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Germination Characteristics of Korean and Southeast Asian Redrice (*Oryza sativa* L.) Seeds as Affected by Temperature

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Abstract: Red rice (*Oryza sativa* L.) is considered an important weed in many paddy fields. We performed a laboratory investigation to evaluate the germination percent, germination speed and days to 50% germination (T50) of red rice seed three groups were selected: (1) four Southeast Asian varieties/germplasms, (2) six Korean varieties/germplasms with enhanced yield and (3) four Korean varieties/germplasms which are problem in direct-sown paddy fields. The selected varieties/germplasms were incubated at four different day/night temperature settings: 15/10, 20/15, 25/20 and 30/25°C. This study has been carried out at phytotron and glass house between 2007 through 2009 to find out the characteristics of Asian redrice germ plasms. According to results, the germination percent and germination speed of red rice seed generally increased with increasing temperature. At low temperature (20/15°C), red rice seeds, selected or imported red rice from cold areas, resulted in lowest germination percent (9%) and germination speed (12.3), however, T50 was the lowest (7.2 at 15/10°C) compared to all the Southeast Asia red rice varieties/germplasms. Germination characteristics of Korean red rice seeds showed similar responses to temperature conditions depending on where they came from and local temperature: southern part of Korea (Hapcheon) or northern part (Suwon). However, Yeongcheon red rice showed high germination percent (96-100%) and low T50 (9.0-2.7) which was very similar to group 2 which were already selected as cultivars/germplasms for high vigor and high yield. The critical temperature for red rice germination related characteristics was 25/20°C and activity (germination speed and T50) did not increase much at 30/25°C. In conclusion, red rice varieties/germplasms selected from a local area would represent the temperature of the area partially.

Key words: Germination, red rice (*Oryza sative* L.), temperature, genotypes, Korea and Southeast Asia

INTRODUCTION

Red rice (*Oryza sative* L.) is called as functional rice because of variable nutrients sources (Lee *et al*., 2006), however, it rapidly spreading in paddy fields worldwide through direct seeding of rice and it found more than 50% paddy field in Korea (Cho *et al*., 1998). Red rice density is mostly related to cultivation methods and seeding density is relatively high in direct-sown paddy fields, especially when dry seeding rather than wet seeding is practiced. Thus, many studies suggest that transplanting is the best tool to control the spread of red rice in paddy fields. Delayed tillage operations, often leading to increase in temperature, could reduce red rice density because of its poor germinability at high temperature (Cohn and Hughes, 1981). Also, early germinated red rice can be buried or uprooted by tillage in fields where rice is either transplanted or directly seeded.

The germination characteristics vary among red rice varieties. Some red rice varieties tend to germinate after several months of dormancy under field conditions, whereas some could germinate approximately 20 days after seeding if stored at 20°C for 30 days (Vidotto and Ferrero, 2000). Additionally, the germination percentage after wintering could reduce especially in located on soil surface than placed on deep soil (Kyoung *et al*., 1999) and its dormancy is variable for many years when fully imbibed (Gianetti and Cohn, 2008).

In the whole of the Korean peninsula, 22 red rice varieties and 120-150 germplasms (which did not selected or cultivated by farmers or researchers in field, however it grow in the rice field almost every year, especially which is more serious in direct-seeding condition) are found (Suh, 2003; Suh *et al*., 1992). Red rice is also found in the Philippines, Vietnam, Nepal, Cambodia and other Asian countries. The climates for these countries are mostly temperate or sub-tropical except for Nepal. In Nepal, most rice cultivars are cultivated with red rice in mountainous area but no practices are applied to control it. Thus, red rice in Nepal are expected to show high germinability under low temperature conditions.

In Korea, most of red rice varieties/germplasms are classified by categories, such as plant type, panicle type and rice color (Suh, 2003). Many studies (Suh *et al*., 1999; Yang and Yeo, 1997) suggested that temperature is an important factor controlling the germination characteristics of red rice and it could be useful to classify red rice cultivars and germplasms. However, no research was conducted to examine germination characteristics of red rice from various sources at several alternative temperature levels. The objectives of this study were to (1) clarify germination characteristics of red rice at different temperature levels and (2) provide the basic information to breeders for selection or using red rice varieties/germplasm of vigorous germinability.

MATERIALS AND METHODS

This study has been carried out at phytotron and glass house between 2007 through 2009 to find out evaluate the characteristics of Asian red rice germ plasms.

Based on results from a previous screening test in field conditions (data not shown), seeds of 13 redrice varieties/germplasms having high seed vigor were selected for this study. Each seed was classified into three groups according to its origin and growth characteristics. The first group consisted of four sources collected from Southeast Asia, in Cambodia, Nepal, the Philippines and Vietnam which were identified by the country name and red rice for convenience and Korean sources were called Engmi after a local name (Table 1). The second group consisted of six sources collected in Korea, all presenting vigorous activity for seed germination and growth. The third group consisted of four sources also collected in Korean paddy fields which were all directly sown in rice fields.

Most of plant types, panicle sizes and hulled rice colors were reported previously (Suh, 2003). However, there was few available data for the seed germination characteristics under temperature changes of red rice.

Table 1: Name and origin of tested germplasms and group definition

Group	Origin	Name
South-East Asian (I)	Cambodia*	Punompen Eastern redrice 18
	Nepal	Lumbini 12
	Philippiness	Talac 4
	Vietnam	Vietnam redrice 4
Korea (II) (High	Korea	Geumreungaengmi 2
vigorous germplasms)	Korea	Geumsanengmi 4
	Korea	Gongjuaengmi 5
	Korea	Jainaengmi
	Korea	Sancheongaengmi 7
Korea (III) (Popular	Korea	#Suwonredrice
germplasms)	Korea	#Yeongcheonengmi
	Korea	#Jeonbukengmi
	Korea	#Hapcheonengmi

*: Classified and previously evaluated by Suh (2003)

Four alternative day/night temperature were used: 15/10°C, 20/15°C, 25/20°C and 30/25°C. The duration of day and night was set as 14 and 10 h for 18 days after seeding. The 18-day incubation was reasonable because red rice could not survive by the suppression of already grown rice approximately 20 days after emergence of rice. One hundred seeds were placed on two filter papers and 30 mL of distilled water was added before covering and germination was counted as emerging of radicle or epicotyl (>1 mm) and their number was recorded everyday from one day after the initiation of incubation to the end of the experiment (Li *et al*., 2002). Seed germination percent (%); Germination speed = $\Sigma Gn/\Sigma(Gn\times Dn)\times 100$, where, Gn is number of germinated seed on that day, Dn is days after initial sowing; and T50 were investigated for each temperature treatment. Days to 50% of the final germination percentage was calculated from the Eq.:

$$T50 = \frac{\Sigma Ni \times Ti}{\Sigma Ni}$$

where, Ni is the number of newly germinated seeds at time Ti.

The statistical analysis of variance was done (SAS program) on F-test to finding statistical differences of each parameters.

RESULTS AND DISCUSSION

The results of this study mostly focused on the difference of seed germinability among Asian red rice and expressed focused on the grouping by the germination characteristics (Table 2-4).

Seed germination (%): The cultivar group 2 had the highest seed germination percent at all temperature levels, followed by group 3 and 1 (Table 2). Germination percent of red rice seeds at 15/10°C was 97% for group 2 compared to 60% for group 1 (60%) and 72% for group 3 (Table 2). The high percentage of seed germination at such a low temperature was in agreement with a previous report. However, there was difference in seed germination percent at 15/10°C between groups 2 and 3. However, seed germination at 25/20°C was 100% for group 2 but 77 and 81% for group 1 and 3. Seed germination at 30/25°C for group 2 was the highest percent (99%) and was similar to those found at 25/20°C and groups 1 and 3 had 67 and 61%, respectively. Among all the temperature levels, seed germinate percent was the highest at the temperature range of 25/20°C that might greatly increase the seed germination of redrice, as shown in other studies

Table 2: Germination percent of redrice germplasms at 15/10°C, 20/15°C, 25/20°C and 30/25°C

		Temperature (°C)			
Groups	Germplasm	15/10	20/15	25/20	30/25
South-East	Punompen E. 18	75b[#]	69c	95a	100a
Asian (I)	Lumbini 12	14d	9d	32c	12b
	Talac 4	81a	94a	84b	54b
	Vietnam redrice 4	69c	84b	98a	100a
Average		60	64	77	67
Korea (II)	Geumreungengmi 2	99a	93b	100a	100a
(High vigorous	Geumsanengmi 4	99a	69e	100a	100a
germplasms)	Gongjuaengmi 5	100a	85c	100a	95b
	Jainaengmi(Temp1)	96b	100a	100a	100a
	Sancheongaengmi 7	92c	81d	100a	100a
Average		97	86	100	99
Korea (III)	#Suwonredrice	83c	64d	64d	21d
(Popular	#Yeongcheonengmi	96a	98a	99a	100a
germplasms)	#Jeonbukengmi	89b	87b	72c	35c
	#Hapcheonengmi	21d	85c	88b	87b
Average		72	83	81	61
F-value	Variety group×variety	5.5***	3.3*	4.5**	4.3**

[#]: Means separation within columns in each group by Duncan test at 5% level. *p = 0.05, **p = 0.01, ***p = 0.001

Table 3: Germination speed of redrice germplasms 15/10°C, 20/15°C, 25/20°C and 30/25°C

		Temperature (°C)			
Group	Country name/germplasm	15/10	20/15	25/20	30/25
South-east	Punompen E. 18	11.2b[*]	31.4a	37.5a	37.5a
asian (I)	Lumbini 12	13.9a	12.3d	23.5c	29.5c
	Talac 4	9.5d	19.0c	26.8b	31.8b
	Vietnam redrice 4	10.5c	26.3b	37.5a	37.5a
Average		11.2	22.2	31.3	34.1
High vigorous	Geumreungaengmi 2	11.5ab	24.6cd	37.5a	37.5a
germplasms	Geumsanengmi 4	12.2a	34.8a	37.5a	37.5a
Collected in	Gongjuaengmi 5	12.7a	26.1c	37.5a	37.5a
Korea (II)	Jainaengmi (Temp1)	10.0c	21.6d	33.5b	37.5a
	Sancheongaengmi 7	10.9b	28.7b	37.5a	37.5a
Average		11.5	27.1	36.7	37.5
Popular	#Suwonredrice	8.8b	18.4b	24.2	21.2d
germplasms	#Yeongcheonengmi	11.1a	24.7a	37.5	37.5a
found in	#Jeonbukengmi	8.6b	18.4b	22.6	23.0c
Korea (III)	#Hapcheonengmi	7.7c	17.7b	22.8	28.2b
Average		9.1	19.8	26.8	27.5
F-value	Variety group×variety	2.5ns	3.3*	4.5**	4.3**

[#]: Means separation within columns in each group by Duncan test at 5% level. *p = 0.05, **p = 0.01, ns: Not significant

(Gianetti and Cohn, 2008; Yang and Yeo, 1997). However, mean seed germination (%) in each group was mostly related with the temperature of origin country in group 1 and 2. At 30/25°C, seed germination percent of red rice Talac4 and Lumbini12 were 54% and 12%, respectively and had effect on the increasing of the variation. In group 3, seed germination percent of Yeongcheonengmi was 100%. However, it was 21 and 35% for other cultivars from Suwon and Jeonbuk, resulting in low mean germination percent in group 3. At a high temperature level, such as that of 30/25°C, seed germination percent of Yeongcheonengmi and Hapcheonengmi were 100 and 87%, however, Jeonbukengmi and Suwonengmi were only 35 and 21%. Our results indicate that red rice seeds mostly germinate on the growing local temperature because germination characteristics were higher in high temperature of most redrice except originated from Nepal (Table 2-4).

Germination speed of seed (Σgn/Σ(Gn×Dn)×100): Seed germination speed increased with increasing temperature for all the groups. At 15/10°C, there were no significant differences among the groups, however, it was likely to be slightly higher in group 1 and 2 compared to group 3. Seed germination speed at 20/15°C, 25/20°C and 30/25°C was the highest in group 2, followed by group 1 and 3. The group 1 at 15/10°C, seed germination speed was highest in Nepal red rice (13.9), which might be due to its cultivation in the mountainous area. In the group 2, Gongju red rice had the highest seed germination speed but the difference was not significant within the group. In the group 3, seed germination speed was the highest for Yeongcheon red rice and the lowest for Hapcheon red rice probably because of the temperature differences of areas where the seeds were collected. For example, Hapcheon is located in the southern part of Korea and temperature is relatively high compared to that of other Korean red rice sources. However, at 20/15°C, seed germination speed was two times faster than that at 15/10°C. The seed germination speed was 27.1 in group2, 22.2 in group1 and 19.8 in group3 (Table 3). The seed germination speed increased three times at 25/20°C and one and half times faster than that at 15/10°C and at 20/15°C. Among the groups, at 15/10°C and 20/15°C, it was highest in group 2 followed by group1 and 3. However, at 30/25°C, the increase in seed germination speed was very small as it increased only value in group1. However, seed germination speed decreased for Suwon redrice with increasing temperature from 20/15°C to 30/25°C, which was similar to the pattern of seed germination percent (Table 2, 3).

Days to 50% germination (T50) (ΣNi×Ti/ΣNi): T50 decreased in all the groups with increasing temperature. Difference in T50 was largely decreased from 9.1 at 15/10°C to 5.1 at 20/15°C in group 1, from 8.8 to 3.8 in group2 and 11.2 to 5.1 in group 3 (Table 4). Increase in temperature from 20/15°C to 25/20°C decreased T50 by 2 in group1, 0.3 in group2 and 0.1 in group3. However, there were no changes in T50 between 25/20°C and 30/25°C for all the groups, showing no temperature effect on T50 at corresponding temperature change. However, at 15/10°C, T50 was the lowest for Nepal red rice (7.2) within group 1, 8.2 for Geonsam red rice in group 2 and 9.0 for Yeongcheon red rice in group3. At 20/15°C, Cambodia red rice had 3.2 of T50 in group1, 2.9 for Geomsan red rice 4 in group 2 and 4.1 for Yeongcheon red rice in group 3. At 25/20°C, Cambodia red rice and Vietnam red rice had the lowest (2.7) T50 in group 1 along with the others in group 2 that had 2.7-3.0 of T50. Yeongcheon red rice showed the

Table 4: Days to 50 percent germination (T50) of redrice germplasms of redrice 15/10°C, 20/15°C, 25/20°C and 30/25°C

		Temperature (°C)			
Group	Country name/germplasm	15/10	20/15	25/20	30/25
South-East	Punompen E. 18	8.9b*	3.2b	2.7c	2.7ab
Asian (I)	Lumbini 12	7.2c	8.1a	4.3a	3.4a
	Talac 4	10.6a	5.3b	3.7b	3.1a
	Vietnam redrice 4	9.6b	3.8b	2.7c	2.7ab
Average		9.1	5.1	3.3	3.0
High vigorous	Geumreungaengmi 2	8.7bc	4.1ab	2.7 b	2.7a
germplasms	Geumsanengmi 4	8.2c	2.9c	2.7 b	2.7a
collected in	Gongjuaengmi 5	7.9c	3.8b	2.7 b	2.7a
Korea (II)	Jainaengmi (Temp 1)	10.0a	4.6a	3.0 a	2.7a
	Sancheongaengmi 7	9.2b	3.5b	b2.7	2.7a
Average		8.8	3.8	2.7	2.7
Popular	#Suwonredrice	11.4b	5.4a	4.1a	4.7a
germplasms	#Yeongcheonengmi	9.0c	4.1b	2.7b	2.7c
found in	#Jeonbukengmi	11.6b	5.4a	4.4a	4.4a
Korea (III)	#Hapcheonengmi	13.0a	5.6a	4.4a	3.5b
Average		11.2	5.1	3.9	3.8
F-value	Variety group×variety	1.1*	1.3*	0.7*	0.5*

#: Means separation within columns in each group by Duncan test at 5% level. *p = 0.05

lowest T50 in all temperature treatments except 30/25°C. At 30/25°C, Cambodia and Vietnam red rice also had the lowest T50 with 2.7 and was the same for all sources in group 2. In group 3, T50 was the lowest for Yeongcheon red rice, that showed a similar pattern to those observed at the other temperature levels.

During this study, there was no light effect for the germination even though exposed to light for 1 h for the investigation because germination percent was higher than 10% in all the sources because seed germination will be increased by light at 210 μmole sec^{-1} for 5 sec (Milberg *et al*., 1996) (Table 1, 4).

CONCLUSIONS

In conclusion, there were no previous studies with Asian red rice for seed germination characteristics following results could not compared previous research, however they are abbreviated as seed germination percent at low temperature was higher for the cultivars from Korean than from other sources in Asian and therefore it would be mostly related to the temperature conditions of the areas where seeds are originated from. In general, all experimental results are summarized as at 25/20°C yielded the best germination results of red rice in most of the sources. The seed germination speed T at 20/15°C was the fastest for Nepal red rice among all the sources which might be historically accustomed in at temperature. Increasing in temperature from 15/10 to 20/15°C, increased the seed germination speed by approximately two times. Cambodian redrice had the shortest T50 at 20/15°C in group 1 and Geomsanengmi in group 2 and Yeongcheonengmi in group 3.

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