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*Research Article*

# Rice (*Oryza sativa* L.) Seed Quality after Storage in the Humid Tropics and after Accelerated Aging

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Accelerated aging test (AA) has been applied as a technique to evaluate seed vigor and to predict seed storability. This study evaluated the storability and vigor of Sang Yod Phatthalung, Leb Nok Pattani, and Chaing Phatthalung rice seeds by the AA. The seeds were subjected to AA at 42, 44, 46, and 48°C for durations of 48, 72, 96, and 120 h at 100% relative humidity. The seeds were stored in woven plastic bags at room temperature (28±1°C) for 12 months, and were sampled for physical and physiological quality tests every two months. The results showed that Sang Yod Phatthalung, Leb Nok Pattani, and Chaing Phatthalung rice seeds had 94.75-97.25% germination and 9.05-9.98% seed moisture content, and could be stored in the humid tropics for six months with above 80% germination. It suggests that the appropriate AA conditions for the evaluation of rice seed storability in the humid tropics should be done at 46°C for 96 h and 100% relative humidity. This aging regime gave seed vigor separation among varieties with a germination gap of about 10%, while a greater classification (10-30%) occurred after aging at 44°C for 120 h. These AA regimes (46°C for 96 h) serve as a potential tool for predicting the seed storability and classifying rice seeds by their vigor.



## 1. Introduction

Nowadays, the adverse planting conditions resulting from climate change or global warming are of concern to farmers. High-quality seeds are the most important fundamental factor in rice cultivation, significantly determining the yield and income of farmers. High emergence capacity and maintenance of high germination during storage are the two main characteristics of high vigor seeds. However, the seeds begin to deteriorate after physiological maturity and continue to do so during further storage (Duangpatra, 1986). The seeds used in the humid tropics of Thailand will require storage up to the next planting season, for about 5-8 months (Rice Department, 2016). The germination ability of seeds stored in woven plastic bags under ambient conditions can last for a period ranging from three months (Sukkaew and Wongvarodom, 2022) to eight months (Alahakoon *et al.*,

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2021). Many seed vigor tests are needed to classify the vigor of any lot and to assess its relation to storage (Demir *et al*., 2020). The accelerated aging (AA) test was initially employed to assess seed storage potential and longevity (Delouche and Baskin, 1973) and has since been utilized as a seed vigor descriptor in various crops (Hampton and TeKrony, 1995; AOSA, 2002). The AA test, in which seeds are placed in high relative humidity and elevated temperature for a specified duration, is intended to induce seed aging for subsequent standard germination test (ISTA, 2019). Different accelerated aging responses have been found in various crop seeds. Santipracha *et al*. (1997) suggested that the accelerated aging conditions of 100% relative humidity at 44°C for 96 h can be used to evaluate hybrid corn seed quality in the humid tropics. Accelerated aging at 45°C for 48, 72, and 120 h was shown to be practicable as a seed vigor test for many vegetable crops such as aubergine, cucumber, and melon, respectively (Demir *et al*., 2004). Also, the accelerated aging conditions at 44°C for 72 h could be used in a rice seed vigor test (Chhetri, 2009).

However, accelerated aging studies to assess the potential of the test in evaluating rice seed's storability in the humid tropics and indicating seed vigor differences are scarce. Therefore, this study aims to investigate the seed quality after storage under ambient conditions in the humid tropics, and the responses of rice seeds and their quality to accelerated aging.

## 2. Materials and Methods

Seeds of Leb Nok Pattani, Chiang Phatthalung, and Sang Yod Phattalung rice varieties were obtained from Phatthalung Rice Seed Center (production year 2020/2021). The seed quality test including moisture content, standard germination, speed of germination, and seedling growth rate was evaluated using four replicates (AOSA, 2001 and 2002), as follows.

**Moisture content** Twenty seeds per replication were weighed and tested for moisture content by drying them at 105°C for 24 h. The dry seeds were then weighed, and their moisture content was calculated as a percentage of the wet weight.

**Standard germination** Standard germination test was performed using one hundred seeds per replication on top of paper (TP) at 30°C (Kapoor *et al*., 2011; Santipracha, 2017). First and final counts were evaluated at 5, 10, and 14 days, respectively (ISTA, 2019).

**Speed of germination** Seedlings that exhibited normal growth at 5, 10, and 14 days after germinating in the standard germination test were used to calculate the Speed of Germination Index (SGI) (AOSA, 2002), with the following formula:

$$SGI = \frac{\text{number of normal seedlings}}{\text{days of first count}} + \ldots\ldots + \frac{\text{number of normal seedlings}}{\text{days of final count}}$$

**Seedling growth rate** Seedling growth rate tests were conducted using twenty normal seedlings per replication from the first count germination evaluation. The shoot and root lengths were measured and calculated in cm per seedling. The seedling axis were separately dried at 80°C for 24 h. Dry seedlings were weighed and calculated as mg per seedling.

**Accelerated aging** The test was conducted according to the procedure described by Hampton and TeKrony (1995). Seeds were placed on a wire mesh tray inside a plastic box over water. The tightly closed plastic boxes were incubated in an oven at 42, 44, 46, and 48°C. After 48, 72, 96, and 120 h of accelerated aging, the seed quality was conducted similarly to that for the unaged seeds.

**Seed storage** These seeds were contained in woven plastic bags and stored in ambient conditions (28±1°C) in a room at the Phatthalung Rice Seed Center's warehouse. The average relative humidity and temperature in the room were 72-81% and 26.3-29.0°C.

Seven storage durations were evaluated: 0, 2, 4, 6, 8, 10, and 12 months.

Quality indicators between unaged samples and those after accelerated aging were analyzed using a completely randomized design. The statistical significance of means was tested by Duncan's multiple range test (DMRT), with a significance level set at $p<0.01$ using R software version 4.2.0.

## 3. Results and Discussion

*3.1 Rice seed quality before storage*

The rice seeds of Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung varieties, with moisture content ranging from 9.05% to 9.98%, exhibited a germination rate in the range of 94.75% to 97.25% (Table 1). There was no significant difference (p<0.01) among the three varieties in terms of seed vigor, as indicated by the Speed of Germination Index (18.68-19.42) or seedling dry weight (3.32-3.66 mg/seedling). However, there were notable variations in seedling growth concerning shoot and root length, with significant differences observed among the rice varieties. The shoot lengths of the varieties before storage ranged from 2.78 cm (Leb Nok Pattani) to 4.23 cm (Sang Yod Phatthalung), while the root lengths before storage ranged from 3.34 cm (Chaing Phatthalung) to 5.24 cm (Sang Yod Phatthalung).

**Table 1** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of rice seeds of Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung varieties before storage

| Variety | Moisture content (%) | Germination (%) | Speed of Germination Index | Shoot length (cm/seedling) | Root length (cm/seedling) | Seedling dry weight (mg/seedling) |
|---|---|---|---|---|---|---|
| Leb Nok Pattani | 9.05 | 97.25 | 19.42 | 2.78 b | 3.40 b | 3.66 |
| Chaing Phatthalung | 9.98 | 96.50 | 19.28 | 3.34 b | 3.34 b | 3.32 |
| Sang Yod Phatthalung | 9.71 | 94.75 | 18.68 | 4.23 a | 5.24 a | 3.47 |
| F test | ns | ns | ns | ** | ** | ns |
| %CV | 8.67 | 2.15 | 2.14 | 8.13 | 9.15 | 6.36 |

ns = non-significant; ** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

*3.2 Rice seed quality after storage at room temperature in the humid tropical conditions*

Seed moisture content after storage of Leb Nok Pattani and Sang Yod Phatthalung significantly ($p<0.01$) increased from 9.05-9.71% to 12.00-12.08%, and varied depending on storage duration (Tables 2, 3, and 4). In contrast, the seeds of Chaing Phatthalung variety had no significant change in seed moisture content (8.35-11.30%). The germination of Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung decreased after six months of storage. Leb Nok Pattani (initially 97.25%), Chaing Phatthalung (96.50%) and Sang Yod Phatthalung (94.75%) could maintain germination above 80% for six months of storage. Seed germination rapidly decreased after storage for eight months. A similar result was found for the Speed of Germination Index, which drastically declined from the initial range of 18.68-19.42 to 1.70-6.15 after storage for eight months. Prolonged storage reduced seedling growth rates in terms of shoot length, root length, and seedling dry weight for both Leb Nok Pattani and Chaing Phatthalung when stored for eight months. In contrast, those of Sang Yod Phatthalung decreased after storage for six months (Tables 2, 3, and 4).

Rapid seed deterioration of rice during storage in the humid tropics is a crucial problem for seed producers and farmers due to the high relative humidity (more than 80%) and high temperature (average 30°C) in a typical ambient storage environment (Chuthamat *et al*., 2009). This study found that the rice seeds with 9.05-9.98% initial moisture content and 94.75-97.25% germination could be maintained for germination above 80% only for up to six months. This result aligns with the earlier reports by Santipracha and Santipracha (1998) and Choudhury and Rajanna (2011), who found that rice seeds stored at room temperature maintained a standard germination rate of 80% after six months, despite the various factors influencing seed quality during storage (Tang and Ngome, 2015; Nabila *et al*., 2016; Songkrairat *et al*., 2019; Oke *et al*., 2020). The severe storage conditions in the humid tropics cause a raise in seed moisture content and respiratory activity during storage, which increases biochemical levels of hydrolytic enzyme activity, free fatty acids, and enzymes, causing a speedy rate of deterioration (Perveen *et al*., 2010; Sudhakaran, 2020). Moreover, during seed deterioration, free radicals increase as a result of lipid peroxidation, stimulating damage to enzymes that are important for transforming stored reserve in the embryo into a usable form, thus affecting the production of normal seedlings (Iqbal *et al*., 2002). The decrease in energy supply necessary for germination is caused by free radicals which damage the mitochondrial membrane, thereby rapidly reducing seed germination (Santipracha, 1997; Gidrol *et al*., 1998; Zhang *et al*., 2021). Therefore, additional evaluations of appropriate storage protocols in humid tropics are needed to maintain rice seed quality under storage until the planting date.

**Table 2** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Leb Nok Pattani rice seeds after different storage periods at ambient conditions

| Storage period (months) | Moisture content (%) | Germination (%) | Speed of Germination Index | Shoot length (cm/seedling) | Root length (cm/seedling) | Seedling dry weight (mg/seedling) |
|---|---|---|---|---|---|---|
| 0 | 9.05 c | 97.25 a | 19.42 a | 2.78 b | 3.40 ab | 3.66 ab |
| 2 | 12.00 a | 95.75 a | 19.10 a | 4.02 a | 3.05 b | 3.88 a |
| 4 | 9.74 bc | 94.75 a | 18.82 a | 3.74 a | 3.97 a | 3.42 b |
| 6 | 10.49 abc | 86.00 b | 17.02 b | 3.65 a | 3.92 a | 3.39 b |
| 8 | 11.20 ab | 14.00 c | 2.38 c | 2.21 c | 2.99 b | 2.08 c |
| 10 | 11.12 ab | 0.00 d | 0.00 d | 0.00 d | 0.00 c | 0.00 d |
| 12 | 11.31 ab | 0.00 d | 0.00 d | 0.00 d | 0.00 c | 0.00 d |
| F test | ** | ** | ** | ** | ** | ** |
| %CV | 7.25 | 3.90 | 3.81 | 7.62 | 12.49 | 8.84 |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

**Table 3** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Chaing Phatthalung rice seeds after different storage periods at ambient conditions

| Storage period (months) | Moisture content (%) | Germination (%) | | Speed of Germination Index | | Shoot length (cm/seedling) | | Root length (cm/seedling) | | Seedling dry weight (mg/seedling) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9.98 | 96.50 | a | 19.28 | a | 3.34 | c | 3.34 | bc | 3.32 | ab |
| 2 | 10.87 | 96.00 | a | 19.20 | a | 4.46 | a | 4.06 | a | 3.67 | a |
| 4 | 10.51 | 91.00 | b | 17.98 | b | 4.02 | b | 2.93 | cd | 3.08 | b |
| 6 | 8.35 | 79.75 | c | 15.84 | c | 4.10 | ab | 3.92 | ab | 3.40 | ab |
| 8 | 10.92 | 8.50 | d | 1.70 | d | 2.02 | d | 2.34 | d | 1.87 | c |
| 10 | 10.65 | 0.00 | e | 0.00 | e | 0.00 | e | 0.00 | e | 0.00 | d |
| 12 | 11.30 | 0.00 | e | 0.00 | e | 0.00 | e | 0.00 | e | 0.00 | d |
| F test | ns | ** | | ** | | ** | | ** | | ** | |
| %CV | 13.31 | 4.59 | | 4.49 | | 7.50 | | 14.21 | | 9.75 | |

ns = non-significant; ** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

**Table 4** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Sang Yod Phatthalung rice seeds after different storage periods at ambient conditions

| Storage period (months) | Moisture content (%) | | Germination (%) | | Speed of Germination Index | | Shoot length (cm/seedling) | | Root length (cm/seedling) | | Seedling dry weight (mg/seedling) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 9.71 | d | 94.75 | ab | 18.68 | b | 4.23 | c | 5.24 | b | 3.47 | b |
| 2 | 9.10 | e | 97.00 | a | 19.40 | a | 5.48 | a | 6.11 | a | 4.20 | a |
| 4 | 10.60 | c | 95.25 | ab | 19.05 | ab | 4.68 | b | 4.69 | c | 3.43 | b |
| 6 | 10.50 | c | 91.00 | b | 17.90 | c | 3.53 | d | 3.78 | d | 2.75 | c |
| 8 | 10.54 | c | 37.75 | c | 6.15 | d | 1.97 | e | 2.80 | e | 1.86 | d |
| 10 | 12.08 | a | 0.00 | d | 0.00 | e | 0.00 | f | 0.00 | f | 0.00 | e |
| 12 | 10.94 | b | 0.00 | d | 0.00 | e | 0.00 | f | 0.00 | f | 0.00 | e |
| F test | ** | | ** | | ** | | ** | | ** | | ** | |
| %CV | 0.89 | | 4.03 | | 3.28 | | 4.40 | | 4.92 | | 5.04 | |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

*3.3 Rice seed quality after accelerated aging*

The seed moisture content after accelerated aging had increased from the initial 9.05-9.98% to 16.62-33.97% and differed depending on aging temperature, duration, and rice variety (Tables 5, 6, and 7). Response patterns in the germination of rice seeds after accelerated aging also varied depending on those factors: aging temperature, duration, and variety. In terms of seed germination, the Leb Nok Pattani and Chaing Phatthalung varieties had almost the same responses to accelerated aging (Tables 5, 6, and 7), while the Sang Yod Phatthalung variety showed a very strong response at 42 °C with a dramatic reduction in germination from 94.75% to 71.75-42.00%. However, as the level of stress was raised (44 and 46 °C), the pattern of germination response to accelerated aging by Sang Yod Phatthalung was approximately similar to that of Leb Nok Pattani and Chaing Phatthalung. The remarkable reduction in germination for all varieties first started at an accelerated aging temperature of 44 °C over 120 h, mostly falling below 75% germination. However, the highest stress at 48°C accelerated aging temperature led to a sharp decrease in germination for all rice seed varieties to very low values (Tables 5, 6, and 7). The same response pattern to accelerated aging regimes as seen in germination was also found in the Speed of Germination Index for all rice varieties. Accelerated aging reduced seedling growth rates in terms of root length and seedling dry weight for Leb Nok Pattani, in shoot length and seedling dry weight for Chaing Phatthalung at 44 °C for 120 h, and in shoot length and seedling dry weight for Sang Yod Phatthalung at 46°C for 96 h. In addition, all these varieties showed a marked reduction under the more stressful aging conditions at 48°C for 96 h.

The results indicate that the response of rice seeds to accelerated aging depends not only on the stress conditions (temperature and duration of AA) but also varies by rice variety (Tables 5, 6 and 7). This agrees with earlier reports on hybrid corn and Bambara groundnut (Santipracha *et al.*, 1997; Wongvarodom and Naulkong, 2006). The results showed that seeds of the Sang Yod Phatthalung variety initially had a strong response at 42°C with a dramatic reduction in germination from 94.75% to 71.75-42.00%, while the germination abilities of Leb Nok Pattani and Chaing Phatthalung seeds were still maintained at high levels. In addition, the rice seeds of all varieties showed a very mild response to an AA duration of 48 h at most of the temperature levels tested. However, the same trend of germination response by all varieties tested, with a sharp decline in germination, was found at AA 44 and 46°C for 72-120 h. Also, at the highest AA temperature studied (48°C for 96-120 h), all the seeds lost their germination ability sharply, dropping to near zero (Tables 5, 6, and 7). These results indicate that higher aging temperatures and longer aging durations reduced seed germination to very low values (Wongvarodom, 1995; Wongvarodom and Naulkong, 2006; Chhetri, 2009).

The results also revealed that the Speed of Germination Index followed the same trend in response to AA as the germination percentage (Tables 5, 6, and 7). The Speed of Germination Index exhibited the strongest response to accelerated aging in hybrid corn seeds (Santipracha *et al*., 1997). In contrast to the Speed of Germination Index, the seedling growth rate in terms of shoot length, root length, and seedling dry weight showed pronounced declines at the higher temperature of 48°C applied for 96 h. The same was found for all three varieties, Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung, suggesting that the seedling dry weight could not be used to indicate the degeneration after AA of rice seeds, as in groundnut (Wongvarodom, 1995) and Bambara groundnut seeds (Wongvarodom and Naulkong, 2006).

**Table 5** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Leb Nok Pattani rice seeds after accelerated aging at different temperatures and durations

| Accelerated aging conditions °C/h | Moisture content (%) | Germination (%) | Speed of Germination Index | Shoot length (cm/seedling) | Root length (cm/seedling) | Seedling dry weight (mg/seedling) |
|---|---|---|---|---|---|---|
| 0/0 | 9.05 f | 97.25 a | 19.42 a | 2.78 gh | 3.40 de | 3.66 efg |
| 42/48 | 21.65 bc | 92.00 abc | 18.12 ab | 3.90 bcd | 3.90 b-e | 3.55 fg |
| 42/72 | 22.28 abc | 89.00 abc | 17.52 bc | 3.95 bcd | 4.22 abc | 4.00 b-e |
| 42/96 | 22.72 ab | 89.75 abc | 17.62 b | 3.72 cde | 4.05 bcd | 3.62 efg |
| 42/120 | 23.42 a | 93.25 ab | 18.45 ab | 3.35 ef | 3.52 cde | 3.60 efg |
| 44/48 | 20.95 c | 95.50 ab | 19.08 a | 4.25 ab | 3.98 b-e | 4.18 abc |
| 44/72 | 22.12 abc | 88.00 bc | 17.30 bc | 3.80 b-e | 3.72 b-e | 3.42 g |
| 44/96 | 21.12 c | 79.00 de | 14.92 d | 3.58 de | 4.12 bcd | 3.60 efg |
| 44/120 | 21.80 bc | 55.50 g | 9.58 g | 2.92 fg | 2.40 f | 2.78 h |
| 46/48 | 21.90 bc | 93.50 ab | 18.65 ab | 4.45 a | 4.05 bcd | 4.35 ab |
| 46/72 | 21.85 bc | 88.25 bc | 17.42 bc | 4.12 abc | 4.40 ab | 3.98 b-f |
| 46/96 | 19.05 d | 84.50 cd | 16.20 c | 3.68 cde | 4.10 bcd | 3.68 d-g |
| 46/120 | 21.02 c | 64.50 f | 11.75 f | 3.52 de | 4.00 bcd | 4.08 bcd |
| 48/48 | 16.62 e | 92.50 abc | 18.32 ab | 4.48 a | 4.88 a | 4.52 a |
| 48/72 | 22.28 abc | 74.25 e | 13.05 e | 4.12 abc | 3.78 b-e | 3.90 c-f |
| 48/96 | 21.00 c | 54.00 g | 7.70 h | 2.42 h | 3.25 e | 2.72 h |
| 48/120 | 23.00 ab | 9.50 h | 0.90 i | 0.00 i | 0.00 g | 0.00 i |
| F test | ** | ** | ** | ** | ** | ** |
| %CV | 3.23 | 5.17 | 4.42 | 6.59 | 9.60 | 5.75 |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

**Table 6** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Chaing Phatthalung rice seeds after accelerated aging at different temperatures and durations

| Accelerated aging conditions °C/h | Moisture content (%) | | Germination (%) | | Speed of Germination Index | | Shoot length (cm/seedling) | | Root length (cm/seedling) | | Seedling dry weight (mg/seedling) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0/0 | 9.98 | e | 96.50 | ab | 19.28 | ab | 3.34 | f | 3.34 | cd | 3.32 | def |
| 42/48 | 20.74 | bcd | 87.50 | c-f | 16.38 | de | 3.68 | def | 4.14 | ab | 3.06 | fg |
| 42/72 | 22.09 | abc | 82.50 | d-g | 15.64 | ef | 4.22 | bc | 3.49 | bcd | 3.32 | def |
| 42/96 | 22.65 | a | 87.75 | c-f | 17.22 | cd | 3.87 | cde | 3.07 | cd | 3.22 | ef |
| 42/120 | 22.59 | a | 89.00 | b-e | 17.42 | cd | 3.77 | de | 3.20 | cd | 3.57 | b-e |
| 44/48 | 21.40 | abc | 94.00 | abc | 18.75 | abc | 4.57 | ab | 3.46 | cd | 3.65 | bcd |
| 44/72 | 21.66 | abc | 91.25 | abc | 18.05 | abc | 4.75 | a | 3.60 | bc | 3.54 | b-e |
| 44/96 | 19.75 | d | 80.25 | fgh | 15.20 | ef | 4.23 | bc | 3.52 | bcd | 3.56 | b-e |
| 44/120 | 20.93 | a-d | 74.25 | h | 13.45 | gh | 2.59 | g | 3.28 | cd | 2.76 | g |
| 46/48 | 22.01 | abc | 97.25 | a | 19.45 | a | 4.87 | a | 3.37 | cd | 3.65 | bcd |
| 46/72 | 21.99 | abc | 90.50 | a-d | 17.75 | bcd | 4.76 | a | 3.44 | cd | 3.80 | abc |
| 46/96 | 20.55 | cd | 81.50 | e-h | 15.47 | ef | 4.11 | cd | 2.83 | d | 3.92 | ab |
| 46/120 | 21.26 | a-d | 65.75 | i | 12.08 | h | 3.45 | ef | 3.01 | cd | 3.50 | cde |
| 48/48 | 21.45 | abc | 92.50 | abc | 18.38 | abc | 4.58 | ab | 4.30 | a | 3.73 | bc |
| 48/72 | 22.16 | abc | 79.25 | gh | 14.31 | fg | 3.90 | cd | 4.68 | a | 4.14 | a |
| 48/96 | 21.75 | abc | 35.00 | j | 4.48 | i | 2.28 | g | 1.92 | e | 2.06 | h |
| 48/120 | 22.29 | ab | 4.50 | k | 0.43 | j | 0.00 | h | 0.00 | f | 0.00 | i |
| F test | ** | | ** | | ** | | ** | | ** | | ** | |
| %CV | 3.73 | | 4.95 | | 5.36 | | 5.74 | | 10.10 | | 5.55 | |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

**Table 7** Moisture content, germination, Speed of Germination Index, shoot length, root length, and seedling dry weight of Sang Yod Phatthalung rice seeds after accelerated aging at different temperatures and durations

| Accelerated aging conditions °C/h | Moisture content (%) | | Germination (%) | | Speed of Germination Index | | Shoot length (cm/seedling) | | Root length (cm/seedling) | | Seedling dry weight (mg/seedling) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0/0 | 9.71 | i | 94.75 | a | 18.68 | ab | 4.23 | ef | 5.24 | a-d | 3.47 | de |
| 42/48 | 22.89 | h | 71.75 | b | 14.19 | cd | 5.45 | ab | 6.27 | ab | 4.26 | ab |
| 42/72 | 24.09 | efg | 53.75 | cd | 10.70 | e | 4.58 | cde | 5.48 | a-d | 3.48 | de |
| 42/96 | 24.68 | de | 56.00 | c | 11.08 | e | 4.92 | b-e | 5.83 | abc | 3.62 | de |
| 42/120 | 24.81 | de | 42.00 | e | 8.32 | f | 4.78 | b-e | 5.75 | abc | 3.53 | cde |
| 44/48 | 22.96 | h | 93.00 | a | 18.54 | ab | 5.63 | a | 6.39 | a | 4.33 | a |
| 44/72 | 23.49 | gh | 78.00 | b | 15.55 | c | 5.08 | abc | 5.97 | abc | 3.90 | bc |
| 44/96 | 24.42 | ef | 55.75 | c | 11.08 | e | 4.54 | cde | 5.46 | a-d | 3.23 | efg |
| 44/120 | 24.74 | de | 45.75 | de | 9.08 | f | 4.51 | cde | 6.02 | abc | 3.30 | def |
| 46/48 | 23.66 | fgh | 97.50 | a | 19.42 | a | 4.98 | a-d | 5.67 | a-d | 3.71 | cd |
| 46/72 | 24.43 | ef | 95.25 | a | 18.92 | ab | 4.63 | cde | 5.42 | a-d | 3.56 | cde |
| 46/96 | 24.11 | efg | 90.50 | a | 17.59 | b | 3.36 | g | 4.98 | bcd | 2.86 | gh |
| 46/120 | 25.50 | d | 74.00 | b | 14.22 | cd | 3.69 | fg | 4.78 | cd | 3.04 | fg |
| 48/48 | 31.21 | c | 91.00 | a | 17.68 | b | 4.32 | def | 5.01 | a-d | 3.31 | def |
| 48/72 | 32.77 | b | 74.50 | b | 13.25 | d | 3.20 | g | 4.33 | d | 2.51 | hi |
| 48/96 | 33.87 | a | 23.00 | f | 2.69 | g | 1.01 | i | 1.31 | f | 0.62 | j |
| 48/120 | 33.97 | a | 5.00 | g | 0.58 | h | 2.00 | h | 2.87 | e | 2.15 | i |
| F test | ** | | ** | | ** | | ** | | ** | | ** | |
| %CV | 1.71 | | 6.78 | | 6.28 | | 7.84 | | 12.36 | | 6.01 | |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

*3.4 Comparison between seed quality after storage and accelerated aging*

Analysis of variance was undertaken to assess rice seed germination and the Speed of Germination Index among the AA treatments performed at 42, 44, 46, and 48°C for 48, 72, 96, and 120 h, and after six months of storage at room temperature (Table 8). The seeds treated with accelerated aging at 46°C for 96 h showed statistically similar germination percentages and Speed of Germination Indexes as those after room temperature storage for six months, across all three varieties tested.

Differences in germination among seeds of the three varieties are shown in Figures 1, 2 and 3 for the various treatments. The difference in germination varied by accelerated aging regime and variety, while aging at 44°C for 120 h provided a separation among the Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung varieties with a germination gap of about 10-30%, similar to aging at 48°C for 96 h. However, the latter gave a more severe germination reduction.

The results show that AA tests carried out on rice seeds at 46°C for 96 h had the potential to estimate seed storage longevity (at room temperature for six months) and distinguish between seed vigor levels among different varieties. The aging regimes gave seed vigor classification among varieties with a germination gap of about 10%. However, a larger separation (10-30%) took place after aging at 44ºC for 120 h. High temperature and relative humidity caused rapid seed aging or loss of seed viability (ISTA, 2019). High-vigor seed lots will tolerate these intense stress conditions and deteriorate more slowly than low-vigor seed lots. Therefore, after AA, high-vigor lots maintain high germination rates, while that of low- vigor lots is decreased (AOSA, 2002; ISTA, 2019). The germination test, however, is practical for evaluating seed viability under favorable conditions (ISTA, 2019). Nevertheless, the results of the germination test do not necessarily reflect seed vigor and often fail to correlate with field establishment under various sowing conditions (Wongvarodom, 2006).

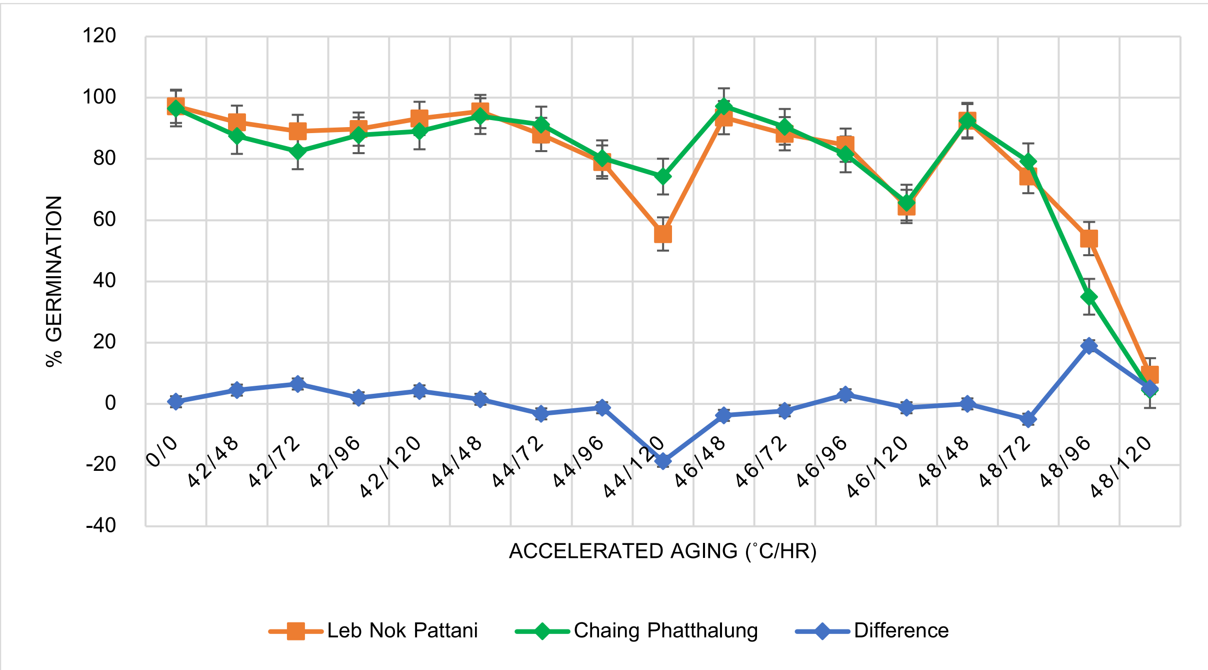


**Figure 1** Germination and difference in germination between the varieties Leb Nok Pattani and Chaing Phatthalung after accelerated aging at different temperatures and durations.

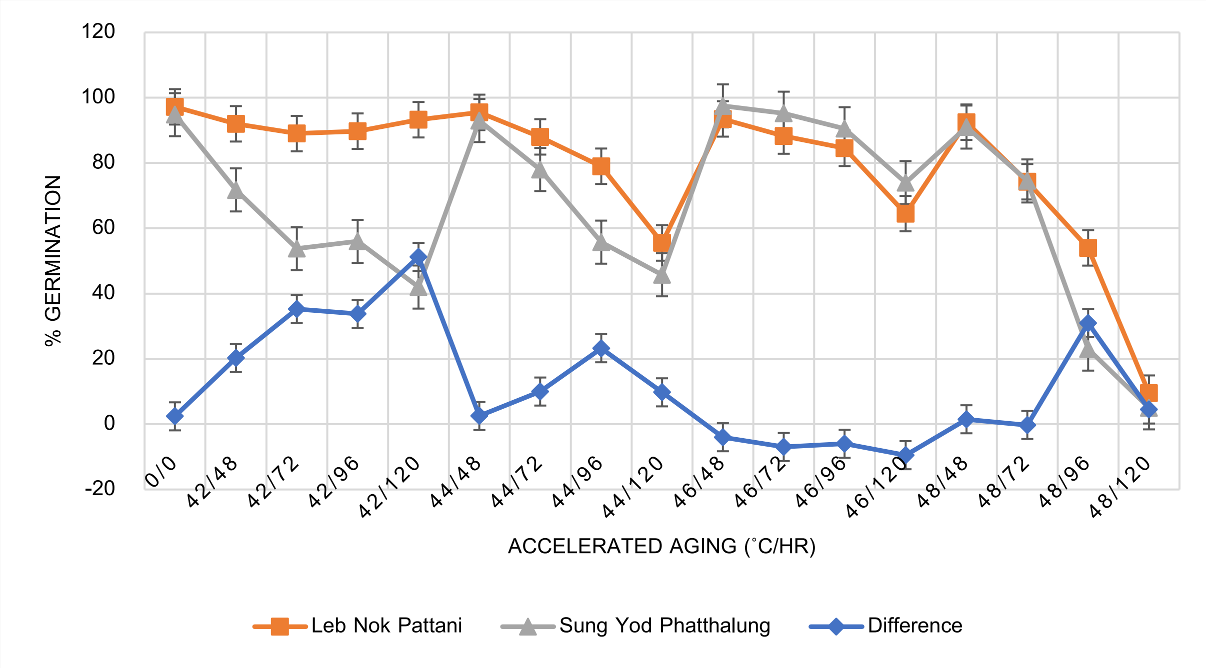


**Figure 2** Germination and difference in germination between the varieties Leb Nok Pattani and Sang Yod Phatthalung after accelerated aging at different temperatures and durations.

**Table 8** Germination and speed germination index of Leb Nok Pattani, Chaing Phatthalung, and Sang Yod Phatthalung rice seeds stored for six months at ambient room conditions, and over accelerated aging conditions

| Treatment | Leb Nok Pattani | | | | Chaing Phatthalung | | | | Sang Yod Phatthalung | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Germination (%) | | SGI | | Germination (%) | | SGI | | Germination (%) | | SGI | |
| 6 months (ambient) | 86.00 | bcd | 17.02 | cd | 79.75 | ef | 15.84 | d-g | 91.00 | a | 17.90 | ab |
| 42/48 | 92.00 | abc | 18.12 | abc | 87.50 | b-e | 16.38 | c-f | 71.75 | b | 14.19 | cd |
| 42/72 | 89.00 | abc | 17.52 | bcd | 82.50 | c-f | 15.64 | efg | 53.75 | cd | 10.70 | e |
| 42/96 | 89.75 | abc | 17.62 | bc | 87.75 | b-e | 17.22 | b-e | 56.00 | c | 11.08 | e |
| 42/120 | 93.25 | abc | 18.45 | abc | 89.00 | a-d | 17.42 | bcd | 42.00 | e | 8.32 | f |
| 44/48 | 95.50 | a | 19.08 | a | 94.00 | ab | 18.75 | ab | 93.00 | a | 18.54 | ab |
| 44/72 | 88.00 | abc | 17.30 | bcd | 91.25 | ab | 18.05 | abc | 78.00 | b | 15.55 | c |
| 44/96 | 79.00 | de | 14.92 | e | 80.25 | ef | 15.20 | fg | 55.75 | c | 11.08 | e |
| 44/120 | 55.50 | g | 9.58 | h | 74.25 | f | 13.45 | hi | 45.75 | de | 9.08 | f |
| 46/48 | 93.50 | ab | 18.65 | ab | 97.25 | a | 19.45 | a | 97.50 | a | 19.42 | a |
| 46/72 | 88.25 | abc | 17.42 | bcd | 90.50 | abc | 17.75 | abc | 95.25 | a | 18.92 | ab |
| 46/96 | 84.50 | cd | 16.20 | d | 81.50 | def | 15.47 | fg | 90.50 | a | 17.59 | b |
| 46/120 | 64.50 | f | 11.75 | g | 65.75 | g | 12.08 | i | 74.00 | b | 14.22 | cd |

**Table 8** (Continuous)

| Treatment | Leb Nok Pattani | | | | Chaing Phatthalung | | | | Sang Yod Phatthalung | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Germination (%) | | SGI | | Germination (%) | | SGI | | Germination (%) | | SGI | |
| 48/48 | 92.50 | abc | 18.32 | abc | 92.50 | ab | 18.38 | ab | 91.00 | a | 17.68 | b |
| 48/72 | 74.25 | e | 13.05 | f | 79.25 | ef | 14.31 | gh | 74.50 | b | 13.25 | d |
| 48/96 | 54.00 | g | 7.70 | i | 35.00 | h | 4.48 | j | 23.00 | f | 2.69 | g |
| 48/120 | 9.50 | h | 0.90 | j | 4.50 | i | 0.43 | k | 5.00 | g | 0.58 | h |
| F test | ** | | ** | | ** | | ** | | ** | | ** | |
| %CV | 5.20 | | 4.44 | | 5.21 | | 5.60 | | 6.90 | | 6.40 | |

** = significant at $p < 0.01$

Different letters in the same column indicate statistically significant differences at $p < 0.01$ by DMRT.

## 4. Conclusion

It is concluded that these rice seeds can be stored for a duration not exceeding six months with seed germination rates consistently above 80%. The responses of these seeds to accelerated aging varied by variety. The Sang Yod Phatthalung and Chaing Phatthalung varieties were more sensitive to accelerated aging than Leb Nok Pattani. Seeds of Sang Yod Phatthalung and Chaing Phatthalung exhibited reduced germination and vigor after accelerated aging at 42°C for 48 h. However, subjecting the seeds to the highest stress at 48°C during accelerated aging resulted in a significant decrease in germination for all rice seed varieties, reaching very low values. Accelerated aging to evaluate rice seed storability in the humid tropics should be conducted at nearly 100% relative humidity and at 46°C for 96 h. This aging regime provided seed vigor separation by variety with a germination gap of about 10%, while a more significant classification (10-30%) occurred after aging at 44°C for 120 h. These findings might assist in classifying rice varieties based on their seed vigor.

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