each packaging types. For plastic packaging, the equation is $Y = -0.0315x^2 + 7.8857x - 436.4650$ ($R^2 = 0.997$). For PE plastic, it is $Y = -0.0116x^2 + 3.1127x - 153.9575$ ($R^2 = 0.953$), and for PP plastic, the equation remains the same as PE. In contrast, aluminum foil packaging equation is $Y = -0.0328x^2 + 8.2148x - 458.85$ ($R^2 = 0.969$). The optimal harvest ages for maximum starch content were identified as 127 DAS for plastic sack, 125 DAS for PE and aluminum foil, and 123 DAT for PP plastic.

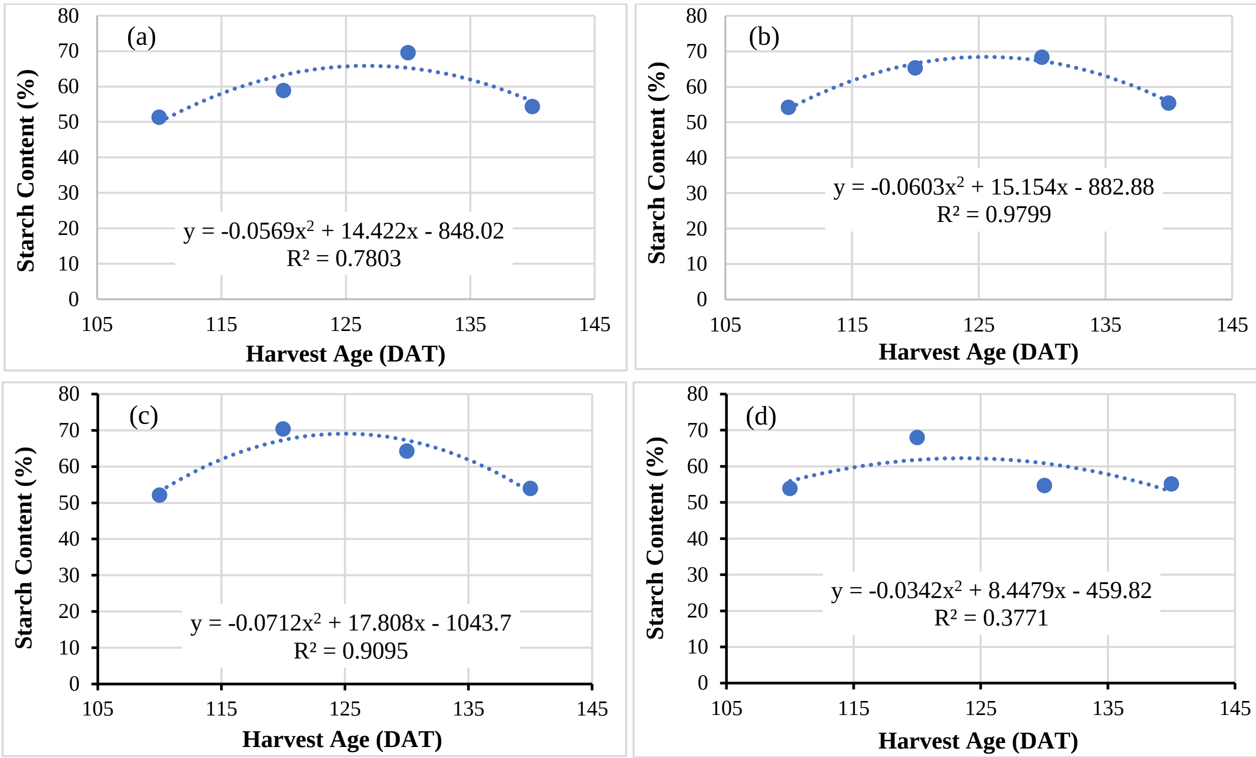

Figure 1. Quadratic regression analysis of the relationship between the harvest age and starch content of rice seeds stored for 2 months in different packaging type: (a) Plastic sack, (b) PE plastic, (c) PP plastic, (d) Aluminum foil.

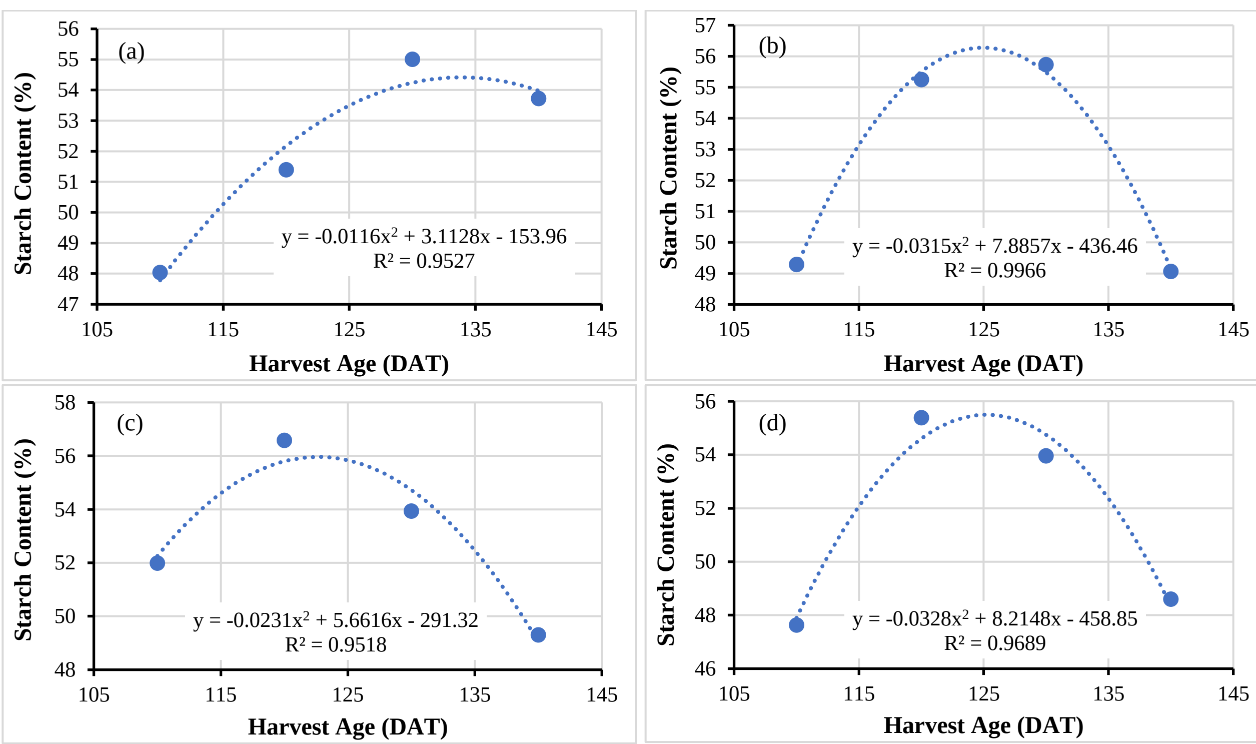

Figure 2. Quadratic regression analysis of the relationship between the harvest age and starch content of rice seeds stored for 4 months in different packaging type: (a) Plastic sack, (b) PE plastic, (c) PP plastic, (d) Aluminum foil.

Notably, starch content peaked at 120 DAS with PP plastic packaging, attributed to the seeds reaching physiological maturity, which ensures adequate food reserves (Padmavathi *et al*., 2020). Immature seeds lack sufficient food reserves and exhibit poor enzyme development and morphological growth (Sripathy & Groot, 2023). The impermeability of PP plastic packaging further inhibits starch degradation, as it effectively retains moisture. PP plastic is recognized for its low water vapor permeability and stability at high temperatures, outperforming PE plastic and plastic sacks (Cheng *et al*., 2024). Permeability values indicate that PP plastic (0.675 g day^{-1} m^2 mmHg) offers better protection than PE (0.795 g day^{-1} m^2 mmHg) and plastic sacks (8.14 g day^{-1} m^2 mmHg). Conversely, at 110 DAS, rice seeds in plastic sack packaging exhibited the lowest starch content, indicating that these seeds were harvested before physiological maturity, leading to insufficient food reserves and accelerated deterioration due to permeable packaging (Ramadhani *et al*., 2018).

3.7. Reducing Sugar Content

The results of the analysis of variance on the variable reducing sugar content of rice seeds stored at the age of 2 and 4 months showed that there was a real interaction. The harvest age factor had a significant effect on the reducing sugar content stored for 2 and 4 months, while the type of packaging factor showed a very significant effect at the 2-month shelf life (Table 7). Analysis of variance (ANOVA) shows that the interaction between harvest age and type of packaging had a very significant effect in both storage periods, namely 2 months (F-count = 12.98) and 4 months (F-count = 4.33). These results indicate that harvest age and the interaction between the two factors have a significant effect on reducing sugar levels, while the type of packaging only affects shorter shelf life. Reducing sugar content is a critical indicator of seed quality and longevity because it reflects the metabolic activity of seeds during storage. Lower reducing sugar levels are associated with reduced respiration rates, which slow down the degradation of stored reserves and minimize cellular damage. This, in turn, helps maintain seed viability and extends shelf life. Therefore, optimizing harvest age and packaging type to minimize reducing sugar content can significantly enhance seed storage performance and longevity.

Table 7. Effect of harvesting age and packaging type on reducing sugar content (%) of rice seeds stored for 2 and 4 months.

Shelf life (month)	Harvest Age (DAS)	Packaging Type			
		Plastic sack	PE Plastic	PP Plastic	Aluminum Foil
2 Month	110	0.43 d	0.17 ab	0.17 ab	0.21 b
	120	0.26 bc	0.31 c	0.21 b	0.20 ab
	130	0.24 bc	0.37 cd	0.42 d	0.40 cd
	140	0.26 bc	0.27 bc	0.14 ab	0.13 a
4 Month	110	0.44 c	0.38 c	0.35 bc	0.42 c
	120	0.35 bc	0.40 c	0.39 c	0.38 c
	130	0.31 ab	0.33 b	0.33 b	0.33 b
	140	0.37 bc	0.33 b	0.33 b	0.27 a

Notes: Mean numbers followed by the same letter in the same shelf life treatment showed no significant difference in the DMRT test (0.05).

Table 7 shows that at a storage age of 2 months, the lowest reducing sugar content is shown by the combination of harvest age 140 DAS and aluminum foil packaging type and is significantly different from other treatment combinations. At the storage age of 4 months, it shows that the reducing sugar content of rice seeds shows that the treatment combination of harvest age 140 DAS and aluminum foil packaging type produces the lowest reducing sugar content and is significantly different from other treatment combinations. The low reducing sugar content by the effect of the combination of the treatment of harvesting age 140 DAS and the type of aluminum foil packaging indicates that the respiration process runs slower so that the reducing sugar content is in a low condition. The impermeable nature of aluminum foil packaging caused the respiration process to be inhibited. Aluminum foil packaging has high protective properties against water vapor, light, fat and gas because it is composed of metal materials that are hermetic, flexible, and opaque (Lastriyanto *et al*., 2016). The slower rate of increase in moisture content in aluminum packaging causes slower breakdown of food reserves such as amylum. According to Sutopo (2010), the slow breakdown of food reserves causes less reduced sugar content to form. This is in accordance with the research of Triani (2021), reduced sugar content and respiration rate of sprouts from seeds stored in bagor bags are higher than PE plastic.

4. CONCLUSION

These findings can guide seed producers in selecting the optimal harvest age and storage method to maintain seed quality, reduce post-harvest losses, and enhance rice production efficiency. The combination of harvesting age 120 DAS and packaging type PP plastic produced the highest starch content of rice seeds at 2 and 4 months of storage. Harvesting age 140 DAT and aluminum foil packaging type produced the lowest reducing sugar content. Harvesting age 130 DAT produced the highest germination and growth speed, the lowest electrical conductivity. Harvesting age 140 DAT produced the highest 1000-grain weight. Aluminum foil packaging type produced the lowest moisture content, highest germination and growth speed and was significantly different from other types of packaging. The results of quadratic regression at a shelf life of 2 months, the best harvest age of rice seeds to produce the highest starch content for the packaging types of plastic bags, PE plastic, PP plastic and Aluminum foil, respectively 127, 126, 125, and 124 DAT. At a storage period of 4 months, the best harvesting age of rice seeds to produce the highest starch content for plastic sacks, PE plastic, PP plastic and Aluminum foil, respectively, were 127, 125, 123 and 125 DAT. Future research should focus on optimizing harvest timing and exploring innovative packaging solutions to ensure the preservation of seed quality, thereby supporting the sustainability of rice production systems, and further research could explore the long-term impact of different storage conditions beyond four months and assess varietal differences.

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