Effects of Drying Temperature and Tempering Duration on Hybrid Rice Seed Germination, Thin-Layer Drying Characteristics, and Power Requirement

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This study presents the results of thin-layer drying tests for hybrid rice seeds. The independent factors were drying air temperature (45, 55, and 65 °C) and tempering duration (1, 2, and 4 h), while the dependent parameters were seed germination and drying characteristics, including drying rate, total and effective drying operation times, and power requirement. Considering one hybrid and 3 mo storage period after drying, the results showed that samples continuously dried at 45 and 55°C resulted in 91 and 86% germination percentages, respectively, which were above the acceptable Philippine national standard of at least 85%. However, when tempered for 2 or 4 h, even samples dried at 65°C resulted in more than 90% germination percentage. Tempered samples had an effective operation time of only 1 - 3 h, which was 50% less than those continuously dried (1.5 - 6 h of effective operation time). In effect, the total power used was halved by applying tempering. These results showed considerable advantages of tempering in terms of seed quality improvement and potential energy savings.

Keywords: hybrid rice seed, tempering, seed viability, germination, drying rate

INTRODUCTION

Philippine rice production for 2018 stood at 19.07 MMT, slightly lower (approximately 1.1%) than the 2017 output (PSA 2019). Hybrid rice has increased in popularity as it can outyield other cultivated non-hybrid rice varieties through enhanced nutrient uptake and absorption, weed competition, and pest and disease resistance (Barclay 2007). Therefore, hybrid seeds are recommended for farmers seeking to increase their income (Litonjua et al. 2017).

A typical concern on high moisture content of the harvested rice, especially during the wet season, is the deterioration of the rice quality (Mujumdar 2014). To address this concern and to reduce moisture to a targeted value, immediate rice drying must be done to preserve the rice quality.

According to Sharma et al. (1992), rough rice should be dried to 10.7 - 11.5% moisture content for storage since grains break faster at a higher moisture content. It was also found that the highest percentage of un fissured rice was obtained at lower moisture content levels. The flatbed dryer, a layer-type static bed, is a commonly employed piece of equipment for rice drying in the Philippines since it requires less drying time than conventional solar drying. It is also more flexible in terms of drying capacity and is independent of the weather. The accepted basis for developing a commercial deep-bed drying protocol is thin-layer drying. In general, the drying of grains is done in a deep-bed or thick layer. However, thin-layer drying experiments may also be done at the laboratory to provide information on the parameters that influence the drying rate to allow simulations that predict the thick-layer drying process (Franco et al. 2020).

In contrast to uninterrupted exposure to the heated air in continuous drying, intermittent drying has tempering periods between its drying cycles. Tempering controls the
rate of drying by restricting the supply of thermal energy (Kumar et al. 2014). The tempering stages then reduce the moisture gradient within the grain (Cihan et al. 2007), reducing the likelihood of fissures/breaks during the active drying phase (Aquerreta et al. 2007) and improving the drying rate (or the amount of water removed per unit of drying time) (Franco et al. 2020).

The air temperature during drying has been reported to significantly affect seed quality in terms of germination (Hasan et al. 2014). Drying methods were combined with tempering stages to lessen stress cracks and damage from exposure to too much heat for long periods of time (Wang et al. 2017).

Seed quality pertains to multiple considerations, such as physical, chemical, and biological factors. However, the seed’s viability or ability to germinate is the most useful and commonly used indicator of seed quality (Padhi et al. 2017). Seed germination is the process by which a seed embryo develops into a seedling (Bewley 1997, as cited by Tuan et al. 2019). Germination percentage of viable seeds is indicated by the development of all the essential structures of a seedling such as a healthy shoot and root after 7 d of evaluation (Schmidt 2000).

The literature on drying temperature and tempering effects on the quality of hybrid rice seeds is limited, especially for varieties produced in the Philippines. This study aims to determine the effect of drying air temperature and tempering duration on the seed quality of hybrid rice seeds, particularly on their germination percentages. Drying rates, total drying operation times, and effective drying operation time were also determined to check their effects on the total power requirement.

MATERIALS AND METHODS

Preparation of Hybrid Rice Seeds

Freshly harvested rice seeds from one hybrid variety were collected from Laguna, Philippines. Before drying, seeds were cleaned using a RAPSCO Bates aspirator and 2.38 mm and 12.50 mm sized sieves to remove any impurities, insects, or empty/broken grains. The bulk density of the hybrid rice grains was also determined using a laboratory bulk density tester. The measured bulk density of samples was used in the computation of the mass of seeds to be used per test cell with dimensions of 15.24 × 15.24 cm and layer thickness of 1.0 cm. The samples’ initial moisture content (wet basis) was determined using a moisture content analyzer (MOC63u Shimadzu UniBloc Moisture Analyzer). For each drying run, a 2 g sample of seeds was placed inside the moisture content analyzer to dry at 120°C for 100 min or until the reading stabilized. The obtained initial moisture content was then used to compute the succeeding moisture content values for each drying time.

Drying Experiments

Three temperature and relative humidity data loggers (TinyTag Plus 2 [TGP-4500] Temperature & Relative Humidity Logger) were placed on the drying and storage areas to monitor the change in ambient conditions of the surrounding environment throughout each replication.

The fresh hybrid samples were uniformly spread on the square test cells with an approximate thickness of 1.0 cm (Chen and Wu 2001). The thin-layer drying experiments were conducted at 45, 55, and 65 °C with a constant air velocity of 0.5 m/s. The air temperature of the flatbed heated air dryer was controlled using a temperature control device (MC700 Sinotimer). Type-K thermocouple wires were placed below the drying cells then connected to the temperature logger program to record the temperature change. Fig. 1 shows the schematic diagram of the convective flatbed dryer used in the experiment.

For continuous drying (without tempering), the samples were weighed using an electronic balance (Shimadzu BL-2200H) at 15 min intervals for the first hour, at 30 min intervals for the second hour, and finally at 1 h intervals for the remaining duration—until the seeds reached 11% moisture content.

For samples with tempering, seeds were placed on another forced-air dryer of similar specifications for 30 min and weighed every 15 min before being sealed.
inside a polyethylene bag and left at ambient conditions for either 30 min, 1.5, or 3.5 h for the 1, 2, and 4 h of tempering time, respectively. After completing the tempering period, the hybrid rice seeds were reweighed before being returned to the dryer for 15 min of drying. This procedure was repeated until the seed moisture content reached 11%. The experimental drying setup is presented in Fig. 2.

Following drying, the samples were placed inside a polyethylene bags which were sealed using a manual impulse sealer. These were then subjected to further analysis after 3 mo of storage to determine their germination percentage. The details of the drying and tempering experiments are schematically shown in Fig. 3.

Germination Test

After approximately 3 mo of storage at ambient temperature, the dried hybrid rice seeds were tested for germination percentage. Four replicates were used for the germination test, with 100 seeds used per replicate.

The ragdoll or the rolled paper towel method was used to determine the germination percentage of the dried hybrid rice seeds. In this method, a germination paper moistened with water was spread. Seeds were placed at equal distances, and a plastic sheet was placed over the seeds. The lower 5 cm of the paper towel was turned over and rolled up before being placed in a standing position and incubated for 7 d at 25°C at 95 - 98% relative humidity.

The grown seedlings were counted as normal, abnormal, and dead seeds. Normal seeds are those that develop all the essential structures of a seedling (healthy shoot and root). Abnormal seeds are those that have germinated but lack essential structures such as cotyledon, have weak roots, or those that are infected by seed-borne pathogens (Schmidt 2000). Dead seeds did not germinate at all.

Germination percentage of normal seeds or observed grown seedlings were counted by the seventh day.

Statistical Analysis

Three replicates of the drying process were performed for each drying air temperature (45, 55, and 65 °C) to properly determine the effects of varying drying air temperatures and tempering periods. Using the programming language R (R Core Team), analysis of variance (ANOVA) two-factor with replication and t-test (95% level of significance) were done to determine whether there was a significant difference in the treatments. The black lines overlaid on each bar graph were used to indicate the percentage standard deviation of the data.

RESULTS AND DISCUSSION

After drying, the rice samples were cooled down and sealed in packs for ambient storage. Results of germination tests after 3 mo of storage, with four replicates, are shown in Fig. 4. Germination is the simple emergence of the radicle resulting in seed coat rupture and emergence of the young plant (Kozlowski and Pallardy 1997).

Fig. 2. Convective flatbed dryer used in the experiment showing the blower (a), temperature controller (b), and drying cells (c).

Germination percentage of normal seeds or observed grown seedlings were counted by the seventh day.

Fig. 3. Experimental details for tempering during the drying process.
Seeds continuously dried under lower temperatures and stored for around 3 mo exhibited higher germination percentages. The germination percentages of hybrid seed samples dried continuously at 45 and 55 °C were close to the national standard of the Philippines, which is 85% (Department of Agriculture 2010), averaging at 91 and 86%, respectively. A study on hybrid rice seeds from Bangladesh reported differently, noting the exponential decrease of the germination percentages for seeds dried above 40°C (Hasan et al. 2014), but results of this research showed that only seeds treated at 65°C showed a much lower germination percentage at an average of 74%.

A one-way ANOVA showed that continuous drying temperature significantly affects the germination percentage (p-value of 1.12E-06). Table 1 confirms that germination results of samples continuously dried at 45, 55, and 65 °C were statistically different from each other. A similar study on batch-dried paddy seeds from Turkey reported relatively high germination percentages at drying temperatures of 50, 60, and 70°C at 96, 90, and 87.3 %, respectively (Erdoğan and Işik 2017). The difference in the seeds’ viability or ability to germinate may be accounted for by several factors such as predator and pathogen damage, environmental conditions, age of the seed, and genetics (Shaban 2013).

Tempering has been proven to be efficient in drying agricultural produce; however, many agricultural processing industries still choose not to perform it because of the high drying temperature and extended operation time, which result in products with low essential nutrients, tougher textures, and hard surfaces due to case hardening (Pham et al. 2017). Though continuous drying at 65°C resulted in very low germination percentage, introducing tempering may increase germination even at this high temperature.

Fig. 5 illustrates that from 74% when continuously dried, samples tempered for 2 and 4 h have yielded acceptable germination percentages of 90 and 93 %, respectively.

A t-test was performed to compare the effect of different tempering durations on germination. Table 2 shows no significant differences between samples that were tempered. However, samples that were continuously dried significantly varied from those that were tempered. The average germination percentage of tempered samples was 87%.

Improved seed vigor of Japonica and Indica rice seeds was reported when dried at 50°C with tempering of 5 min per drying cycle. This was because of lower exposure time and less thermal damage to seeds when tempering was applied. Increased germination was also attributed to the breakage of seed dormancy with proper thermal treatment (Wang et al. 2017).

In addition to higher germination, tempering will also result in improved drying rates and, consequently, power savings. To assess drying behavior more clearly, the drying rate or the change in moisture per unit time

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![Table 1. T-test for germination percentages as affected by the drying rate.](https://pas.cafs.uplb.edu.ph)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°C vs. 55°C</td>
<td>0.0077</td>
</tr>
<tr>
<td>45°C vs. 65°C</td>
<td>0.0007</td>
</tr>
<tr>
<td>55°C vs. 65°C</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

![Table 2. T-test for germination percentages as affected by tempering treatments.](https://pas.cafs.uplb.edu.ph)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 h tempering vs. 1 h tempering</td>
<td>0.3776</td>
</tr>
<tr>
<td>4 h tempering vs. 1 h tempering</td>
<td>0.4285</td>
</tr>
<tr>
<td>4 h tempering vs. 2 h tempering</td>
<td>0.9997</td>
</tr>
<tr>
<td>Continuous vs. 1 h tempering</td>
<td>0.0296</td>
</tr>
<tr>
<td>Continuous vs. 2 h tempering</td>
<td>0.0000</td>
</tr>
<tr>
<td>Continuous vs. 4 h tempering</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

![Fig. 4. Germination percentages of hybrid rice seeds continuously dried at 45, 55, and 65 °C.](https://pas.cafs.uplb.edu.ph)

![Fig. 5. Germination percentages of hybrid rice seeds at 65°C, tempered for 1, 2, and 4 h.](https://pas.cafs.uplb.edu.ph)
It should be noted that the significant kinks in the plots are due to tempering. Tempering lessens the moisture gradients inside the grain by allowing the moisture to transfer to the surface from the center of the grain. This results in a uniform moisture distribution within the grain and a higher moisture content at the grain surface, improving the drying rate in the subsequent drying stage (Golmohammadi et al. 2010).

Total operation time consisted of the in-dryer time (effective operation time) plus the tempering time. Under the same drying temperature, continuous drying shows less total operation time than tempering since the latter would require setting aside the sample for some time to cool down. Samples with tempering took a total of 2 - 22 operation hours. However, the actual time the samples were exposed to heated air (i.e. effective operation time) was lower for treatments with tempering periods (Fig. 7). These results were in accordance with earlier literature that the tempering process effectively increased the drying rate. As observed in rough rice, tempering permitted moisture to diffuse to the surface and allowed moisture concentration within the seed to equalize, affecting the next drying cycle to have a lesser moisture gradient (Cihan et al. 2007).

Tempered samples had an average effective operation time of only 1.47 h, 67% less than continuously dried ones, which took 4.58 h of average effective operation time. Similar results were observed with Brazilian rough rice cultivars that were dried and tempered, wherein reduced effective operating time and accelerated drying process were observed with combined high temperature (50 - 70°C) and one pause for tempering for 120 min (Pereira et al. 2020).

Since the time for energy input or when the dryer is turned on is lower when tempering is applied, the actual power requirement also decreases (Fig. 8). Considering the dryer’s current of 2.4 amp and voltage of 215.6 V and multiplying it with the effective operation time, the power supply of samples dried continuously at 5.17 kWh was reduced to 0.99 kWh when 4 h tempering was applied. On average, tempered samples had 50% less actual power requirement compared with continuously dried samples. Less active drying time will reduce the energy cost of the overall operation through tempering. An improvement of 1% in energy efficiency can result in up to a 10% increase in profit in an industry that uses an intense drying process (Franco et al. 2020).

The variation in the drying rate for each run of continuous drying was used to compute the drying
Drying models may be used for future research and simulations of scaled-up dryers for hybrid rice seeds.

**CONCLUSION**

In this study, thin-layer drying tests were conducted for hybrid rice seeds with varying drying air temperature levels of 45, 55, and 65 °C and tempering treatments of 1, 2, and 4 h. Drying temperature significantly affected germination, with samples continuously dried at 65°C resulting to 74% germination percentage. Statistical analysis showed that continuously dried significantly varied from those that were tempered. The average germination percentage of tempered samples was 87%. Samples dried at 65°C and tempered for 2 or 4 h had 90 and 93% germination percentages, respectively.

This study found that it is possible to have a higher drying rate and accelerate the drying process by combining high temperatures with tempering. Tempered samples had more effective operation times, which were 50% less compared with continuously dried samples. In effect, the actual power supply requirement was also lessered. These results showed the considerable advantages of using tempering.
advantages of tempering in terms of hybrid rice seed’s germination while saving on the energy required.

Among the eight models considered, the Midilli and Two-Term Models resulted in the best goodness-of-fit with the actual continuous thin-layer drying process. It is recommended that drying models with tempering treatments be developed in the future.

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