Jurnal Agronomi Indonesia
(Indonesian Journal of Agronomy)

ISSN 2085-2916 | e-ISSN 2337-3652
August 2025, *53*(2), 161-171
DOI: https://dx.doi.org/10.24831/jai.v53i2.63421

Research Article

Determination of seed physiological maturity and storability of several sorghum varieties

Karima Rizki Faizal [1], Satriyas Ilyas [2,*], Abdul Qadir [2], and Soeranto Human [3]

[1] Seed Science and Technology Study Program, Graduate School, 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

[3] Research Center for Food Crop (PRTP), National Research and Innovation Agency (BRIN), Jl. Raya Jakarta-Bogor KM 46, Cibinong, West Java 16915, INDONESIA

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

ABSTRACT

Seed vigor reaches a maximum at physiological maturity and decreases during storage. This study aimed to determine the physiological maturity and enhance the storability of sorghum seeds. Experiments were conducted at BRIN Lebak-Bulus from March 2023 to March 2024. The initial experiment employed a two-factor randomized complete block design, incorporating five sorghum varieties and five seed maturity levels. The second experiment used a complete randomized design with two factors (nest: temperature storage 18 °C and 26 °C, and nested: combined seed moisture content (MC) 10-11% and 12-13%, and storage period (1-24 weeks). The results indicated the seed physiological maturity stages of the five sorghum varieties were: Numbu 46 days after anthesis (DAA), Super-1 39 DAA, Bioguma-1 51 DAA, Samurai-2 55 DAA, and Pahat 40 DAA. The Numbu stored at 18 °C, 10-11% MC had storability up to 24 weeks (72.3% germination) and at 18 °C, 12-13% MC up to 20 weeks (72.3%), while at 26 °C, 10-11% MC had storability up to 18 weeks (71.3%) and 26 °C, 12-13% MC up to 22 weeks (70.3%). The Bioguma-1 and Samurai-2 seeds were suspected of having after-ripening dormancy. From the beginning until 24 weeks, the seeds did not deteriorate, although the viability was below 70%.

Keywords: germination; seed moisture content; storage period; viability; vigor

Edited by:
Okti Syah Isyani Permatasari
IPB University

Received:
24 March 2025
Accepted:
9 July 2025
Published online:
29 August 2025

Citation:
Faizal, K. R., Ilyas, S., Qadir, A., & Human, S. (2025). Determination of seed physiological maturity and storability of several sorghum varieties. *Jurnal Agronomi Indonesia (Indonesian Journal of Agronomy), 53*(2), 161-171. DOI: https://dx.doi.org/10.24831/jai.v53i2.63421

INTRODUCTION

Sorghum is one of the cereal plants that has high carbohydrates and is suitable for supporting food diversification in Indonesia (Afriansyah et al., 2021). Sorghum grains contain 65-76% carbohydrates, 2-7% fat, 8-12% protein, and 2-7% fat (Abah et al., 2020). Sorghum is utilized as a food (Kazungu et al., 2023), livestock feed (Whitfield et al., 2011), and bioethanol production (Eulogio et al., 2017).

As of June 2022, the sorghum harvest area in Indonesia was 4,355 hectares, with a production of approximately 15,243 tons and a productivity rate of 3.63 tons ha^{-1} (Coordinating Ministry for Economic Affairs, 2022). This productivity is still relatively low compared to the potential yield described in newly released sorghum varieties. To address this issue, a key solution is to utilize high-quality seeds. Seed quality encompasses four crucial aspects: physical, physiological, genetic, and health quality (Sundareswaran et al., 2023). Seeds with high physical quality have a prime appearance, uniform size, and are free from impurities and other seed mixtures. Genetic quality is indicated by pure and homogeneous genetic identity. Physiological quality is reflected in seed viability and vigor.

In contrast, seed health quality is indicated by the absence of seed-borne diseases, which could otherwise affect viability, vigor, and seedling growth (Ilyas, 2012).

One critical factor in producing high-quality sorghum seed is determining the optimal harvest time when the seeds reach physiological maturity (Gala et al., 2017). Physiological maturity is a critical stage in seed development, characterized by peak dry matter accumulation and the absence of further significant weight increase. This stage influences seed physiology and enhances long-term storability (Bareke, 2018). Harvesting seeds before or after physiological maturity can compromise seed quality, leading to both physical and physiological damage (Rusmin & Darwati, 2018). For example, Samurai-2 sorghum seeds harvested 100 days after sowing (DAS) had a dry-seed weight (DSW) of 0.37239 g and a moisture content of 13.03%, with a germination rate of 84.88%; while seeds harvested at 110 DAS had a DSW of 0.37242 g, a moisture content of 12.46%, and a germination rate of 87.04% (Najam, 2022).

The large-scale development of sorghum seeds requires the availability of high-quality seeds over a long period, which can be achieved through optimal seed storage. A major issue in seed storage is deterioration, which can damage proteins, lipids, cell membranes, and DNA, ultimately affecting seed metabolism and reducing viability (Vitis et al., 2020). The deterioration of seed quality during storage can be minimized by maintaining optimal conditions, particularly temperature and seed moisture content. Maksum et al. (2020) found that Super-1 sorghum seeds stored for 12 months at a low temperature (18±1.58 ºC) with an initial moisture content of 8% maintained an 84% germination, compared to seeds stored at higher room temperatures. Current research reveals notable gaps in our understanding of optimal seed storage techniques and physiological maturity indicators for diverse sorghum varieties, especially the five Indonesian sorghum varieties targeted by this study. The existing literature particularly lacks comprehensive data on storage efficacy and seed viability during six months of storage across various sorghum types and under differing environmental conditions, as well as the challenges of applying maturity indicators to such varied germplasm. This study, therefore, aimed to determine the physiological maturity and enhance the storability of these five specific Indonesian sorghum varieties.

MATERIALS AND METHODS

Research site

The experiment was done at the Center for Food Crops Research, Agricultural and Food Research Organization, National Research and Innovation Agency (BRIN) in Lebak Bulus from January 2023 to February 2024. Seed testing was conducted at the Seed Storage and Quality Testing Laboratory, Department of Agronomy and Horticulture, Faculty of Agriculture, Bogor Agricultural University (IPB). The overall research spanned from January 2023 to June 2024.

Experiment I: Determination of the physiological maturity level of sorghum seeds

This experiment followed a two-factor randomized complete block design. The first factor consisted of five seed maturity levels, measured at 5-day intervals. The determination of the seed maturity level for each variety varies according to the variety description, namely, the difference between harvest age and flowering age of 50%. The 50% flowering age was counted as one day after anthesis (DAA) in each variety. The second factor was sorghum varieties, consisting of five varieties: Pahat, Samurai-2, Numbu, Super-1, and Bioguma-1. Maturity level 1 was 10 days before anthesis, maturity level 2 was five days before anthesis, maturity level 3 was 0 days after anthesis according to the variety description, maturity level 4 was five days after anthesis, and maturity level 5 was 10 days after anthesis. Table 1 shows the determination of the physiological maturity level of five sorghum seed varieties used in the first experiment. The combination of treatments formed was 25, tested in three replications, comprising 75 experimental units.

The experiment was started by covering with a nylon net before the panicle was formed (Poehlman, 1979). Covering was done to reduce yield losses due to bird attacks. Each covered panicle was tagged. Harvesting was done according to the maturity level of each variety. The criteria for harvesting sorghum seeds included yellowing of the flag leaf, seeds becoming hard and resistant to breakage when pressed by a finger, and the presence of a black layer at the seed base. Sorghum was harvested by cutting the panicle stalk 15 cm below the neck of the panicle, then the panicle was air-dried in the screen house for 5 days (Al Fikri et al., 2015). The seeds used were taken from 2/3 of the panicle shoots.

Table 1. Determination of seed maturity level in five sorghum varieties.

Variety	Determination of seed maturity level in five sorghum varieties		
	Harvest age (DAP)*	Flowering age 50% (DAP)*	DAA
Pahat	89	59	30
Bioguma-1	105	64	41
Numbu	105	69	36
Samurai-2	113	63	50
Super-1	105	56	49

Variety	Maturity levels (DAA)				
	1	2	3	4	5
Pahat	20	25	30	35	40
Bioguma-1	31	36	41	46	51
Numbu	26	31	36	41	46
Samurai-2	40	45	50	55	60
Super-1	39	44	49	54	59

Note: *Source: Description of varieties released by the Ministry of Agriculture. DAP: days after planting, DAA: days after anthesis

The seeds were germinated in a controlled seed germinator (Gen1000-GE, Conviron) with a temperature of 25 °C and RH of 80%. The observed variables are as follows: Seed water content (ISTA, 2018), using the oven method at a temperature of 130-133 °C for 2 hours. Germination percentage (ISTA, 2018): total percentage of normal germination in the first and final counts (4 and 10 days after planting). Vigor index: the total percentage of normal germination in the initial count (4 days). Seed dry weight: seeds were weighed (4.5 g) and dried in an oven at a temperature of 80 °C for 24 hours.

Experiment II: Seed storage of three sorghum varieties

Experiment II was done in a nested experiment with two factors using a completely randomized design. The nest factor was the storage room temperature, consisting of two levels: the AC room with 18 °C, RH 75% (T1), and the non-AC room with 26 °C, RH 55% (T2). The combination of seed water content and storage period was nested in the storage room temperature factor, consisting of 26 levels. A total of 52 treatment combinations were established, each repeated three times, resulting in 156 experimental units.

The experiment used sorghum seeds obtained from Experiment I at maturity level 3 or according to the variety description. The three varieties used were Numbu, Bioguma-1, and Samurai-2. The seeds were placed in 0.1 mm-thick polyethylene plastic packaging for each 30 g of seeds. The packaging was closed using a sealer. The seeds were stored in an AC room at 18 °C (T1) and a non-AC room at 26 °C (T2). Seed quality testing was conducted every 2 weeks through the 24-week storage period (0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24 weeks of storage). The seeds were dried to a water content of 10-11% and 12-13%.

The variables used were: Germination percentage (ISTA, 2018): total percentage of normal germination in the first and final counts (4 and 10 days after planting). Electrical conductivity (Pramono et al., 2019): seventy-five seeds were weighed, soaked in 150 mL of aquabidest for 24 hours, and stored in an AC room with a temperature of ± 20 °C. The electrical conductivity (EC) of the seed-soaking water and aquabidest was measured using a conductivity meter.

Data analysis

Data were analyzed using SAS version 21.0.16 using analysis of variance (ANOVA). The Duncan Multiple Range Test (DMRT) at a 95% significance level was performed if the F-test was significant.

RESULTS AND DISCUSSION

Determination of the physiological maturity level of seeds in five sorghum varieties

The five sorghum varieties have different physical seed shapes as the maturity level increases (Figure 1). The Pahat has a round shape, clear white color with reddish spots, seed size 16 mm^2 to 19.29 mm^2, and a smooth, shiny surface. The Bioguma-1 is round, flat, oval, and cream-colored, and the seed size is larger than other varieties; the range was 16.72 mm^2 to 20.38 mm^2, and the seed surface is smooth and shiny. The Samurai-2 is round, chalky white, relatively small compared to other varieties, 13.28 mm^2 to 16.28 mm^2, and the seed surface is slightly rough and not shiny. The Numbu variety is round, oval, and cream-colored, and the size ranges from 14.54 mm^2 to 19.29 mm^2, and the seed surface is smooth and shiny. The Super-1 is round, oval, brownish white, measuring 14.49 mm^2 to 17.09 mm^2, and the seed surface is slightly rough and not shiny. As seed maturity progresses, the length, width, and surface area of alfalfa seeds increase (Zhang et al., 2022). In contrast to de Medeiros et al. (2019), pepper seeds harvested at 30 DAA had seed sizes that were not significantly different compared to harvest ages of 42 DAA, though significantly different in seed density. Seeds with a high density have better tissue integrity and food reserve content; thus, they can germinate quickly (Abud et al., 2018).

Based on ANOVA recapitulation, physiological maturity level, variety, and interaction of both factors significantly affected the germination percentage (GP), seed moisture content (MC), vigor index (VI), and dry seed weight (DSW). We successfully identified the physiological maturity level for each sorghum variety (Table 2). Numbu was maturity level 5 (46 DAA), Super-1 was maturity level 1 (39 DAA), Bioguma-1 was maturity level 5 (51 DAA), Samurai-2 was maturity level 4 (55 DAA), and Pahat was maturity level 4 (35 DAA).

The Super-1, the first maturity level (39 DAA), exhibited the highest germination percentage (GP) at 85.7%, compared to later maturity levels (Table 2). However, at maturity levels 2 to 5, both GP and vigor index (VI) decreased. This decline is because the seeds accumulated maximum food reserves at the 1st maturity level (39 DAA). As the maturity level progresses, the physiological quality of the seeds deteriorates because they surpass their physiological maturity stage. Seeds harvested beyond physiological maturity tend to experience a decline in quality, characterized by reduced viability and increased susceptibility to fungal infections (Bareke, 2018). Similarly, research by Sugriana et al. (2023) found that the GP of IR64 rice seeds decreased when harvested later, dropping from 93.25% at 100 days after planting (DAP) to 84.35% at 105 DAP. Seeds that remain on the plant after their optimum maturity period are prone to cracking, which reduces seed quality, accelerates aging, and, in high-humidity conditions, increases susceptibility to saprophytic fungi. These fungi can cause seed discoloration and further deterioration (Dadlani & Yadava 2022).

The Numbu, with a maturity level of 5, had a lower seed moisture content (MC) than other varieties at 21.83%, although this was not significantly different from the Samurai-2 (Table 2). Generally, higher seed maturity levels correspond to lower moisture content. The low moisture content in Numbu at maturity level 5 contributed to an increased germination percentage (GP) (78.7%), vigor index (VI) (44.5%), and dry seed weight (DSW) (4.538 g) compared to seeds with higher moisture content. Similarly, Jia et al. (2023) reported that the moisture content of wheat seeds decreases from 52.2% in the milk-ripe phase to 17.77% in the full-ripe phase.

The Pahat at maturity level 5 (40 DAA), exhibited the highest DSW (4.277 g) among all varieties, though this was not significantly different from Numbu (Table 2). The high dry weight of Pahat seeds at maturity level 5 also led to increased GP (54.7%) and VI

(24.1%) while reducing MC (24.05%) compared to other maturity levels. Physiological seed maturity is reached when the seed dry weight is maximized, ensuring optimum seed production, quality, and storage life (Dadlani & Yadava, 2022).

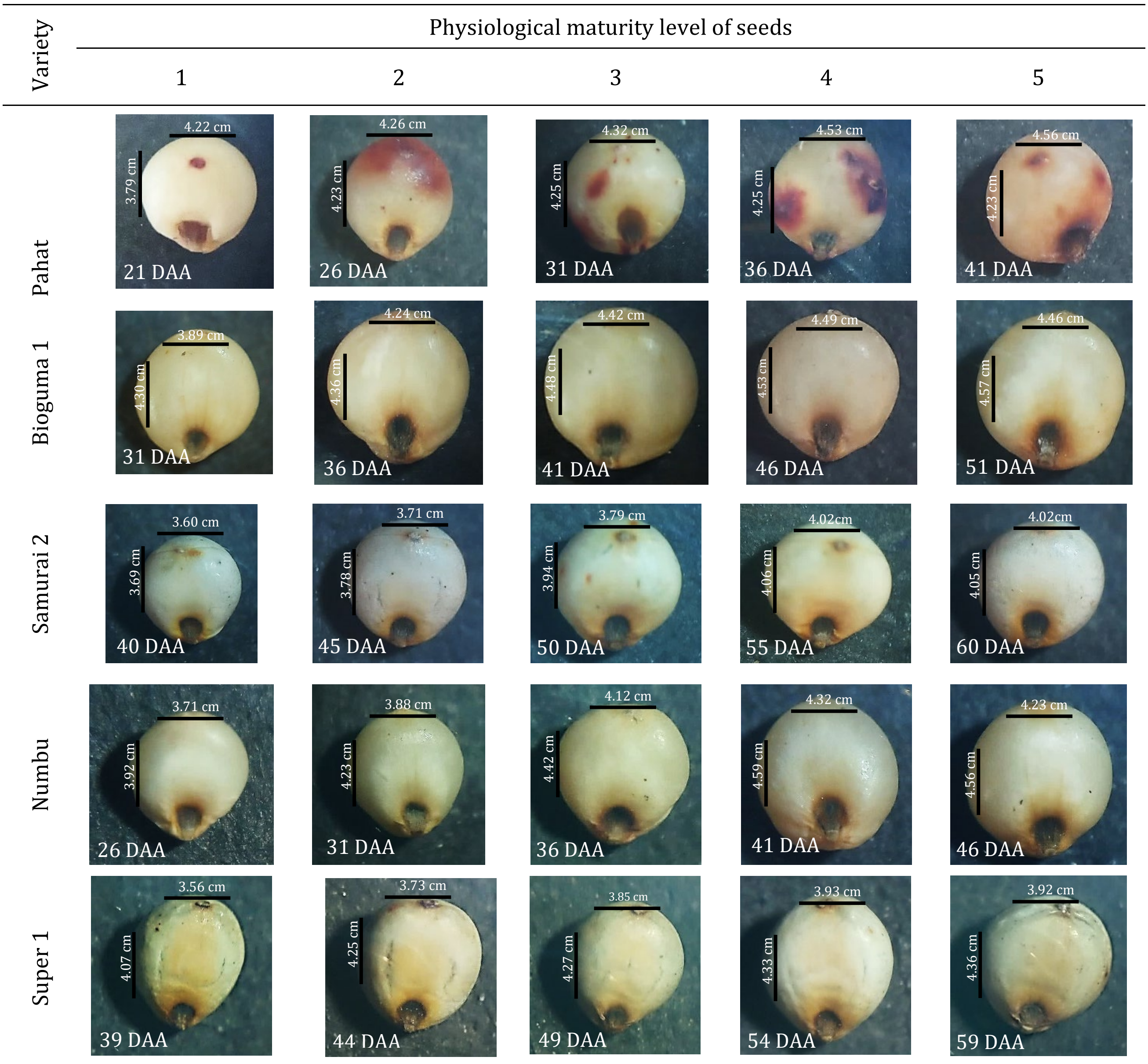

Figure 1. Differences in seed shape and color of five sorghum varieties from five physiological maturity levels. Bar ± 1 cm.

Low seed quality can result from premature harvesting before seeds reach full maturity (Shaheb, 2015). For Samurai-2 at maturity level 1 (40 DAA), GP (36.3%), VI (38.3%), DSW (4.208 g), and MC (27.60%) were lower compared to more advanced maturity levels. At maturity level 4, GP (59.7%), VI (45.1%), and DWS (4.422 g) increased, while MC decreased to 24.09%. The Samurai-2 at maturity level 4 exhibited an increase in GP, VI, and DSW alongside a decline in seed MC. According to Trancoso et al. (2021), soybean seeds harvested in the green phase had lower germination capacity, vigor index, and protein content than those harvested in the yellow or brown phases. However, at maturity level 5 (60 DAA), Samurai-2 experienced a decline in GP and VI, indicating that the seeds had surpassed their physiological maturity.

Table 2. Interaction between seed maturity levels and five sorghum varieties on seed quality.

Seed maturity level (DAA)	Variety				
	Numbu	Super-1	Bioguma-1	Samurai-2	Pahat
	Germination (%)				
1	73.7Bb	85.7Aa	40.7Cd	36.3Ee	50.2Cc
2	74.7ABa	79.7Aa	48.1Bc	51.7Cbc	52.7Bb
3	77.3ABa	70.1Bb	52.3Bd	56.7Bc	53.7ABcd
4	78.1Aa	70.7Bb	65.7Abc	59.7Acd	56.3Ad
5	78.7Aa	66.0Bb	67.3Ab	43.1Dd	54.7ABc
	Seed moisture content (%)				
1	28.34Aa	22.59Ab	29.23Aa	28.18Aa	27.60Aa
2	27.97Aa	23.26Ab	27.53Ba	27.31ABa	24.60Bb
3	23.09Bc	23.43Ac	26.77Ba	26.92Ba	24.52Bb
4	22.77Bab	22.14Ab	26.78Ba	25.49Ca	24.09Bab
5	21.83Bd	24.52Ab	26.64Ba	22.71Dcd	24.05Bbc
	Vigor index (%)				
1	21.7Cd	73.3Aa	24.1Cc	28.3Db	11.1Be
2	24.1Ccd	54.1Ba	27.0Bc	35.7Cb	23.0Ad
3	34.7Bb	44.5Ca	41.1Aa	40.5Ba	23.5Ac
4	41.3Aa	42.3Ca	42.7Aa	45.3Aa	24.3Ab
5	44.5Aa	42.3Ca	43.7Aa	25.9Db	24.1Ab
	Dry seed weight (g)				
1	4.239Ba	4.096Ba	3.900Bb	4.208Ba	4.114Ba
2	4.303Ba	4.123ABa	4.345ABa	4.231Ba	4.153ABa
3	4.316Ba	4.142ABb	4.391ABa	4.246Bab	4.202ABab
4	4.455Aa	4.155ABc	4.422ABa	4.422Aa	4.266Ab
5	4.538Aa	4.272Ab	4.473Aa	4.427Aab	4.277Ab

Note: Capital letters in one column indicate the effect of the seed maturity level of each variety. Small letters in one row indicate the effects of varieties on each seed maturity level. Values followed by the same letter in the same column or row were not significantly different according to DMRT at α = 5%. DAA = days after anthesis.

The study's method for determining physiological maturity primarily employs relative comparisons established by the Ministry of Agriculture (2023), specifically a germination percentage of 75% and a moisture content of 13%. This study showed germination percentages (GP) remain below 75% (e.g., Samurai-2 at 55 DAA was only 59.7%). Physiologically mature seeds do not necessarily have a moisture content of 13%. A moisture content of 13% requires drying. This significantly contrasts with prior research (Najam, 2022), indicating that Samurai-2 seeds harvested at 100–110 DAS exhibited GP values between 84.88% and 87.04%. This discrepancy, likely coupled with low seed dry weights (SDW), suggests potential suboptimal or stress-induced growing conditions, an incomplete or premature interpretation of GP as a maturity indicator, or uncontrolled confounding factors. Acknowledging these limitations, including environmental influences and the necessity for broader sampling, is crucial for validating the study's conclusions.

The germination percentage and other physiological indicators appear insufficient to fully capture the seed development curve, hindering the confident determination of physiological maturity. This may be linked to potential seed dormancy or environmental stress impacting seed quality during development. Consequently, these observations highlight the need for more comprehensive sampling both before and after peak GP values to precisely define physiological maturity. Therefore, it is necessary to consider these limitations and their implications for determining the seed maturity stage, as well as possible external influences such as dormancy or stress.

Seed storage of three sorghum varieties

ANOVA results showed that storage room temperature significantly affected germination percentage (GP) and electrical conductivity (EC) across all three sorghum varieties. The interaction of seed moisture content and storage period, nested within storage room temperature, also significantly affected GP and EC. The decline in GP (Table 3) and the increase in EC (Table 4) over 24 weeks of storage indicated seed deterioration.

For the Numbu, seeds stored at 18 °C (T1), the highest GP value was observed after 6 weeks of storage with an MC of 10-11% (82.0%), while the lowest was recorded at 24 weeks with an MC of 12-13% (66.7%), showing a significant difference (Table 3). At 26 °C (T2), GP was highest at 2 weeks of storage with 10-11% MC (79.7%) and lowest at 24 weeks with 12-13% MC (67.7%), also showing a significant difference.

Overall, Numbu exhibited higher GP compared to other varieties. When stored at 18 °C (T1) with 10-11% MC, it maintained viability for up to 18 weeks (77.0%) (Table 3). However, at 26 °C (T2) with 12-13% MC, viability was maintained for only 6 weeks (75.0%). According to the Ministry of Agriculture (2023), the minimum GP standard for sorghum seeds is 70%. Research by Anggraini et al. (2020) found that Kawali sorghum seeds had a storability of 4 months, after which GP dropped from 76.7% to 56.0% at 28 °C. Similarly, soybean seeds maintained viability for up to 10 weeks, declining from 80.0% to 74.7% by week 12 (Khalilah et al., 2022).

The Bioguma-1 stored at 18 °C (T1), the highest GP was recorded at week 4 with 12-13% MC (60.7%), while the lowest was at week 24 with 10-11% MC (48.0%), showing a significant difference (Table 3). At 26 °C (T2), the highest GP was observed at week 0 with 12-13% MC (61.7%), while the lowest was at week 20 with 10-11% MC (47.0%), also showing a significant difference. The 12% MC still maintains the quality standards of sorghum seed based on the Ministry of Agriculture (2023). According to Qiu et al. (2022), sorghum Janza-34 with 14% MC physically had a thicker seed coat, was resistant to seed cracking, and improved the physical quality of seeds compared to 10.3% MC.

The Samurai-2 stored at 18 °C (T1), GP remained stable throughout the storage period, increasing slightly from 57.7% to 63.0% (Table 3). However, at 26 °C (T2), the highest GP was recorded at week 12 with 10–11% MC (64.7%), while the lowest was at week 24 with 12-13% MC (50.7%), showing a significant difference. At 26 °C with 12-13% MC, GP began to decrease significantly from 58.0% (0 week) to 53.0% (24 weeks). Mbughi et al. (2024) reported that sorghum Macia, GP began to decrease at 16 weeks after storage from 74.8 % to 67.6%. Both the Bioguma-1 and Samurai-2 had initial GP below 75% before storage and did not show significant changes in GP by the end of storage. This suggests that both varieties may have undergone after-ripening dormancy, as they exhibited no noticeable deterioration over time.

The high GP of three sorghum varieties with 10–11% MC stored at 18 °C (T1) indicates a longer storability compared to other treatments (Table 3). Specifically, the Numbu remained viable for 18 weeks, Bioguma-1 for 20 weeks, and Samurai-2 for 24 weeks. In contrast, under non-AC conditions at 26 °C (T2), the storage period was significantly shorter: Numbu lasted only 4 weeks, Bioguma-1 for 10 weeks, and Samurai-2 for 18 weeks. At a higher seed water content of 12-13%, all three varieties showed a decline in GP after storage. These findings align with Harrington's (1972) statement that reducing seed water content by 1% can extend storability, and orthodox seeds are best stored at low temperatures. Research by Fang and Juan (2021) on sorghum seed storage found that seeds with 10% MC maintained their viability and vigor for up to 16 days, whereas seeds with 12% and 16% MC deteriorated after just 4 days.

The temperature at 26 °C (T2) resulted in greater deterioration and a more significant decline in seed quality than at 18 °C (T1) (Table 3). However, for the Samurai-2, storage at 18 °C (T1) showed no significant difference in GP throughout the storage period, maintaining seed quality for up to 24 weeks despite the GP remaining relatively low (below 70%). Maksum et al. (2020) reported that Samurai-1 sorghum seeds stored at 18 °C retained 16% higher viability than those stored at room temperature (25 °C) after 12 months. Similarly, Agustiansyah et al. (2020) reported that an optimum low temperature of 18 °C helped preserve soybean seed quality. Low storage temperatures suppress moisture absorption from the air, thereby reducing respiration activity and preventing an increase in seed water content (Vitis et al., 2020).

Table 3. The germination percentage after 24 weeks of seed storage of the three sorghum varieties.

Storage period (week)	Seed moisture content	Numbu		Bioguma-1		Samurai-2	
		18 °C (T1)	26 °C (T2)	18 °C (T1)	26 °C (T2)	18 °C (T1)	26 °C (T2)
0	10-11%	74.0b	77.3a	50.3bc	51.3bc	57.7a	57.0ab
	12-13 %	77.3ab	78.0a	60.0a	61.7a	57.3a	58.0ab
2	10-11%	77.0ab	79.7a	56.7ab	59.0a	58.3a	58.3ab
	12-13 %	80.0a	76.7a	58.0a	60.0a	58.0a	59.7ab
4	10-11%	81.3a	77.7a	56.7ab	55.3ab	59.3a	57.3ab
	12-13 %	80.7a	76.3a	60.7a	60.3a	59.0a	60.7a
6	10-11%	82.0a	75.0a	56.7ab	52.3abc	59.0a	61.7a
	12-13 %	78.7a	75.0a	59.3a	58.7a	59.7a	59.0ab
8	10-11%	81.3ab	74.0a	55.0ab	52.0abc	58.0a	62.7a
	12-13 %	77.0ab	73.3ab	58.7a	58.3a	62.0a	58.3ab
10	10-11%	82.0a	74.3a	54.7ab	51.7abc	60.7a	62.7a
	12-13 %	77.0ab	73.0ab	57.7a	57.0a	63.0a	58.3ab
12	10-11%	77.7a	73.7a	54.0ab	50.3bc	61.0a	64.7a
	12-13 %	77.7ab	72.7ab	56.7ab	55.3ab	63.0a	57.0ab
14	10-11%	78.7a	73.0ab	53.3ab	49.7bc	63.7a	62.3a
	12-13 %	76.0ab	73.3ab	56.7ab	54.7ab	63.3a	56.0ab
16	10-11%	77.3ab	72.3ab	53.0ab	48.3bc	60.0a	60.7a
	12-13 %	75.3ab	71.7ab	56.3ab	54.3ab	63.0a	56.0ab
18	10-11%	77.0ab	71.3ab	52.0bc	47.7bc	61.0a	58.0ab
	12-13 %	73.3bc	71.3ab	55.3ab	52.7ab	65.0a	54.0bc
20	10-11%	73.0bc	69.7ab	50.7bc	47.0c	60.7a	55.0bc
	12-13 %	72.3bc	71.0ab	55.3ab	51.0bc	62.7a	53.0cd
22	10-11%	72.7bc	69.7ab	49.0bc	47.3bc	60.0a	52.3bc
	12-13 %	69.7cd	70.3ab	54.7ab	50.3bc	63.3a	52.0bc
24	10-11%	72.3bc	67.7b	48.0c	49.3bc	60.0a	52.0bc
	12-13 %	66.7d	69.3ab	53.7ab	49.7bc	63.0a	50.7c

Note: Values followed by the same letter in the same column are not significantly different according to DMRT at α = 5% level

The electrical conductivity test (EC) is a physical assessment of seed vigor that measures cell membrane leakage, where a higher EC value indicates lower cell membrane integrity (ISTA, 2018). As shown in Table 4, EC values increase with storage duration. Specifically, Bioguma-1 from 11.05 μS $cm^{-1}g^{-1}$ to 22.52 μS cm $cm^{-1}g^{-1}$, Numbu from 14.49 μS $cm^{-1}g^{-1}$ to 19.66 μS $cm^{-1}g^{-1}$, and Samurai-2 from 6.68 μS $cm^{-1}g^{-1}$ to 16.76 μS $cm^{-1}g^{-1}$. High EC levels indicate cell membrane damage, leading to the leakage of electrolytes such as amino acids, sugars, enzymes, and organic ions (K^+, Ca^{2+}, Mg^{2+}, Na^+, and Mn^{2+}) (Beedi et al., 2018). The EC of soybean seeds increases with prolonged storage due to ongoing deterioration processes (Pamungkas & Kusberyunadi, 2020).

The EC results showed that seeds stored at 26 °C (T2) had relatively higher EC values than those stored at 18 °C (T1) (Table 4). Arini and Ahadiyat (2021) reported that carica seeds stored at 25 °C for 20 days had significantly higher EC (10.96 76 μS $cm^{-1}g^{-1}$) compared to those stored at 15 °C (9.89 76 μS $cm^{-1}g^{-1}$). A higher temperature accelerates seed water content absorption during storage, increasing respiration rates and leading to faster deterioration than seeds stored at lower temperatures (Maksum et al., 2020). The high moisture content of *Trachyspermum ammi* L. seeds can also cause seed porosity, and the coefficient of friction in seeds will increase so that the integrity of the seed membrane will decrease (Singh & Meghwal 2020). Seed deterioration results in a loss of viability in orthodox seeds, which is associated with macromolecular damage, reduced ATP synthesis, protein degradation, and a weakened antioxidant defense system, ultimately leading to a loss of cell membrane integrity (Corbineau, 2024).

Table 4. The electrical conductivity test after 24 weeks of seed storage of three sorghum varieties.

Storage period (week)	Seed moisture content	Numbu		Bioguma-1		Samurai-2	
		18 °C	26 °C	18 °C	26 °C	18 °C	26 °C
0	10-11%	15.14c	14.60c	11.05b	12.88d	6.67c	7.66d
	12-13 %	15.87bc	16.19abc	12.12ab	12.70d	8.45b	7.94d
2	10-11%	18.34a	15.63abc	11.74b	19.69b	6.88c	11.46c
	12-13 %	18.32a	15.75abc	13.77a	17.07bc	11.39a	13.90ab
4	10-11%	17.52ab	14.56c	12.61ab	18.53bc	6.93c	11.72c
	12-13 %	17.53ab	16.63ab	14.69a	18.29bc	10.84a	14.68a
6	10-11%	18.12ab	14.49c	12.97ab	18.68bc	7.83bc	11.47c
	12-13 %	17.50ab	16.40abc	15.65a	18.28bc	10.68a	14.35a
8	10-11%	17.88ab	16.26abc	13.15a	19.66b	7.85bc	10.78c
	12-13 %	18.81a	17.93a	15.55a	18.43bc	11.47a	13.99ab
10	10-11%	18.34a	17.00a	13.73a	18.60bc	7.54bc	11.05c
	12-13 %	19.47a	17.95a	14.78a	18.86bc	11.42a	14.01ab
12	10-11%	18.28ab	15.32abc	13.75a	19.21bc	7.39bc	11.76c
	12-13 %	17.96 ab	16.91a	15.22a	18.26bc	11.49a	14.28a
14	10-11%	19.20a	15.76abc	13.61a	19.80b	7.87bc	11.61c
	12-13 %	17.30ab	16.94a	14.53a	19.58b	11.66a	14.44a
16	10-11%	18.51a	15.66abc	13.75a	19.81b	7.71bc	11.86c
	12-13 %	17.75ab	17.37a	15.36a	19.97b	11.03a	14.24a
18	10-11%	19.12a	15.75abc	13.69a	19.50b	7.77b	11.09c
	12-13 %	17.95ab	17.85a	15.28a	19.32bc	11.80a	15.32a
20	10-11%	18.23ab	14.84bc	14.55ab	19.54b	8.04bc	11.47c
	12-13 %	18.39a	16.96ab	14.66a	18.69bc	11.27a	15.89a
22	10-11%	19.18a	14.69c	14.82a	22.19a	7.95bc	11.52c
	12-13 %	18.14ab	17.59a	15.10a	19.54b	10.91a	15.36a
24	10-11%	19.66a	15.18abc	14.02a	22.52a	7.86bc	12.34bc
	12-13 %	18.66a	18.74a	15.60a	19.41bc	11.15a	16.77a

Note: Values followed by the same letter in the same column are not significantly different according to DMRT at α = 5% level

CONCLUSIONS

The five sorghum varieties exhibited distinct physiological seed maturity levels: Numbu was 46 days after anthesis (DAA), Super-1 was 39 DAA, Bioguma-1 was 51 DAA, Samurai-2 was 55 DAA, and Pahat was 36 DAA. During the 24-week storage, the germination percentage declined, while electrical conductivity increased across all three tested varieties (Numbu, Bioguma-1, and Samurai-2). Storage at 18 °C (T1, air-conditioned) prolonged seed viability compared to 26 °C (T2, non-air-conditioned). Numbu seeds could be stored at 18 °C with 10–11% moisture content, and retained viability for 18 weeks (GP: 72.3%), whereas seeds stored at 26 °C with 12-13% moisture deteriorated after 6 weeks (GP: 70.3%). Meanwhile, Bioguma-1 and Samurai-2 showed a minimum GP reduction over 24 weeks, despite low initial germination (<70%), suggesting potential after-ripening dormancy. The EC values peaked at 24 weeks in the 26 °C storage room, correlating with seed deterioration in all stored varieties. These results highlight the critical role of temperature and moisture control in optimizing sorghum seed storability, with dormancy behavior necessitating further investigation.

REFERENCES

Abah, C. R., Ishiwu, C. N., Obiegbuna, J. E., & Oladejo, A. A. (2020). Sorghum grains: Nutritional composition, functional properties, and its food applications. *European Journal of Nutrition & Food Safety, 12*(5), 101-111. https://doi.org/10.9734/ejnfs/2020/v12i530232

Abud, H. F., Cicero, S. M., & Junior, F. G. G. (2018). Radiographic images and relationship of the internal morphology and physiological potential of broccoli seeds. *Acta Scientiarum, 40*, e34950. https://doi.org/10.4025/actasciagron.v40i1.34950

Afriansyah, M., Ermawati, E., Pramono, E., & Nurmiaty, Y. (2021). Seed viability and vigors of four genotypes of sorghum (*Sorghum bicolor* [L.] Moench) post storage 16 months. (In Indonesian.). *Jurnal Agrotek Tropika, 9(1),* 129-136. https://doi.org/10.23960/jat.v9i1.4779

Agustiansyah, A., Nurmiaty, Y., Ermawati, E., & Putri, A. S. (2020). Quality of fifteen lots of soybean seeds stored for six months at different temperatures. (In Indonesian.). *Jurnal Galung Tropika, 9*(3), 223–232. https://doi.org/10.31850/jgt.v9i3.603

Al-Fikri, M. N., Zuhry, E., & Nurbaiti, N. (2015). The attempt of yield potential and seed physiologic quality for some genotypes of BATAN's sweet sorghum (*Sorghum bicolor* (L.) Moench). (In Indonesian.). *Jurnal Online Mahasiswa Faperta, 2*(1), 1-11.

Anggraini, I. H., Kamal, M., Pramono, E., & Setiawan, K. (2020). Seed storage time effect on seed vigor and sprouts of sorghum (*Sorghum bicolor* L. Moench) genotype Kawali and P/F-10-90A. (In Indonesian.). *Jurnal Agrotek Tropika*, *8*(2), 327-335. https://doi.org/10.23960/jat.v8i2.3909

Arini, P. B., & Ahadiyat Y. R. (2021). Regulation of incubation temperature and seed treatment in order to increase the carica seed viability. (In Indonesian.). *Jurnal Kultivasi, 20*(3), 149-158. https://doi.org/10.24198/kultivasi.v20i3.32626

Bareke, T. (2018). Biology of seed development and germination physiology. *Advances in Plants Agriculture Research, 8*(4), 336-346.

Beedi, S., Macha, S. I., Gowda, B., Savitha, A. S., & Kurnallikar, V. (2018). Effect of seed priming on germination percentage, shoot length, root length, seedling vigour index, moisture content and electrical conductivity in storage of kabuli chickpea cv. MNK-1 (*Cicer arietinum* L.). *Journal of Pharmacognosy and Phytochemistry*, 7(1), 2005-2010.

Castro, E., Nieves, I. U., Rondon, V., Sagues, W. J., Fernandez-Sandoval, M. T., Yomano, L. P., York, S. W., Erickson, J., & Vermerris, W. (2017). Potential for ethanol production from different sorghum cultivars*. Industrial Crops and Products*, *109*, 367-373. https://doi.org/10.1016/j.indcrop.2017.08.050

Coordinating Ministry for Economic Affairs. (2022). *Commencement of sorghum development pilot project marks substitution and diversification efforts in strengthening crop security*. https://ekon.go.id

Corbineau, F. (2024). The effects of storage conditions on seed deterioration and ageing: How to improve seed longevity. *Seeds*, *3*, 56-75. https://doi.org/10.3390/seeds3010005

Dadlani, M., & Yadava, D. K. (2022). *Seed science and technology: Biology, production, quality.* Springer. https://doi.org/10.1007/978-981-19-5888-5

Eulogio, C., Ismael, U. N., Vanessa, R., William, J. S., Marco, T. F. S., Lorraine, P. Y., Sean, W. Y., John, E., & Wilfred, V. (2017). Potential for ethanol production from different sorghum cultivars*. Journal Industrial Crops and Products*, *109*, 367-373.

Fang, Y. H., & Juan, S. (2021). Effect of seed moisture content and deterioration time on seed vigor and seedling growth of *Sorghum bicolor* × *Sorghum sudanense*. *Acta Prataculturae Sinica, 30*(12), 152-160.

Gala, E. W., Pramono, E., & Nurmiaty, Y. (2018). Effect of maturity level on seed field production and quality of four sweet sorghum varieties (*Sorghum bicolor* L. Moench). (In Indonesian.). *Jurnal Pertanian Terapan, 18*(01), 1-12.

Harrington, J. F. (1972). Seed storage and longevity, In TT Kozlowski (Eds.), *Seed biology.* Academic Press.

Ilyas, S. (2012)*. Seed Science and Technology: Theory and Research Results.* (in Indonesian.). IPB Press.

ISTA. (2018). *International Rules for Seed Testing.* Basserdorf: Switzerland: International Seed Testing Association.

Jia, Z., Ou, C., Sun, S., Wang, J., Liu, J., Sun, M., Ma, W., Li, M., Jia, S., & Mao, P. (2023). Integrating optical imaging techniques for a novel approach to evaluate Siberian wild rye seed maturity. *Frontiers in Plant Science*, *14*, 117974. https://doi.org/10.3389/fpls.2023.1170947

Kazungu, F. K., Muindi, E. M., & Mulinge, J. M. (2023). Overview of sorghum (*Sorghum bicolor* L), its economic importance, ecological requirements, and production constraints in Kenya. *International Journal of Plant and Soil Science*, *35*(1), 62-71. https://doi.org/10.9734/ijpss/2023/v35i12744

Khalilah, S., Syamssuddin, S., & Kurniawan, T. (2022). Quality of soybean seeds stored in various types of containers and storage duration. (In Indonesian.). *Jurnal Agrium*, *19*(4), 360-365. https://doi.org/10.29103/agrium.v19i4.9738

Maksum, N. Z., Pramono, E., Agustiansyah, A., & Nurmianty, Y. (2020). The effect of temperature and genotype in sorghum seed viability (*Sorghum bicolor* [L.] Moench.) post save 12 months. (In Indonesian.). *Jurnal Agrotek Tropika, 8*(1), 67-75. https://doi.org/10.23960/jat.v8i1.3684

Mbughi, Y. K., Kilasi, N. L., & Mourice, S. K. (2024). The effect of seed packaging materials, storage period, and conditions on the physiological sorghum seedlings. *Journal of Current Opinion in Crop Science, 5*(3), 173-183. https://doi.org/10.62773/jcocs.v5i3.261

de Medeiros. A., Zavala- Leon, M. J., da Silva, L. J., Oliveira, A. M. S., & Dias, D. C. F. D. S. (2019). Relationship between internal morphology and physiological quality of pepper seeds during fruit maturation and storage. *Agronomy Journal, 112*(1), 25-35. https://doi.org/10.1002/agj2.20071

Ministry of Agriculture. (2023). *Decision of the Minister of Agriculture, Republic of Indonesia No: 465/HK.220/c/02/2023 about technical instructions for certification of crop plant seeds*. Ministry of Agriculture.

Najam, A. (2022). *Effect of harvest ages on production, seed quality, biomass of sorghum varieties of Samurai 2* [Master's Theses, IPB university]. IPB University Digital Repository. https://repository.ipb.ac.id/handle/123456789/112698

Pamungkas, P. B., & Kusberyunadi, M. (2020). The study of electric conductivity with physiological quality of soybean (*Glycine max* (L.) Merr.) seed by matriconditioning and osmoconditioning invigoration treatment. (In Indonesian). *Agroteknika, 3*(1), 16-25. https://doi.org/10.32530/agroteknika.v3i1.56

Poehlman, J. M. (1979). *Breeding Field Crops.* Springer. https://doi.org/10.1007/978-94-015-7271-2

Pramono, E., Kamal, M., Setiawan, K., & Tantia, M. A. (2019). Effect of storage time and storage chamber temperature on seed determination and vigor of seed sorghum (*Sorghum bicolor* (L.) Moench.) variety of Samurai-1. (In Indonesian.). *Jurnal Agrotek Tropika, 7*(2), 383-389. http://dx.doi.org/10.23960/jat.v7i2.3261

Qiu, S., Yu, Y., Feng, Y., Tang, Z., Cui, Q., & Yuan, X. (2022). Crushing characteristics of sorghum grains subjected to compression and impact loading at different moisture contents. *Agriculture, 12*(9), 1422. https://doi.org/10.3390/agriculture12091422

Rusmin, D., & Darwati, I. (2018). Phenological study and determination of physiological maturity of purwoceng seeds. (In Indonesian.). *Jurnal Agronida, 1*(1), 45-55.

Shaheb, M. R., Islam, M.N., Nessa, A., & Hossain, M. A. (2015). Effect of harvest times on the yield and seed quality of French bean. *SAARC Journal of Agriculture, 13*(1), 1-13.

Singh, H., & Meghwal, M. (2020). Physical and thermal properties of various ajwain (*Trachyspermum ammi* L.) seed varieties as a function of moisture content. *Journal of Food Process Engineering, 43*(3), e13310.

Sugriana, L. T., Rajiman, R., & Wartapa, A. (2023). Effect of harvesting ages and threshing technique on seed quality of variety IR64. (In Indonesian.). *Junal Polbangtanyoma, 5*, 132-137.

Sundareswaran, S., Choudhury, P, R., Vanitha, C., & Devendra, K. (2023). *Seed Quality: Variety Development to Planting-An Overview*. Springer. https://link.springer.com/chapter/10.1007/978-981-19-5888-5_1

Trancoso, A. C. R., Dias, D. C. F. D. S., Picoli, E. A. D. T., Junior, R. A. D. S., da Silva, L. J., & Nascimento, W. M. (2021). Anatomical, histochemical, and physiological changes during maturation of chickpea (*Cicer arietinum* L.) seeds. *Revista Ciencia Agronomica, 52*(4), e20207534.

Vitis, M. D., Hay, F. R., Dickie, J. B., Trivedi, C., Choi, J., & Fiegener, R. (2020). Seed storage: maintaining seed viability and vigor for restoration use. *Restoration Ecology, 28*(3), S249-S255. https://doi.org/10.1111/rec.13174

Whitfield, M. B., Chinn, M. S., & Veal, M. W. (2011). Processing of materials derived from sweet sorghum for biobased products. *Industrial Crops and Products*, *37*(1), 362-375. https://doi.org/10.1016/j.indcrop.2011.12.011

Zhang, S., Zeng, H., Ji, W., Yi, K., Yang, S., Mao, P., Wang, Z., Yu, H., & Li, M. (2022). Non-destructive testing of alfalfa seed vigor-based multispectral imaging technology. *Sensors, 22*(7), 2760. https://doi.org/10.3390/s22072760