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Enhancing Seed Germination and Seedlings Growth of Khao Dawk Mali 105 Rice Cultivar via Seed Coating and Infrared Drying Apparatus

Juckamas Laohavanich[1], Waranya Phola[1], Umaporm Phuhongphet[1], Wantana Sinsiri[2], Wilailux Sudwilai[3], Wei Hu[4] and Chadaporn Senakun[5,*]

[1]Faculty of Engineering, Mahasarakham University, Maha Sarakham 44150, Thailand
[2]Department of Agriculture Technology, Faculty of Technology, Mahasarakham University, Maha Sarakham 44150, Thailand
[3]Program of Biology, Department of Science, Faculty of Science and Technology, Loei Rajabhat University, Loei 42000, Thailand
[4]International Cooperation Department of Lanzi Education Foundation, Beijing 100075, China
[5]Walai Rukhavej Botanical Research Institute, Mahasarakham University, Maha Sarakham 44150, Thailand

([*]Corresponding author's e-mail: chadaporn.s@msu.ac.th)

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Abstract

Seed coating techniques had emerged as a promising approach for precise planting and safeguarding crops against environmental stresses. Simultaneously, infrared drying, renowned for its cost-effectiveness and efficiency, held promises for enhancing the quality of drying processes. This investigation delved into the procedures applied to Khao Dawk Mali 105 rice seeds during the coating and drying process using a prototype of the hexagonal drum. The results found that the drying temperature (factor B) and duration of drying time (factor C) had substantial primary effects ($p \leq 0.05$), while the drum rotational speed (factor A) did not exert a noteworthy influence. Additionally, meaningful interactions were observed among the factors AB, AC, BC, and ABC. Impressively, it resulted in germination rates of 80.56 and 80.25 %, coupled with germination indices of 84.88 and 85.47 %, when utilizing a drum speed of 20 rpm, a drying temperature of 45 °C, and a drying time of 8 min (R-204508), and a drum speed of 10 rpm, a drying temperature of 45 °C, and a drying time of 8 min (R-104508), respectively. Additionally, the mean germination time amounted to 9.64 days, and the length of the rice seedling stem reached 13.66 cm when employing a drum speed of 20 rpm, a drying temperature of 50 °C, and a drying time of 8 min (R-205008). These discoveries emphasized the potential of the prototype's seed coating and infrared drying technology integration to improve rice germination and subsequent growth. This enhancement could ultimately result in higher yields and increased productivity, especially in small-scale agricultural settings.

Keywords: Seed coating, Seed germination, Infrared radiation, Drying temperature, Drying time

Introduction

Rice, being the primary crop for both the global economy and the consumption of various populations, holds significant importance [1]. Among the rice cultivars, Khao Dawk Mali 105 (*Oryza sativa* L.), also known as Jasmine Rice, stands out for its aromatic and flavorful characteristics, making it highly esteemed worldwide [2]. The cultivation practices of rice are tailored to specific weather conditions and water management strategies [3]. Fundamental aspects of rice farming include soil preparation, planting, harvesting, threshing, and storage. Consequently, the utilization of superior seeds becomes essential, as they promote the development of vigorous seedlings and increase yields [4].

Seed coating technology, has emerged as a promising technique that offers numerous advantages in planting operations, including enhanced precision and ease of planting through specialized equipment. The strategic application of dynamic constituents onto crop seeds, serves as a pivotal conduit to amplify seed efficacy and bolster crop establishment. Coating seeds provides protection against environmental stressors such as drought and extreme temperatures. This protection promotes optimal germination and establishment, resulting in improved crop yield and quality. Seed coating and drying constitute fundamental agricultural processes. Varied methodologies encompassing dry powder applicators, rotary pans, and pelleting pans proffer avenues for achieving uniform coating and augmenting seed mass. This innovation is further enriched through the incorporation of bio stimulants, nutrients, and plant protectants, culminating in sustainable agricultural enhancements [5-10]. The seed coating and drying technology is usually patented by companies. Most of the processes of seed coating and drying are usually done separately. After seed coating machine is drying process by natural dry. Due to these factors, there exists a scarcity of research in this regard. An exemplary instance can be found in Yamauchi [11] comprehensive assessment, which explores the application of iron-coating technology to enhance the stability of rice direct seeding.

Seed coating and infrared drying techniques play a pivotal role in the processing of rice seeds. Seed coating encompasses the removal of impurities, application of a coating agent, and subsequent seed drying. Infrared drying, when integrated with compact and space-efficient systems, presents a viable solution. In this process, infrared radiation directly imparts heat to the material surface, penetrating to a significant extent, obviating the need for heat transfer via an intermediary medium. The brief drying duration associated with infrared radiation renders it particularly suitable for thin layer drying. Moreover, infrared radiation activates coating materials, augmenting their adherence to seed surfaces, while also heightening the effectiveness of biological control agents and facilitating efficient nutrient absorption by plants [12-15]. For example, a noteworthy study by Chervinsky *et al.* [16] in the realm of modern plant cultivation in Ukraine focuses on the cost-reduction aspect. The study evaluates the efficacy of infrared irradiation for pre-sowing treatment of winter wheat seeds. Remarkably, the treatment yielded the highest rates of germination energy (97.3 %) and seed germination (100 %), along with a remarkable 37.3 % increase in the aboveground part of seedlings when subjected to a 60-second treatment compared to the standard conditions. Despite these advancements, the standardization of rice seed coating procedures faces constraints due to the multitude of rice cultivars and the multifaceted factors influencing seed quality.

Integration of seed coating and drying machines with infrared radiation are very few research reports. The objective of this study was to address the research gap concerning the limited exploration of integrating seed coating and drying machines with infrared radiation in rice processing. Specifically, we aimed to investigate how critical parameters like drum speed (rpm), drying temperature (°C), and drying time (min) influenced the germination and early growth of the Khao Dawk Mali 105 rice cultivar. By employing a prototype seed coating and drying machine equipped with infrared radiation, our research focused on optimizing the seed coating and drying process. The ultimate goal was to contribute to the advancement of rice cultivation techniques, leading to enhanced crop yields and promoting more sustainable agricultural practices in this context.

Materials and methods

A prototype of seed coating and drying machine with infrared radiation

The Innovative Agricultural Machinery and Post-harvest Technology Research Cluster (IAMPT) at Mahasarakham University, Thailand, was responsible for the development of a prototype labeled as 2023001- IAMPT- MSU. This prototype was designed using SolidWorks software and aimed at a seed coating and drying machine that harnessed infrared radiation. In this research, a hexagonal tank for coating and drying seeds in a single device had been developed. Hexagon drum seed coating, also known as hexagon rotary drum seed coating, was an agricultural technique that involved applying various treatments to seeds by placing them inside a rotating hexagonal drum. The prototype developed had been designed to keep the seeds turning during the coating and drying process (**Figure 1**). The top of the tank had been equipped with an infrared lamp for heating, and a seed temperature measurement device had been installed inside the coating tank (**Figure 2**). The side of the main structure had been equipped with a control unit for controlling the tank rotation speed and seed temperature during drying.

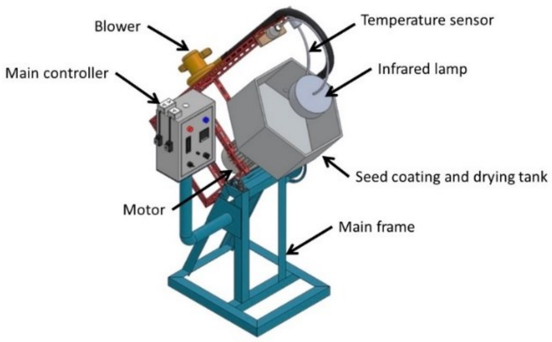

Figure 1 The prototype was designed in the shape of a hexagonal tank for even mixing of the seed with the coating, the top was equipped with an infrared lamp for complete drying in 1 unit.

(A) (B)

Figure 2 Procedure for seed coating test preparation (A) and showing the pattern of rice seed coating and infrared drying (B).

The seed coating process involved the application of a coating material composed of 3 % Polyethylene glycol (PEG), 1 % *Alpinia galanga* (L.) Willd. stem extract, and food coloring dissolved in distilled water. For the examination of varied factors, a completely randomized design (CRD) with a factorial arrangement was utilized, and the study was conducted with 4 replications. The factors included 2 drum speeds (10 and 20 rpm), 2 drying times (8 and 16 min), and 3 drying temperatures (45, 50 and 55 °C). The rice seeds were coated with various combinations of these factors, resulting in a total of 12 treatments. The uncoated rice seeds were used as the control group (**Figure 3**).

(A) (B)

Figure 3 Samples of rice seeds (A) Control rice seeds (B) Coated and dried rice seeds.

Seed germination test and seedling growth of rice

A total of 12 treatments, encompassing an uncoated seed control group, on the vitality and robustness of rice seeds. The comprehensive assessment centered on vital metrics associated with seed performance and seedling development, specifically the germination rate (% G), germination index (GI), mean germination time (MGT), and the length of rice stem seedling (LS). The experiment followed the guidelines provided by the International Seed Testing Association [17] or the Association of Official Seed Analysts [18]. The germination test was conducted in a laboratory at the Walai Rukhavej Botanical Research Institute, Mahasarakham University. The top of paper (TP) technique was employed, involving the placement of 100 seeds onto an 18×25 cm^2 plastic box (**Figure 4**). The laboratory environment was carefully controlled within a temperature range of 25 - 35 °C, maintaining a photoperiod of 16 h of light and 8 h of darkness consistently over a 14-day duration. A lighting setup consisting of a 16-hour photoperiod with an intensity of around 900 lux, utilizing LED lights, is a widely employed configuration in plant research. Germination assessments were performed twice, initially on the 7^{th} day and subsequently on the 14^{th} day after seed coating.

Figure 4 The top of paper (TP) technique was employed, involving the placement of 100 seeds onto an 18×25 cm^2 plastic box.

The germination rate (% G) is a measure of the percentage of seeds that successfully undergo the germination process and develop into robust seedlings. It is calculated by taking the ratio of the healthy seedlings to the total number of seeds employed in the experiment, which is then multiplied by 100. The formula for calculating % G is as follows:

$$\% G = \left(\frac{\text{Number of healthy seedling}}{\text{Total number of seeds}}\right) \times 100$$

The germination index (GI) or emergence index is a metric that evaluates both the percentage and rate of germination. It was determined following the guidelines provided by the Association of Official Seed Analysis (1993) and can be calculated using the following formula:

$$GI = \frac{\text{No. of germinated seeds}}{\text{Days of first count}} + \ldots\ldots + \frac{\text{No. of germinated seeds}}{\text{Days of final count}}$$

The mean germination time (MGT) or germination speed was observed daily in accordance with the protocols outlined by the International Seed Testing Association. Germination counts were recorded for a duration of 10 days, with the first count conducted on the 5th day and the final count on the 14th day after seed coating. The MGT was computed using the equation established by Ellis and Roberts [19], as depicted below:

$$MGT = \sum \frac{Dn}{n}$$

The mean germination time (MGT) is determined by calculating the average number of days it takes for germination to occur. In the formula, "n" represents the number of seeds that have germinated on a specific day "D," which is the count of days starting from the initiation of germination.

The growth of rice seedlings was evaluated by quantifying the length of the stem (LS) after a 14-day period of seed cultivation.

Statistical analysis

The statistical analysis was conducted using SPSS version 29.0. This analysis involved a three-way analysis of variance (ANOVA), where the 3 independent factors were drum speed (at 10 and 20 rpm), drying temperature (at 45, 50 and 55 °C), and drying time (at 8 and 16 min). The dependent variables in this analysis included germination rate (% G), germination index (GI), mean germination time (MGT), and seedling stem length (LS). Furthermore, a one-way analysis of variance was performed to compare the mean values of the 12 treatments with those of the control group. In order to identify significant differences, Duncan's Multiple Range Test (DMRT) was applied, with a significance level set at 0.05. The ANOVA model can be expressed as follows:

$$Y_{ij} = \mu_i + \varepsilon_{ij}$$

In this equation, Y_{ij} represented the value of the dependent variable (response variable) in the j^{th} trial for the i^{th} treatment, μ_i denoted the treatment effect, and ε_{ij} indicated the experimental error associated with the i^{th} treatment.

Results and discussion

In this study, a seed coating process was successfully developed using a prototype seed coating and drying machine equipped with infrared radiation. The moisture content of the seeds after coating and drying fell within the standard range of 11 - 14 % for rice seed storage. The results, as obtained from the statistical analysis (**Tables 1 - 4**), indicated significant differences in the primary effects of factors A, B, and C, as well as in their interactions (AB, AC, BC, and ABC). This suggests that the variables associated with drum speed (Factor A), drying temperature (Factor B), and drying time (Factor C), along with their combined influences, exerted a substantial influence on the seed coating process outcomes. Additionally, a one-way analysis of variance was conducted to evaluate the mean values of the twelve-rice seed coating and infrared drying conditions (R-104508, R-105008, R-105508, R-104516, R-105016, R-105516, R-204508, R-205008, R-205508, R-204516, R-205016, and R-205516) in comparison to the uncoated seed control. The analysis revealed significant distinctions, as depicted in **Table 5** and **Figures 5 - 9**.

For the germination rate (% G), which served as an indicator of seed quality following the coating process (**Table 1**), the analysis unveiled notable distinctions among the conditions concerning drying temperature (Factor B) and drying time (Factor C). These findings pointed to the significant roles these factors played in influencing seed germination. Conversely, drum speed (Factor A) did not display a substantial impact on germination. Additionally, the study brought to light the presence of significant interaction effects involving factor combinations AB, AC, BC, and ABC. These observations indicated that the intricate interplay among these factors had a remarkable influence on the germination process. Following the post-DMRT analysis of the seed coating process, the drying temperatures were classified into 2 groups: 45 and 50 °C in Group A, and the uncoated seed control and 55 °C in Group B. Similarly, the duration of the drying time across the 3 conditions, comprising 8, 16 min, and the uncoated seed control, revealed notable disparities. Notably, a drying time of 8 min resulted in the highest germination rate at 72.32 %. These findings underscored the substantial impact of these parameters on seed germination, emphasizing the need for their optimization to enhance seed quality and subsequent crop growth.

Table 1 The germination rate (% G) of Khao Dawk Mali 105 rice seeds achieved through the use of a coating and infrared drying machine, with variations in drum speeds (rpm), drying temperatures (°C), and drying times (min).

Factor/ Mean of % G		**Drum speed**			
Drying temperature	**Control**	**10 rpms**		**20 rpms**	
		Drying time			
		8 min	**16 min**	**8 min**	**16 min**
Control	58.13±2.79				
45		80.25±8.5	47.57±5.4	80.56±2.0	52.72±9.5
50		73.02±3.1	49.75±3.4	47.30±4.8	57.49±5.6
55		77.77±3.5	49.35±3.4	75.02±11	54.06±4.1
Drying temperature		Drum speed		Drying time	
Control	58.13±2.7 ^{b*}	Control	58.13±2.7 ^{ns}	Control	58.13±2.7 ^{b*}
45	65.27±16 ^{a*}	10	62.95±15 ^{ns}	8	72.32±13 ^{a*}
50	56.89±11 ^{b*}	20	61.19±13 ^{ns}	16	51.82±6.2 ^{c*}
55	64.05±14 ^{a*}				
			Total 67.77±13.99		
		F-test	Sig		
Drum speed (A)		1.006	0.322		
Drying temperature (B)		8.857	0.000		
Drying time (C)		135.962	0.000		
A×B		4.308	0.020		
A×C		18.883	0.000		
B×C		16.597	0.000		
A×B×C		6.749	0.003		

Means sharing the same column with identical capital letters are not significantly distinct at the level of $p \leq 0.05$ as indicated by Duncan's Multiple Range Test (DMRT). ns = not significant * = significantly at $p \leq 0.05$

Table 2 displayed the germination index (GI), which provided insights into both the percentage and rate of germination. The average germination index values closely mirrored the findings from the germination rate analysis. The main effects analysis demonstrated that drying temperature and drying time had a substantial impact ($p \leq 0.05$) on the germination index. In contrast, drum speed (Factor A) did not exert a significant effect. Furthermore, the analysis of interaction effects involving factor combinations AB, AC, BC, and ABC revealed their significant influence, much like what was observed in **Table 1** for the germination rate. Specifically, following the DMRT analysis, the drying temperature was categorized into 2 groups: 45 and 50 °C in Group A, and the uncoated seed control and 55 °C in Group B. Similarly, the duration of the drying time was separated into 2 groups, encompassing 8 min in Group A, and 16 min and the uncoated seed control in Group B. These divisions yielded significant differences, with a drying time of 8 min resulting in the highest germination index at 75.96 %.

Table 2 Germination index (GI) of Khao Dawk Mali 105 rice seeds achieved through the use of a coating and infrared drying machine, with variations in drum speeds (rpm), drying temperatures (°C), and drying times (min).

Factor/ Mean of GI		**Drum speed**			
Drying temperature	**Control**	**10 rpms**		**20 rpms**	
		Drying time			
		8 min	**16 min**	**8 min**	**16 min**
Control	60.89± 3.1				
45		85.47±9.4	46.86±4.0	84.88±2.0	54.219±6.1
50		78.83±2.5	54.59±4.4	45.59 ±4.7	59.91±4.3
55		80.43±7.4	55.42±7.6	80.57±13.0	58.01±4.9
Drying temperature		Drum speed		Drying time	
Control	60.89±3.1^{b*}	Control	60.89±3.1^{ns}	Control	60.89±3.1^{b*}
45	67.85±18^{a*}	10	66.93±15^{ns}	8	75.96±15^{a*}
50	59.73±13^{b*}	20	63.86±15^{ns}	16	54.83±6.3^{b*}
55	68.61±14^{a*}				
			Total 65.05±15.3		
		F-test	Sig		
Drum speed (A)		2.745	0.106		
Drying temperature (B)		9.386	0.000		
Drying time (C)		129.659	0.000		
A×B		8.712	0.001		
A×C		19.331	0.000		
B×C		21.331	0.000		
A×B×C		9.166	0.001		

Means sharing the same column with identical capital letters are not significantly distinct at the level of $p \leq 0.05$ as indicated by Duncan's Multiple Range Test (DMRT). ns = not significant * = significantly at $p \leq 0.05$

Table 3 displays the mean germination time (MGT), which indicates the speed of germination. The analysis of the main effects, including drum speed (Factor A), drying temperature (Factor B), and drying time (Factor C), revealed no significant impact on the speed of germination. The overall average MGT was determined to be 9.5 days. However, significant interaction effects were observed for factor combinations AB, AC, BC, and ABC, indicating that these interactions influenced the speed of germination ($p \leq 0.05$).

Table 3 Mean germination time (MGT) of of Khao Dawk Mali 105 rice seeds achieved through the use of a coating and infrared drying machine, with variations in drum speeds (rpm), drying temperatures (°C), and drying times (min).

Factor/ Mean of MGT		**Drum speed**			
Drying temperature	**Control**	**10 rpms**		**20 rpms**	
		Drying time			
		8 min	**16 min**	**8 min**	**16 min**
Control	9.47±.03	9.45±0.01	9.56±0.11	9.46±0.11	9.50±0.02
45		9.47±0.01	9.52±0.46	9.64±0.03	9.47±0.02
50		9.52±0.08	9.48±0.05	9.45±0.05	9.47±0.04
55					
Drying temperature		Drum speed		Drying time	
Control	9.47±0.03 ^{ns}	Control	9.47±0.03^{ns}	Control	9.47±0.03^{ns}
45	9.48±0.07^{ns}	10	9.50±0.07^{ns}	8	9.50 ±0.08^{ns}
50	9.52±0.07 ^{ns}	20	9.50 ±0.07^{ns}	16	9.50 ±0.06^{ns}
55	9.48±0.06^{ns}				
			Total 9.501±0.070		
		F-test	Sig		
Drum speed (A)		0.002	0.965		
Drying temperature (B)		2.552	0.091		
Drying time (C)		0.029	0.867		
A×B		4.027	0.026		
A×C		5.764	0.021		
B×C		6.203	0.005		
A×B×C		6.531	0.004		

Means sharing the same column with identical capital letters are not significantly distinct at the level of $p \leq 0.05$ as indicated by Duncan's Multiple Range Test (DMRT). ns = not significant * = significantly at $p \leq 0.05$

Table 4 displayed the measurements of rice growth, specifically the length of the stem (LS) of the rice seedlings, after a 14-day growth period. The analysis uncovered significant main effects attributable to drum speed (Factor A) and drying time (Factor C), signifying their influence on stem length ($p \leq 0.05$). Conversely, drying temperature (Factor B) did not manifest a significant effect. The examination of factor interactions, including AB, AC, and BC, did not reveal significant effects on stem length. However, a significant interaction effect emerged when considering all 3 factors (ABC) ($p \leq 0.05$).

During the DMRT analysis, drum speed was divided into 2 groups: 10 rpm in group A and 20 rpm in group B. The uncoated seed control was included in both group A and group B. Similarly, the drying time was separated into 2 groups, with 8 min in group A and 16 min, along with the uncoated seed control, in group B. While the drying temperature did not show significant differences. The longest stem length, measured at 12.82 cm, was achieved with a drying time of 8 min.

Table 4 Length of Stem (LS) of of Khao Dawk Mali 105 rice seeds achieved through the use of a coating and infrared drying machine, with variations in drum speeds (rpm), drying temperatures (°C), and drying times (min).

Factor/ Mean of LS		**Drum speed**			
		10 rpms		**20 rpms**	
Drying temperature	**Control**	**Drying time**			
		8 min	**16 min**	**8 min**	**16 min**
Control	12.28±1.6				
45		12.40±1.3	10.32±2.5	13.18±1.9	12.24±1.1
50		12.05±1.3	11.81±1.9	13.66±1.5	11.20±2.2
55		12.44±1.2	12.19±1.4	13.17±1.5	12.65±1.3
Drying temperature		Drum speed		Drying time	
Control	$12.28±1.6^{ns}$	Control	$12.28±1.6^{ab*}$	Control	$12.28±1.6^{ab*}$
45	$12.03±2.0^{ns}$	10	$11.87±1.8^{b*}$	8	$12.82±1.6^{a*}$
50	$12.18±1.9^{ns}$	20	$12.68±1.8^{a*}$	16	$11.73±1.9^{b*}$
55	$12.61±1.4^{ns}$				
			Total 12.27±1.8		
.		F-test	Sig		
Drum speed (A)		13.966	0.000		
Drying temperature (B)		2.541	0.081		
Drying time (C)		24.677	0.000		
A×B		1.507	0.224		
A×C		1.064	0.303		
B×C		2.591	0.077		
A×B×C		4.976	0.008		

Means sharing the same column with identical capital letters are not significantly distinct at the level of $p \leq 0.05$ as indicated by Duncan's Multiple Range Test (DMRT). ns = not significant * = significantly at $p \leq 0.05$

Table 5 presents the significant effects ($p \leq 0.05$) of 13 different seed coating and drying conditions on the germination rate, germination index, mean germination time, and length of the stem. The treatment with a drum speed of 20 rpm, drying temperatures of 45 °C, and drying time of 8 min (R-204508) exhibited the highest values for seed germination rate (80.56 %) and germination index (84.88 %). Similarly, the treatment with a drum speed of 10 rpm, drying temperatures of 45 °C, and drying time of 8 min (R-104508) demonstrated a high germination rate (80.25 %) and germination index (80.43 %). The treatment with a drum speed of 20 rpm, drying temperatures of 50 °C, and drying time of 8 min (R-205008) resulted in the highest mean germination time. In terms of seedling growth, the treatments R-205008, R-204508, and R-205508 showed stem lengths of 13.66, 13.18 and 13.17 cm, respectively, after 14 days of growth.

The mean germination rates observed in the current study ranged from 47.57 to 80.56 %. Remarkably, treatments with a drum speed of 20 rpm, drying temperature of 45 °C, and drying time of 8 min had shown promising results. Treatment R-204508 and treatment R-104508 had exhibited high mean germination rates of 80.56 and 80.25 %, respectively. This indicated that the specific combination of factors in R-204508 was more effective in promoting germination.

The germination index, which surpassed 80 % on average, was observed in multiple treatments. Specifically, treatments R-104508, R-204508, R-105508, and R-205508 exhibited germination index values of 85.47, 84.88, 80.57 and 80.43 %, respectively. Notably, the highest germination index values were achieved with a drying time of 8 min. This finding suggests that drying time at 8 min may be more favorable compared to 16 min, as a longer drying period could potentially impede seed germination due to prolonged exposure to time and temperature. For a visual representation of these results, refer to **Figure 6**.

In our study, we conducted a DMRT analysis to compare the germination rates and germination index of different rice seed coating treatments. The results showed that the germination rate and germination index were divided into 3 groups, namely R-104508, R-105508, R-204508, R-205508 in Group A, uncoated seed control, and R-205016 in Group B. Group C included R-104516 and R-205008. Meanwhile, R-105016, R-105516, R-205508, R-204516, and R-205016 were combined in Groups B and C. These findings were important for optimizing seed coating processes to enhance crop yields. It was observed that a longer drying time of 16 min resulted in a relatively lower germination rate of 50 %, which was below that of the uncoated seed or control, as depicted in **Figures 5** and **6**. It’s important to note that high-quality seeds typically exhibit germination rates exceeding 80 % [17]. Furthermore, rice seeds often underwent a dormancy period immediately after harvest, and if stored using traditional open systems, their germination rates tended to deteriorate rapidly after 6 months. In the past, a prior study investigated how different drying durations and temperatures affected the moisture content and germination rate (% G) of pea seeds (*Pisum sativum* L.). The study used 4 temperature settings: 40, 60, 80 and 100 °C, and various time periods ranging from 0 to 168 h as treatment conditions for temperature and time. The research revealed that pea seeds were sensitive to both prolonged drying periods and higher drying temperatures. The most suitable drying temperature was identified as 40 °C. Consequently, drying the seeds at 60 °C produced more reliable germination outcomes and served as a superior indicator of field performance compared to temperatures of 80 and 100 °C, which were found to be unsuitable for peas. Additionally, it was noticed that when the temperature was maintained at 40 °C and the drying period lasted for 48 h, the seeds reached a lower moisture level (8 %), while the germination rate (% G) remained at 96 %. This observation suggested that there was no strict correlation between the percentage of moisture content and germination rate; instead, it depended on the intended purpose of seed drying [20]. The study’s findings also indicated that the ideal conditions for seed coating in group A, comprising R-104508, R-105508, R-204508, and R-205508, led to germination rates exceeding 80 % when utilizing infrared radiation for a duration of 8 min. Consequently, the optimal conditions for coating rice seeds to achieve a high germination rate were a drying temperature range of 45 - 55 °C and a drying duration of 8 min. In the same way, in the case of rice, drying temperature and initial moisture content (IMC) had significant effects on rice seed vigor concerning germination performance. Specifically, it was reported that significant effects were observed at drying temperatures of 38 - 45 °C. Higher drying temperatures were found to have a pronounced negative impact on seed vigor [21].

Table 5 Seed coating conditions, considering various drum speeds (rpm), drying temperatures (°C), and drying times (min), and their impact on mean germination rate, germination index, mean germination time, and length of the stem.

Code	Germination rate (%)	Germination index (%)	Mean germination time (day)	Length of stem (cm)
Control	58.13±2.79^{b}	60.898±3.10^{b}	9.47±0.03^{c}	12.28±1.62^{bcd}
R-104508	80.25±8.54^{a}	85.471±9.49^{a}	9.45±0.01^{c}	12.40±1.35^{bcd}
R-105008	73.02±3.14^{a}	78.836±2.59^{a}	9.47±0.01^{c}	12.05±1.30^{bcd}
R-105508	77.77±3.54^{a}	80.434±7.44^{a}	9.52±0.08^{bc}	12.44±1.29^{bc}
R-104516	47.57±5.40^{c}	46.866±4.0^{c}	9.56±0.11^{ab}	10.32±2.52^{e}
R-105016	49.75±3.40^{bc}	54.597±4.46^{bc}	9.52±0.46^{ab}	11.81±1.90^{cd}
R-105516	49.35±5.73^{bc}	55.429±7.65^{bc}	9.48±0.05^{bc}	12.19±1.41^{bcd}
R-204508	80.56±2.00^{a}	84.881±2.09^{a}	9.46±0.11^{c}	13.18±1.99^{ab}
R-205008	47.30±4.86^{c}	45.594±4.76^{c}	9.64±0.03^{a}	13.66±1.58^{a}
R-205508	75.02±11.73^{a}	80.573±13.08^{a}	9.45±0.05^{c}	13.17±1.58^{ab}
R-204516	52.72±9.52^{bc}	54.219±6.15^{bc}	9.50±0.02^{bc}	12.24±1.10^{bcd}
R-205016	57.49±5.65^{b}	59.911±4.37^{b}	9.47±0.02^{c}	11.20±2.24^{de}
R-205516	54.06±4.13^{bc}	58.012±4.91^{b}	9.47±0.04^{c}	12.65±1.38^{abc}
F-test	**19.197***	**20.978***	**3.018***	**5.245***

Means sharing the same column with identical capital letters are not significantly distinct at the level of $p \leq 0.05$ as indicated by Duncan’s Multiple Range Test (DMRT). ns = not significant * = significantly at $p \leq 0.05$

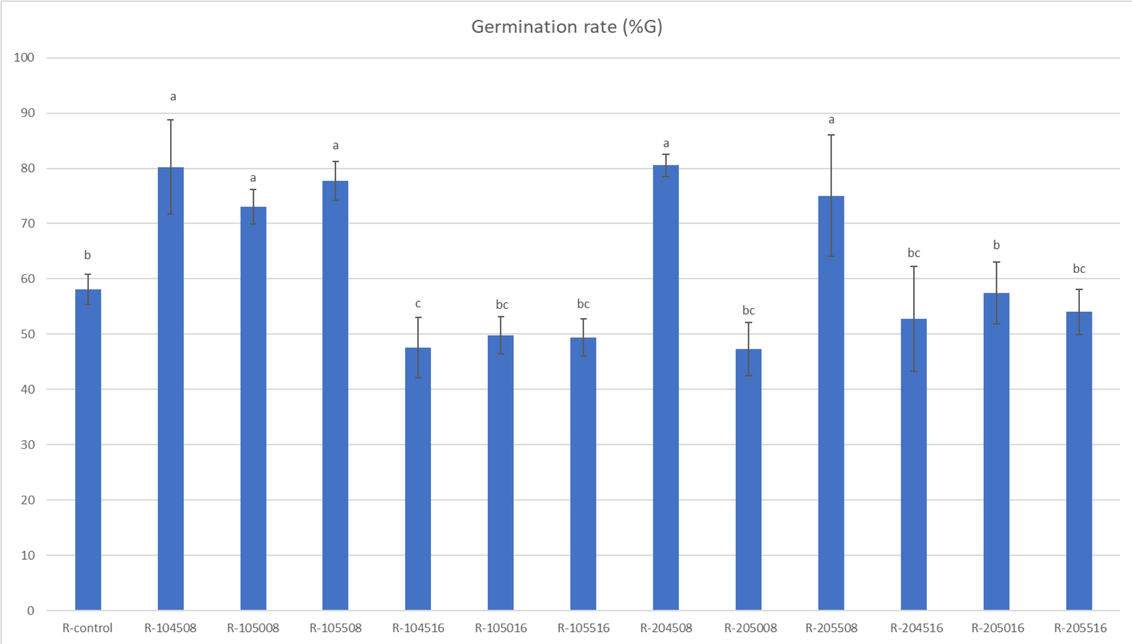

Figure 5 The germination rate of Khao Dawk Mali 105 rice seeds over a 14-day period using the coating and infrared drying machine. The data was presented as the mean value accompanied by the standard deviation (SD), with alphabetic labels above the bars denoting the results of the DMRT analysis.

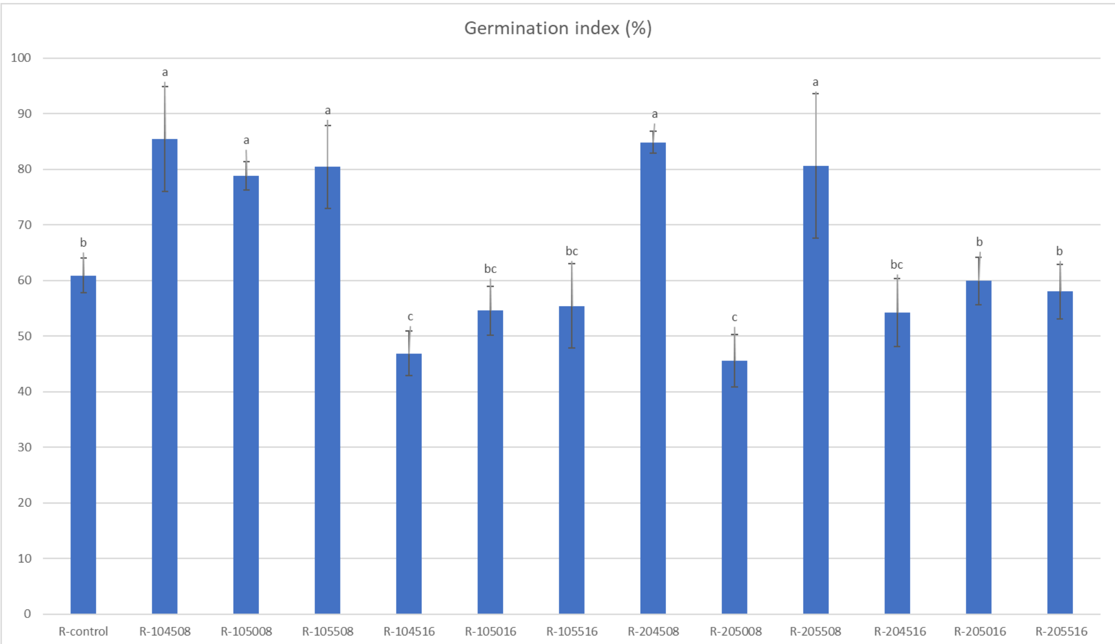

Figure 6 The germination index of Khao Dawk Mali 105 rice seeds, assessed over a period of 10 days. Germination counts were conducted at 2 time points, starting on the 5th day and concluding on the 14th day after the coating process, using the coating and infrared drying machine. The data was presented as the mean value accompanied by the standard deviation (SD), with alphabetic labels above the bars denoting the results of the DMRT analysis.

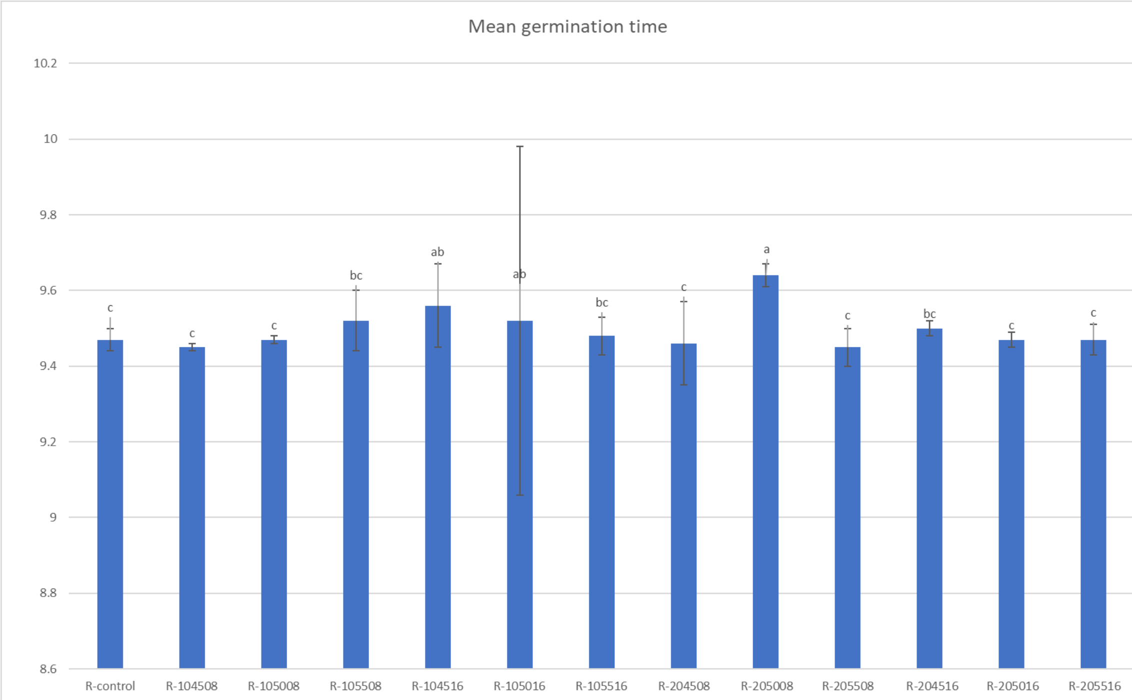

Figure 7 The mean germination time of Khao Dawk Mali 105 rice seeds, which was observed over a period of 10 days. Germination counts were performed at 2 intervals, first on the 5th day and then on the 14th day after the coating process, using the coating and infrared drying machine. The data was presented as the mean value accompanied by the standard deviation (SD), with alphabetic labels above the bars denoting the results of the DMRT analysis.

Figure 7 demonstrates that the mean germination time or speed of germination was not significantly influenced by any of the treatments. The average value of the mean germination time observed in this study was 9.5 days.

Figure 8 displayed the measurements of rice seedling length following a 14-day growth period under various coating and drying conditions. The average length of the seedlings fell within a range from 10.32 to 13.66 cm. Interestingly, treatments featuring a drum speed of 20 rpm and a drying time of 8 min (R-205008) resulted in the tallest seedlings. In terms of drying temperatures (45, 50 and 55 °C), treatment R-205008, R-204508, and R-205508 showcased seedling lengths of 13.66, 13.18 and 13.17 cm, respectively. An analysis using DMRT was employed to compare the seedling length across various rice seed coating treatments, leading to the classification of rice seedling lengths into 4 distinct groups, as illustrated in **Figure 8**.

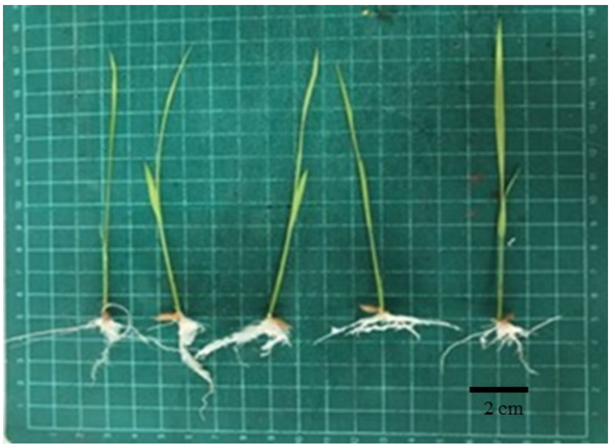

Figure 8 The measurements of seedling stem length in centimeters (cm) after 14 days of germination of coated rice seeds. Scale bar = 2 cm.

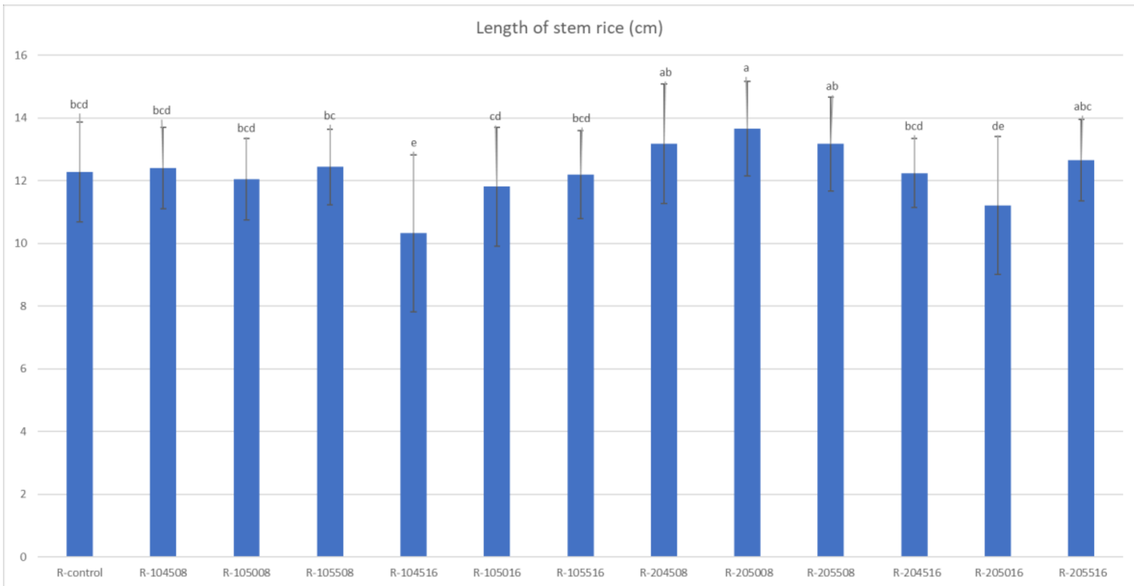

Figure 9 The length of Khao Dawk Mali 105 rice seedlings after 14 days of growth using the coating and infrared drying machine. The data was presented as the mean value accompanied by the standard deviation (SD), with alphabetic labels above the bars denoting the results of the DMRT analysis.

Ensuring precise control over drying temperature and duration is of paramount importance in establishing optimal and consistent conditions for the germination and subsequent growth of rice seeds, thereby augmenting plant vigor and overall yield. Similarity, Siddique and WriThe utilization of infrared radiation assumes a pivotal role in stimulating seed germination and early-stage development, facilitated by its provision of a warm and stable milieu conducive to seed maturation. In a congruent vein, Chervinsky *et al.* [16] underscored the effectiveness of infrared irradiation in their investigation of pre-sowing treatment for winter wheat seeds, yielding exceptional rates of germination energy (97.3 %) and seed germination (100 %). Moreover, the novelty of this research notable, introducing a pioneering endeavor to combine seed coating and infrared radiation drying within the context of Rice cv. Khao Dawk Mali 105. The implications of these findings extend to potentially elevating seed germination rates and optimizing time management.

Conclusions

The integration of seed coating and infrared radiation technology holds significant promise in elevating rice cultivation outcomes. This pioneering methodology enhances the efficiency of seed coating by fostering improved nutrient assimilation and creating ideal circumstances for germination and initial growth. The investigation determined optimal coating and drying conditions, encompassing a drum speed of 20 rpm, a drying temperature of 45 °C, and a drying duration of 8 min (treatment R-204508), along with a drum speed of 20 rpm, a drying temperature of 45 °C, and a drying time of 8 min (treatment R-104508). These conditions resulted in the highest mean germination rates and germination indices. Evaluating seed viability holds paramount importance, given that the germination rate directly influences crop prosperity and yield. Seeds exhibiting lower germination rates can engender less robust and productive plants, culminating in reduced yields or even crop disappointment. Further research directions should encompass the exploration of diverse rice varieties, alternative coating materials, and extended field assessments. Additionally, investigating the economic and environmental implications, adapting these techniques for small-scale farmers, and integrating them with holistic approaches to pest management and nutrient optimization offer exciting avenues for further exploration. Furthermore, research into climate-resilient rice cultivars, quality control measures, and market accessibility could significantly enhance agricultural productivity and promote sustainable practices.

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