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# Optimizing Temperature and Drying Conditions to Break Dormancy in Thai RD79 Rice Seeds

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## ABSTRACT

**Background:** Rice seed dormancy is a problem for farmers because it affects rapid, uniform seed germination and vigor during the early stages of crop growth resulting in reducing productivity. The objective of this study was to determine the optimum heating temperature and time for breaking seed dormancy of rice seed variety RD79.

**Methods:** The study was arranged as a factorial experiment in a completely randomized design with 2 factors. The 1st factor was a heating temperature at 52 and 54°C and the 2nd factor was a heating date with 5, 6, 7, 8, 9 and 10 days.

**Result:** The results found that rice seeds heated with different temperatures and times showed significant difference in germination percentage, soil emergence, mean germination time, shoot length, root length, dry weight and accelerated ageing. The correlation showed that the highest correlation coefficients were observed between germination percentage and soil emergence, accelerated ageing and mean germination time and accelerated ageing and soil emergence. The principal component analysis revealed that seeds heated at 54°C for 7, 8 and 9 days dominated in germination percentage, soil emergence and accelerated ageing. Hence, the suitable condition for breaking seed dormancy of RD79 is heating at 54°C for 7 days.

**Key words:** Dry heat treatment, Hybrid rice, *Oryza sativa*, Seed dormancy.

## INTRODUCTION

Rice (*Oryza sativa* L.) is a crucial crop, providing sustenance for approximately half of the world's population. It plays a significant role globally, fulfilling over 21% of human caloric needs and up to 76% of the caloric intake for Southeast Asian populations (Mohidem *et al.,* 2022; Tripathy, 2024). In Asia alone, over 2 billion people rely on rice for 80% of their energy requirements. Nutritionally, rice is composed of 80% carbohydrates, 7-8% protein, 3% fat and 3% fiber (Chaudhari *et al.,* 2018).

Thailand is one of the largest rice producers, with production for the 2021/22 market year reaching 19.5 million metric tons, an increase of 4 per cent from the previous year. This year-to-year production increase is primarily attributed to favorable seasonal rainfall that benefited early planting and development (Foreign Agricultural Service, 2021). Thailand boasts a diverse range of rice varieties, with more than 100 types including upland rice, lowland rice, indigenous rice, hybrid rice and more. RD79 is one of the most popular rice varieties in Thailand, with the potential to be cultivated throughout the country. RD79 is a hybrid variety, developed from a cross between the leaf blight disease-resistant variety PSL00034-37-3-1-3 (maternal) and the leaf blight disease and brown planthopper-resistant variety PSBRc20 (paternal) at the Chai Nat Rice Research Center, Rice Department, Ministry of Agriculture and Cooperatives, Thailand in 2007. After a decade of testing and selection, the variety was certified by the Rice Department on February 21, 2019. The advantages of RD79 include a high average yield (~5,056 kg ha$^{-1}$), resistance to brown plant hopper and blight disease and suitability for irrigated areas (Rice Department, 2024). However, the limitations of RD79 seeds include long-term dormancy and a low germination percentage, leading to uneven germination and delayed or poor seedling establishment.

Seed dormancy is a temporary condition in which mature and viable seeds fail to germinate for a specific period, even under favorable conditions. Dormancy helps prevent losses due to premature germination during harvesting and storage under unfavorable weather conditions (Wang *et al.,* 2024; Wu *et al.,* 2016). In rice, dormancy can result from a thick seed coat or factors within the embryo. The degree of dormancy among different rice varieties varies significantly and is influenced by genetic

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factors, maturity duration and environmental conditions (Mutinda *et al.,* 2017). Dormancy in rice seeds can pose challenges for farmers, as it affects rapid and uniform seed germination and vigor during the early stages of crop growth, thereby reducing productivity (Waheed *et al.,* 2012). Various methods can be employed to break rice seed dormancy, such as dry heat treatment, hot water and high humidity, with the specific method depending on the rice variety (Shiratsuchi *et al.,* 2017). For the rice variety RD79, there has been limited research on identifying the optimal conditions for breaking seed dormancy. Therefore, the objective of this study was to determine the optimum heating temperature and duration for breaking the seed dormancy of the RD79 rice variety.

## MATERIALS AND METHODS

### Experimental details and plant materials

The study was conducted as a factorial experiment in a completely randomized design with two factors. The first factor was the heating temperature, with levels set at 52 and 54°C as a recommended from Phatthalung Rice Seed Center. The second factor was heating duration, with treatments lasting 5, 6, 7, 8, 9 and 10 days continuously. The experiment included four replications, each consisting of 100 seeds. The RD79 rice seeds, harvested during September 2023 from the experimental field at the Phatthalung Rice Seed Center, were used for the study. The conditions for breaking seed dormancy were examined in the laboratory at the Phatthalung Rice Seed Center (7°33′ 58.7″N 100°07′32.6″E) during September to December 2023.

### Data collection and analysis

Data were recorded for germination percentage, soil emergence, mean germination time, germination index, days to emergence, shoot length, root length, dry weight (100 seeds) and accelerated ageing. Germination percentage was estimated as the ratio of the number of seeds germinated to the total number of seeds sown, using the top-of-paper method (Lurstwut and Pornpanomchai, 2016). Soil emergence was calculated from surviving seedlings at 14 days after sowing. Seeds with radicle longer than 1 mm were considered germinated and mean germination time was calculated every 12 h. The germination index was calculated by summing the proportion of emerged seeds and the days to seed count (Hussain *et al.,* 2015; Li *et al.,* 2022). Accelerated ageing was done by placing 100 seeds replicated 4 times in a plastic box, adding 20 littles water and keeping them at a control condition at 100% humidity, 44°C for 72 h. The seeds were then tested for germination (Mishra *et al.,* 2023). The categorization provided by Hanumanthappa *et al.* (2015) was used to determine the degree of dormancy and its duration of existence based on the germination and tetrazolium viability tests. The seeds that exhibited dormancy for up to 14 days were classified as weakly dormant, those that remained dormant for 14-30 days as medium dormant and those that remained dormant for more than 30 days as strongly dormant. The variance of data was estimated using ANOVA. Treatment means were compared using Duncan's New multiple range test, with differences reported at $p<0.05$. All analyses were conducted using the R program (version 4.3.2) with the agricolae package (De Mendiburu, 2023). Correlation analysis and principal component analysis (PCA) were performed to further evaluate associations and their significance among the studied attributes, utilizing the ggbiplot package (Vu *et al.,* 2024).

## RESULTS AND DISCUSSION

### Analysis of variance

The analysis of variance of rice seed parameters different conditions of breaking dormancy is presented in Table 1. Different temperatures showed significant differences ($p<0.01$) for seed germination percentage, soil emergence, mean germination time, root length and accelerated ageing. Heating dates produced significant differences ($p<0.05$ or $p<0.01$) for germination percentage, soil emergence, mean germination time, shoot length, root length, dry weight and accelerated ageing. In addition, there were statistical interactions ($p<0.05$ or $p<0.01$) between heating temperatures and dates for germination percentage, soil emergence, shoot length, root length and dry weight. Soil emergence provided the highest mean square error (40.80), while mean germination time gave the lowest mean square error (0.09).

**Table 1:** Analysis of variance of rice seed parameters different conditions of breaking dormancy.

| Parameters | MS temp (a) | MS time (b) | a × b | MS error |
|---|---|---|---|---|
| Germination percentage | 330.75** | 248.43** | 183.70** | 6.62 |
| Soil emergence | 4,237.50** | 1,317.80** | 512.00** | 40.80 |
| Mean germination time | 1.24** | 0.37** | 0.05 | 0.09 |
| Germination index | 0.09 | 0.17 | 0.11 | 0.12 |
| Days to emergence | 0.29 | 0.11 | 0.17 | 0.14 |
| Shoot length | 0.003 | 0.88** | 0.49* | 0.19 |
| Root length | 5.96** | 0.88* | 3.63** | 0.43 |
| Dry weight | 0.21 | 0.58** | 0.54** | 0.13 |
| Accelerated ageing | 3,136.33** | 470.23** | 12.43 | 37.56 |

*,** Significant differences at $p<0.01$ and 0.05, respectively.

**Table 2:** Mean comparison of rice seed parameters different conditions of breaking dormancy.

| Heating temperatures (°C) | GP (%) | SE (%) | MGT (days) | GI | DTE (days) | SL (cm) | RL (cm) | DW (g) | AA (%) |
|---|---|---|---|---|---|---|---|---|---|
| 52 | 87.83±9.90$^{b}$ | 69.75±20.00$^{b}$ | 3.96±0.30$^{a}$ | 13.33±0.36 | 3.40±0.21 | 7.91±0.64 | 6.29±0.80$^{b}$ | 5.61±0.54 | 57.83±9.31$^{b}$ |
| 54 | 93.08±2.50$^{a}$ | 88.54±7.86$^{a}$ | 3.64±0.38$^{b}$ | 13.42±0.34 | 3.25±0.48 | 7.92±0.44 | 7.00±1.01$^{a}$ | 5.74±0.40 | 74.00±8.78$^{a}$ |
| F-test | ** | ** | ** | ns | ns | ns | ** | ns | ** |
| Heating times (days) | GP (%) | SE (%) | MGT (days) | GI | DTE (days) | SL (cm) | RL (cm) | DW (g) | AA (%) |
| 5 | 80.13±12.56$^{c}$ | 53.63±26.65$^{b}$ | 4.15±0.26$^{a}$ | 13.43±0.28 | 3.47±0.29 | 8.17±0.38$^{a}$ | 6.99±0.61$^{a}$ | 5.62±0.27$^{ab}$ | 54.88±10.37$^{d}$ |
| 6 | 88.00±5.01$^{b}$ | 84.63±10.50$^{a}$ | 3.90±0.43$^{ab}$ | 13.51±0.31 | 3.25±0.27 | 8.24±0.46$^{a}$ | 6.85±1.47$^{ab}$ | 5.97±0.34$^{a}$ | 59.50±10.64$^{cd}$ |
| 7 | 92.63±3.54$^{a}$ | 82.00±7.65$^{a}$ | 3.84±0.33$^{ab}$ | 13.21±0.33 | 3.28±0.16 | 8.09±0.40$^{a}$ | 6.94±1.31$^{a}$ | 5.62±0.27$^{ab}$ | 64.88±10.68$^{cd}$ |
| 8 | 93.75±2.25$^{a}$ | 85.50±8.30$^{a}$ | 3.76±0.42$^{ab}$ | 13.52±0.43 | 3.25±0.15 | 7.67±0.37$^{ab}$ | 6.48±0.84$^{ab}$ | 5.30±0.24$^{b}$ | 69.63±9.72$^{ab}$ |
| 9 | 94.25±2.55$^{a}$ | 88.75±7.42$^{a}$ | 3.59±0.19$^{b}$ | 13.40±0.47 | 3.48±0.79 | 7.38±0.71$^{b}$ | 6.44±0.71$^{ab}$ | 5.53±0.70$^{ab}$ | 71.50±9.80$^{ab}$ |
| 10 | 94.00±2.33$^{a}$ | 80.38±13.33$^{a}$ | 3.57±0.35$^{b}$ | 13.19±0.17 | 3.24±0.21 | 7.94±0.42$^{ab}$ | 6.16±0.41$^{b}$ | 6.01±0.53$^{a}$ | 75.13±11.17$^{a}$ |
| F-test | ** | ** | ** | ns | ns | ** | * | ** | ** |
| CV (%) | 2.84 | 8.07 | 8.08 | 2.60 | 11.17 | 5.52 | 9.83 | 6.41 | 9.30 |

ns not significant, *,** Significant differences at $p$<0.01 and 0.05, respectively. GP: Germination percentage, SE: Soil emergence, MGT: Mean germination time, GI: Germination index, DTE: Days to emergence, SL: Shoot length, RL: Root length, DW: Dry weight, AA: Accelerated ageing.

### Germination percentage

The germination percentage of rice seeds heated at 54°C (93.08%) was much greater than that of rice seeds heated at 52°C (87.83%). The maximum germination percentage (92.63-94.25%) was observed in rice seeds heated for 7-10 days. The rice seed heated at 52°C for 9 days had the highest germination percentage (96.25%) when temperature and time were combined. However, there was no significant difference between rice seed heated at 52°C for 8 and 10 days (93.00 and 94.75%) and at 54°C for 5-10 days (91.50-95.00%). Rice seeds heated for five days at 52°C produced the lowest germination percentage (68.75%) (Table 2, Fig 1).

### Soil emergence

The soil emergence of rice seeds heated at 54°C (88.54%) was much higher than that of seeds heated at 52°C (69.75%). Higher soil emergence was observed in rice seeds heated for 6-10 days (80.38-88.75%) compared to those heated for 5 days (53.63%). The greatest soil emergence was produced by rice seeds heated at 54°C for 6, 9 and 10 days (92.25-93.50%) when heating temperature and time were combined. However, soil emergence was not significantly different from that of rice seeds treated at 52°C for 8 and 9 days (83.25, 84.25%) and at 54°C for 7 and 8 days (86.75, 87.75%). Rice seeds heated for 5 days at 52°C had the lowest soil emergence (29.50%) (Table 2, Fig 2).

### Mean germination time

The mean germination time for rice seeds heated at 54°C (3.64 days) was significantly lower than that of seeds heated at 52°C (3.96 days). The rice seeds with the shortest mean germination time were those that were heated for 9 and 10 days (3.59 and 3.57 days). The shortest mean germination time was obtained by heating rice seeds at 54°C for 10 days (3.36 days) in combination. However, there was no significant difference between heating rice seeds at 52°C for 7-10 days (3.79-4.01 days) and 54°C for 5-9 days (3.54-4.00 days). Rice seeds heated for five days at 52°C produced the longest mean germination time (4.29 days) (Table 2, Fig 3).

### Germination index

The germination index of rice seeds heated at various temperatures and periods did not show any significant differences. The highest germination index was achieved from rice seeds heated at 54°C for 8 days (13.72) when temperature and time were combined, while the lowest germination index was obtained from rice seeds heated at 52°C for 7 days (13.11) (Table 2, Fig 4).

### Days to emergence

The days to emergence of rice seeds heated at various temperatures and times did not show significant differences. The shortest days to emergence was achieved by heating rice seeds at 54°C for 6 days (3.04 days) when the heating temperature and time were combined and the longest days

to emergence was obtained from rice seeds heated at 54°C for 9 days (3.68 days) (Table 2, Fig 5).

### Shoot length

The shoot length of rice seeds heated to various temperatures did not alter appreciably. The longest shoot was created by heating rice seeds for 5-7 days (8.09-8.24 cm). Rice seeds heated at 52°C for 5-7 days (8.20-8.39 cm) and at 54°C for 5-6 and 10 days (8.02-8.28 cm) provided the longest shoots when combined with heating temperature and duration. After being heated to 52°C for 9 days, rice seeds produced the shortest shoot (6.94 cm) (Table 2, Fig 6).

### Root length

Significantly longer roots were formed by rice seeds heated at 54°C (7.00 cm) as opposed to 52°C (6.29 cm).

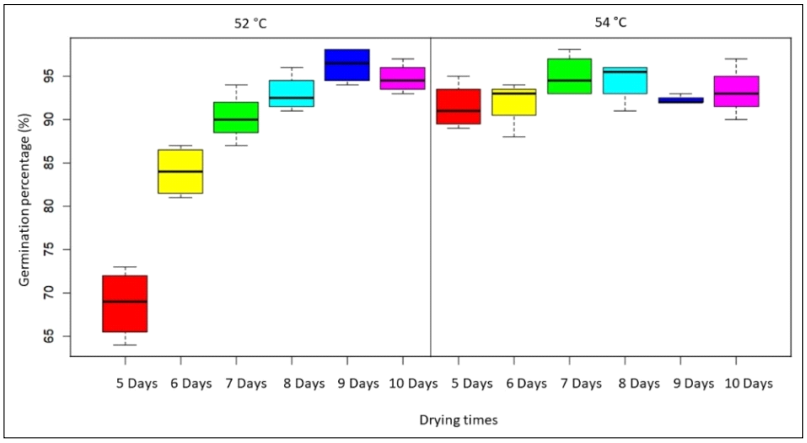



**Fig 1:** Boxplot of germination percentage under different conditions of breaking dormancy.

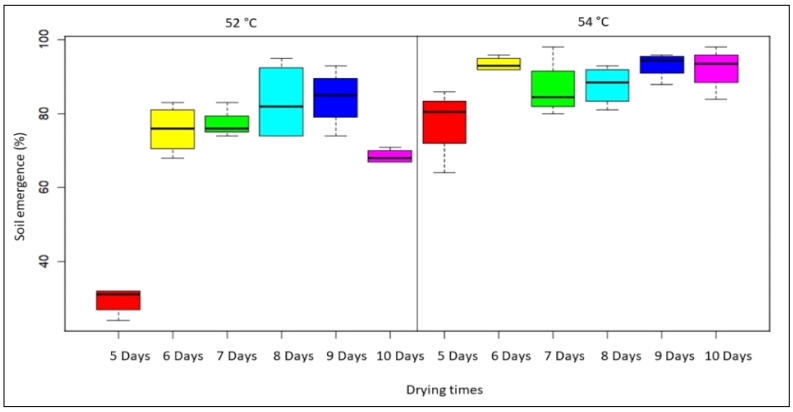



**Fig 2:** Boxplot of soil emergence under different conditions of breaking dormancy.

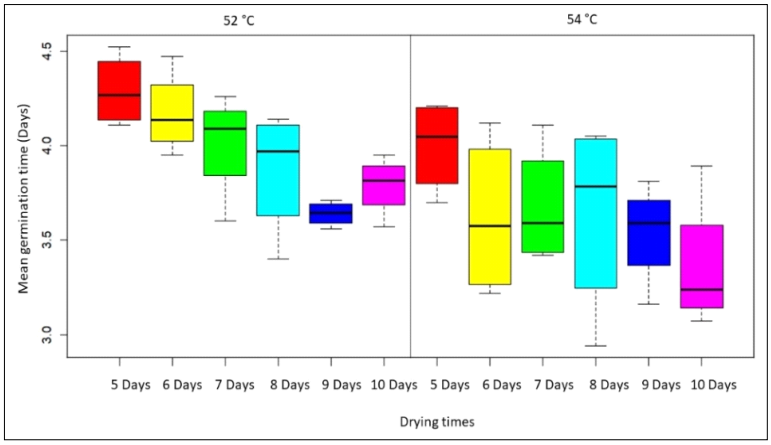



**Fig 3:** Boxplot of mean germination time under different conditions of breaking dormancy.

The longest root (6.99 and 6.94 cm) was created by heating rice seeds for 5 and 7 days. The longest root was created by heating rice seeds at 54°C for 7 and 8 days (8.14 and 7.97 cm), whereas the shortest root was produced by heating rice seeds at 52°C for 7 days (5.57 cm), when temperature and time were combined well (Table 2, Fig 7).

**Dry weight**

The dry weight of rice seeds heated at various temperatures did not differ significantly. The maximum dry weight was obtained from rice seeds heated for 6 and 10 days (5.97 and 6.01 g). The highest dry weight was created by rice seeds heated at 54°C for 10 days (6.39 g) when heating

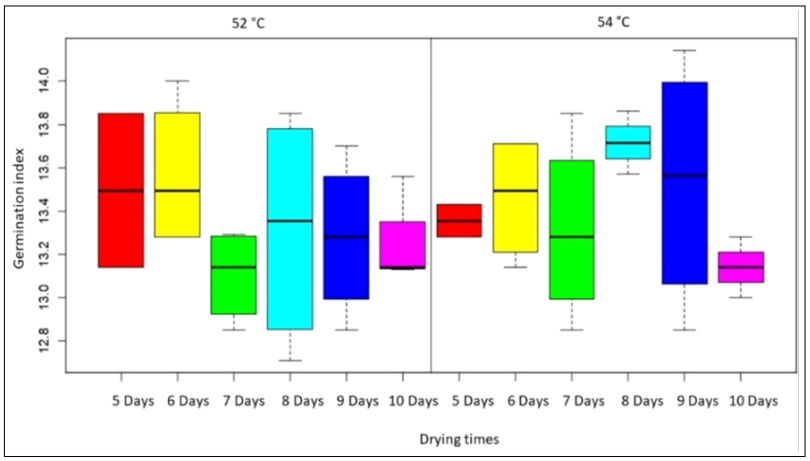



**Fig 4:** Boxplot of germination index under different conditions of breaking dormancy.

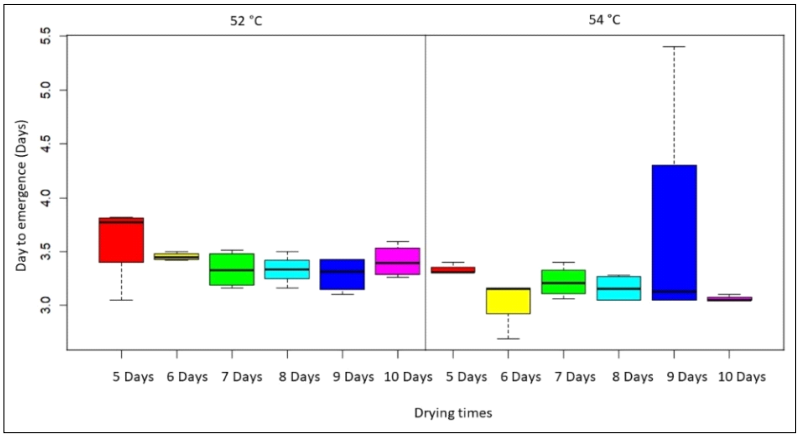



**Fig 5:** Boxplot of days to emergence under different conditions of breaking dormancy.

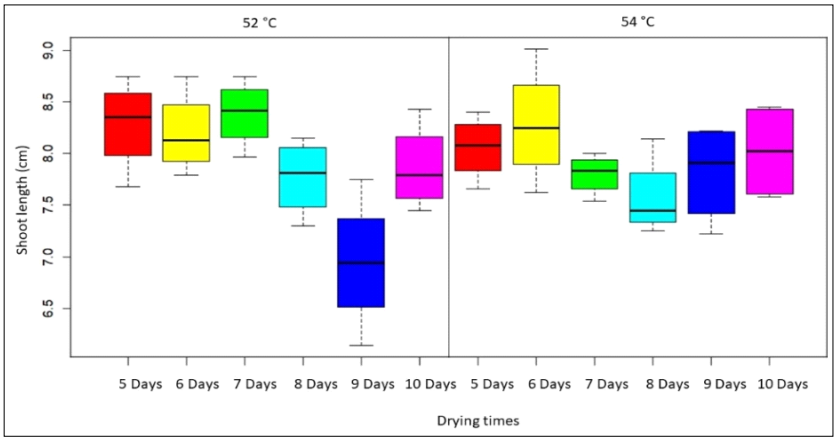



**Fig 6:** Boxplot of shoot length under different conditions of breaking dormancy.

temperature and time were combined; the lowest dry weight was produced by rice seeds heated at 52°C for 8 and 9 days (5.21 and 5.24) and at 54°C for 7 and 8 days (5.40 and 5.41) (Table 2, Fig 8).

**Accelerated ageing**

Significantly more rapid ageing was seen in rice seed heated at 54°C (74.00%) compared to 52°C (57.83%). The most amount of accelerated ageing was seen in rice seed heated for 10 days (75.13%). The rice seeds that were heated at 54°C for 10 days (84.75%) exhibited the highest rate of accelerated ageing when considering the combination of heating temperature and duration, whereas the rice seeds that were heated at 52°C for 5 days showed the lowest (Table 2, Fig 9).

**Correlation and principal component analysis**

Correlation results, based on Pearson's correlation coefficient, are illustrated in Fig 10. The highest correlation coefficients were observed between germination percentage and soil emergence (0.79***), accelerated ageing and mean germination time (-0.62***) and accelerated ageing and soil emergence (0.57***). Additionally, germination percentage was positively correlated with accelerated ageing (0.47***) and negatively correlated with shoot length (-0.31*). Principal component analysis (PCA) of observed parameters under different dormancy-breaking conditions is illustrated in Fig 11. The first three principal components accounted for 32.9%, 17.5% and 12.8% of the total variance, respectively. In the biplots of PC1 vs. PC2 and PC1 vs. PC3, the largest group consisted of rice seeds heated at 54°C for 9 and 10 days, while the smallest group consisted of rice seeds heated at 52°C for 5 days. Rice seeds heated at 52°C for 5 days were predominant in mean germination time and days to emergence. Seeds heated at 52°C for 8 days dominated in germination index and root length, while those heated at 52°C for 4 days dominated in shoot length. Seeds heated at 54°C for 7, 8 and 9 days dominated in germination percentage, soil emergence and accelerated ageing.

The results of this study revealed that heating rice seeds at 54°C was effective for breaking seed dormancy in RD79 rice varieties, as it produced higher germination

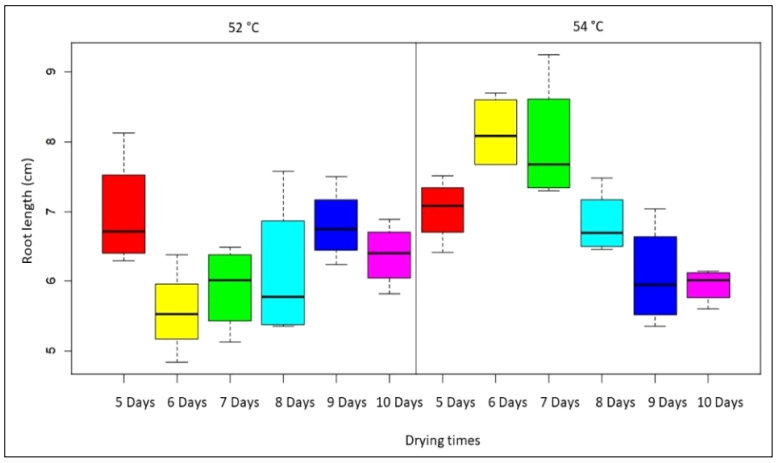



**Fig 7:** Boxplot of root length under different conditions of breaking dormancy.

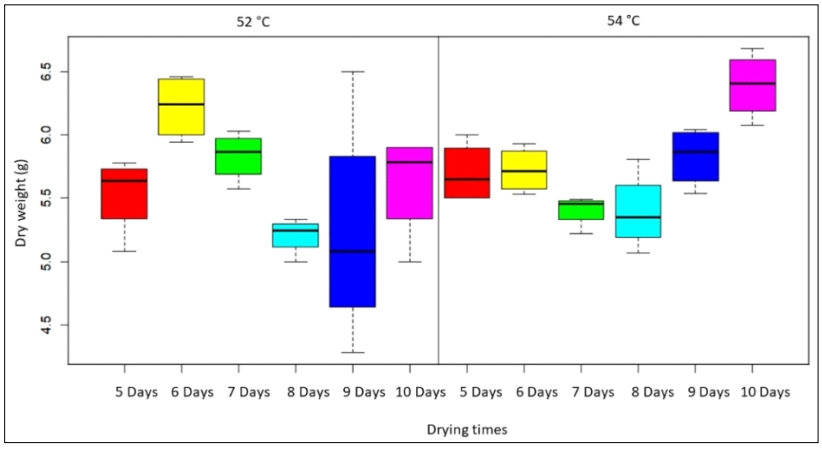



**Fig 8:** Boxplot of dry weight under different conditions of breaking dormancy.

percentages, soil emergence rates, root lengths and accelerated ageing results compared to heating at 52°C. Additionally, heating rice seeds for 7 to 8 days was found to be optimal for RD79 rice, yielding the highest germination percentages, soil emergence rates, shoot lengths, root lengths, dry weights and the lowest mean germination times. Therefore, heating at 54°C for 7 days is recommended for breaking the dormancy of RD79 rice seeds. Dry heat treatment with various temperatures and durations is generally recommended for breaking seed dormancy. Heat treatment reduces the moisture gradient within the grain, thereby decreasing the likelihood of fissures or breaks during the active drying phase and improving the drying rate (*i.e.*, the amount of water removed per unit of drying time). The air temperature during drying significantly affects seed quality in terms of germination. Combining drying methods with tempering stages (2 or 4 h at 65°C) helps to mitigate stress cracks and damage from prolonged exposure to excessive heat (Bawar *et al.,* 2023).

Previous studies have reported that suitable drying conditions depend on rice varieties. Yousof and Ibrahim (2013) investigated the optimal drying conditions for several rice cultivars (Sakha 104, Sakha 103 and Giza 178) in Egypt. They found that drying at 60°C for 2 days produced the highest mean germination percentage and seedling vigor for all cultivars studied. Additionally, this treatment reduced fungal infections from *Alternaria padwickii*, *Alternaria tenuis*, *Bipolaris oryzae* and eliminated *Fusarium moniliforme*, *Fusarium semitectum*, *Helminthosporium* sp., *Rhizoctonia solani*, *Sarocladium oryzae* and *Stemphylium botryosum*. Shiratsuchi *et al.* (2017) determined the appropriate steam treatment conditions (temperatures of

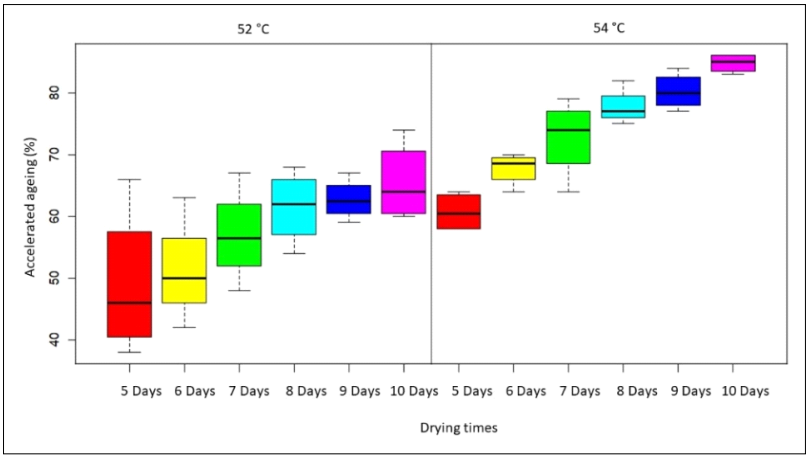
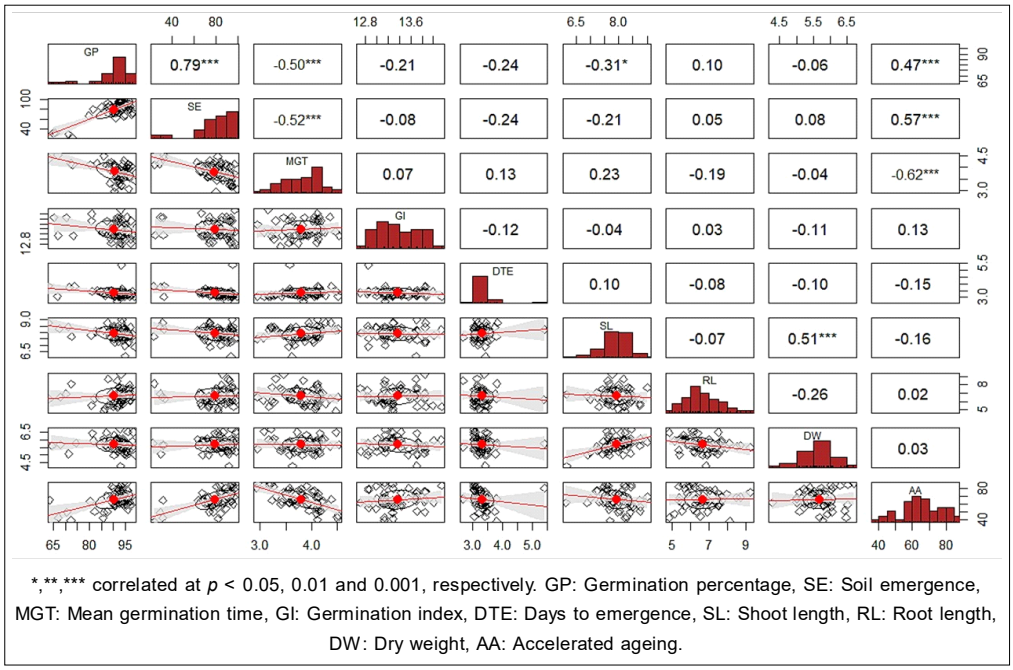
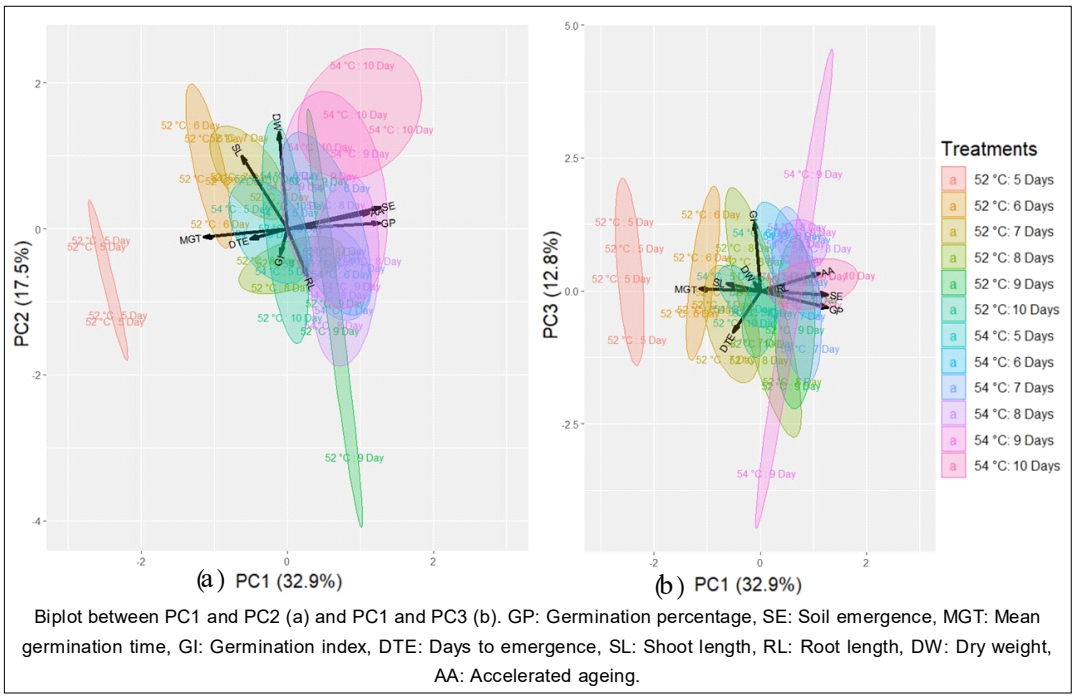



**Fig 9:** Boxplot of accelerated ageing under different conditions of breaking dormancy.




*,**,*** correlated at $p < 0.05$, 0.01 and 0.001, respectively. GP: Germination percentage, SE: Soil emergence, MGT: Mean germination time, GI: Germination index, DTE: Days to emergence, SL: Shoot length, RL: Root length, DW: Dry weight, AA: Accelerated ageing.

**Fig 10:** Correlation plot according to Pearson's correlation coefficient.




Biplot between PC1 and PC2 (a) and PC1 and PC3 (b). GP: Germination percentage, SE: Soil emergence, MGT: Mean germination time, GI: Germination index, DTE: Days to emergence, SL: Shoot length, RL: Root length, DW: Dry weight, AA: Accelerated ageing.

**Fig 11:** Principal component analysis of observed parameters under different conditions of breaking dormancy.

24, 28, 32, 36 and 40°C) to break the dormancy of Japanese rice cultivars using a steam nursery cabinet. Their results indicated that maintaining a temperature of 40°C for 7 days increased germination percentages and reduced the time for 50% germination in highly dormant rice cultivars (Takanari). Similarly, a temperature of 40°C for 5 days reduced the 50% germination time for medium dormant cultivars (Moeminori and Hitomebore). Adebisi *et al.* (2008) evaluated the extent of varietal differences in seed quality of 20 West African rice cultivars under different temperatures (50 and 55°C) and durations (0, 12, 24 and 36 h). They reported that higher temperatures (55°C) with prolonged heating periods (24 and 36 h) reduced seed quality characteristics. The optimal condition for African rice seeds was found to be 50°C for 12 h, which maintained seed germination, energy of seed germination, seedling emergence and increased seedling vigor.

Dormancy in rice seeds is imposed by certain physical and chemical factors associated with its covering structures, such as the hull and pericarp. The exact nature of these germination barriers, their mode of action and the processes regulating the release of dormancy are not fully understood (Seshu and Dadlani, 1991). To improve the effectiveness of methods for breaking seed dormancy, high temperature drying can be combined with additional treatments, such as chemical solutions or growth regulators (Yuningsih and Wahyuni, 2015).

## CONCLUSION

In order to break the seed dormancy of the RD79 rice varieties, seeds heated to 54°C produced higher germination percentages, soil emergence, longer roots and faster ageing than seeds heated to 52°C. The RD79 rice seed demonstrated the best germination percentage, soil emergence, shoot length, root length, dry weight and lowest mean germination time, making it an excellent applicant for heating for seven or eight days. As a result, heating rice seed RD79 to 54°C for seven days is advised in order to break its dormancy. High temperature drying can be supplemented with other treatments, such as extra chemical solution treatment or the use of growth regulators, for further study.

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### Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript

## REFERENCES

Adebisi, M.A., Adeniyi, T.A., Ajala, M.O. and Kintobi, D.C. (2008). Varietal differences in seed physiological quality of West African rice varieties after dry heat treatment. *Nigeria Agricultural Journal.* **39(2):** 159-169.

Bawar, R.A., Foliente, J.P., Yaptenco, K.F. and Cabiles, M.A.L. (2023). Effects of drying temperature and tempering duration on hybrid rice seed germination, thin-layer drying characteristics and power requirement. *Philippine Agricultural Scientist.* **106(1):** 47-54.

Chaudhari, P.R., Tamrakar, N., Singh, L., Tandon, A. and Sharma, D. (2018). Rice nutritional and medicinal properties: A review article. *Journal of Pharmacognosy and Phytochemistry*. **7(2):** 150-156.

De Mendiburu, F. (2023). Agricolae: Statistical Procedures for Agricultural Research. https://cran.r-project.org/web/packages/agricolae/index.html.

Foreign Agricultural Service. (2021). Thailand Rice: Recent Dry Conditions After a Promising Start; Optimism Still Remains for this Crop Season. https://ipad.fas.usda.gov/.

Hanumanthappa, D., Vasudevan, S.N., Ibrahim, M., Shakuntala, N.M., Amaregouda, A., Doddagoudar, S.R. (2015). Studies on seed dormancy in paddy genotypes. *The Ecoscan.* **9(1):** 261-263.

Hussain, S., Zheng, M., Khan, F., Khaliq, A., Fahad, S., Peng, S., Huang, J., Cui, K. and Nie, L. (2015). Benefits of rice seed priming are offset permanently by prolonged storage and the storage conditions. *Scientific Reports*. **5:** 8101. doi: 10.1038/srep08101.

Li, H., Li, X., Wang, G., Zhang, J. and Wang, G. (2022). Analysis of gene expression in early seed germination of rice: Landscape and genetic regulation. *BMC Plant Biology*. **22:** 70. doi: 10.1186/s12870-022-03458-3.

Lurstwut, B., Pornpanomchai, C. (2016). Rice seed germination analysis. *International Journal of Computer Applications in Technology*. **5(4):** 176-182. doi: 10.7753/IJCATR0504.1001.

Mishra, N.S., Kumari, N., Mishra, N.N., Mishra, K. (2023). Estimation of hormonal seed treatments on enzyme activities after accelerated ageing (*artificial ageing*) in chickpea (*Cicer arietinum* L.). *Legume Research*. **46(4):** 421-427. doi: 10.s18805/LR-4796.

Mohidem, N.A., Hashim, N., Shamsudin, R. and Che, M.H. (2022). Rice for food security: Revisiting its production, diversity, rice milling process and nutrient content. *Agriculture*. **12(6):** 741. doi: 10.3390/agriculture12060741.

Mutinda, Y.A., Muthomi, J.W., Kimani, J.M., Chemining'wa, G.N. and Olubayo, F.M. (2017). Viability and dormancy of rice seeds after storage and pre-treatment with dry heat and chemical agents. *The Journal of Agricultural Science*. **9:** 175-185. doi: 10.5539/jas.v9n7p175.

Rice Department. (2024). Rice Knowledge Bank. https://newwebs2.ricethailand.go.th/webmain/rkb3/title-index.php-file=content.phpandid=145.htm.

Seshu, D.V. and Dadlani, M. (1991). Mechanism of seed dormancy in rice. *Seed Science Research*. **1(3):** 187-194. doi: 10.1017/S0960258500000854.

Shiratsuchi, H., Ohdaira, Y., Yamaguchi, H. and Fukuda, A. (2017). Breaking the dormancy of rice seeds with various dormancy levels using steam and high temperature treatments in a steam nursery cabinet. *Plant Production Science*. **20(2):** 183-192. doi: 10.1080/1343943X.2017.1289067.

Tripathy, S.T. (2024). Phenotyping and association analysis of grain zinc and iron content with seed yield in diverse local germplasm of rice. *Indian Journal of Agricultural Research*. **58(6):** 1152-1157. doi: 10.18805/IJARe.A-5843.

Vu, V.Q., Friendly, M. and Tavadyan, A. (2024). Package 'ggbiplot': A grammar of graphics implementation of biplots. https://github.com/friendly/ggbiplot.

Waheed, A., Ahmad, H. and Abbasi, M.F. (2012). Different treatment of rice seed dormancy breaking, germination of both wild species and cultivated varieties (*Oryza sativa* L.). *Journal of Materials and Environmental Science*. **3(3):** 551-560.

Wang, S., Shi, F., Shi, R., Zhang, Y. (2024). Seed dormancy and germination in alfalfa (*Medicago falcata* L.). *Legume Research*. **47(2):** 234-241. doi: 10.18805/LRF-758.

Wu, T., Yang, C., Ding, B., Feng, Z., Wang, Q., He, J., Tong, J., Xiao, L., Jiang, L. and Wan, J. (2016). Microarray-based gene expression analysis of strong seed dormancy in rice cv. N22 and less dormant mutant derivatives. *Plant Physiology and Biochemistry*. **99:** 27-38. doi: 10.1016/j.plaphy. 2015.12.001.

Yousof, F.I. and Ibrahim, E.A.M. (2013). Effect of dry heat treatment on seed vigor and health of some rice cultivars. *Journal of Plant Protection and Pathology*. **4(12):** 1075-1088. doi: 10.21608/JPPP.2013.87682

Yuningsih, A.F.V. and Wahyuni, S. (2015). Effective methods for dormancy breaking of 15 new-improved rice varieties to enhance the validity of germination test. International Seminar on Promoting Local Resources for Food and Health, 12-13 October 2015, Bengkulu, Indonesia.