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Responses of modern and local Thai rice varieties to the aerobic soil

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Abstract

This study evaluated responses of modern and local Thai rices to find varieties that are suitable for growing in water-limited areas under aerobic and anaerobic soils. Nine rice varieties and two soil water conditions were arranged as a factorial design in a completely random design (CRD) with three replications. The agronomic traits that were measured consisted of 50% flowering date, plant height, yield components, harvest index (HI), and grain yield plant^{-1}. Growing rice under aerobic soil significantly reduced plant height, yield components and grain yield, compared with anaerobic soil. However, the reduction differed depending on the variety. The modern rice varieties tend to be more adapted to the aerobic soils, compared to local. Modern rice varieties, RD29, RD49, and RD57, and a local rice variety, Chiang Phatthalung, tend to be better adapted under aerobic soil. These were clearly indicated by the smallest reduction in some agronomic traits under aerobic compared to anaerobic conditions. The plant height of RD57 was 107.93/ 104.53 cm in anaerobic and aerobic, respectively. The tiller number plant $^{-1}$ in RD57 was 15.2/ 8.8; panicle number plant $^{-1}$ in RD57 was 14.67/8.7 and in RD29 12.6/7.7; spikelet number plant $^{-1}$ in RD57 was 188/203 and RD49 was 185/189; filled grain plant $^{-1}$ in RD57 was 166.8/161; empty grain plant $^{-1}$ in Chiang Phatthalung was 76.6/45.87; filled grain (%) in Chiang Phatthalung was 57.3/62.1. A highly significant correlation was found between grain yield and the number of panicle plants^{-1} ($R=0.75$; $P<0.001$) under non-flooded conditions, which indicated that grain yields under aerobic soil largely depended on panicle initiation. Therefore, the panicle initiation stage should first be concentrated under water shortage. Thailand comprises a wide diversity of rice. Therefore, more varieties of both modern and local Thai rice should be studied further.

Keywords: Aerobic soil, Modern rice, Local rice, Adaptation, Water shortage.

Introduction

Today, climate change has affected the world and is likely to be more severe in the future (Xu et al., 2018). Increasing temperatures and lower precipitation have resulted in drought or water shortage in some areas. Drought is one of the most important factors limiting yield production (Passioura, 2007), especially for rice (Pandey and Bhandari, 2009). Rice (*Oryza sativa* L.) is a staple food that is consumed by more than half of the world's population. The reduction in rice yield caused by drought has been reported at various stages such as tillering (Kim et al., 2017), flowering (Ouk et al., 2006), and grain filling (Prathap et al., 2019). Water shortage in rice production is found in many countries throughout Asia, including Thailand and especially in the Northeast (Pandey et al., 2007). Based on its location in a tropical zone, Thailand is easily and frequently faced with drought (Power et al., 2020). In Thailand, there are two rice systems, namely in-season and off-season. However, about 75% of the total area depends on rain-fed areas (Fukai and Fischer, 2012). In 2019, the precipitation level was reduced by 15%, resulting in a lower water level in the reservoir by about 60%. Rice exported during this year was about 8 million metric tons. This was about 25% lower than previous year (2018). Off-season drought (May-July 2019) reduced rice exports by about THB15 billion or 0.1 per cent of Thailand's GDP. Delays in rainfall or lower water in the reservoir each year affect both in-season and off-season rice yields.

The aerobic rice system (ARS) is a new technology used to cultivate rice under water shortage (Bouman, 2001; Bouman et al., 2005; Prasad, 2011). Yields were confirmed by testing in six seasons at the International Rice Research Institute (Bouman, 2005). The concepts of aerobic rice are growing under non-flooded, lower plant

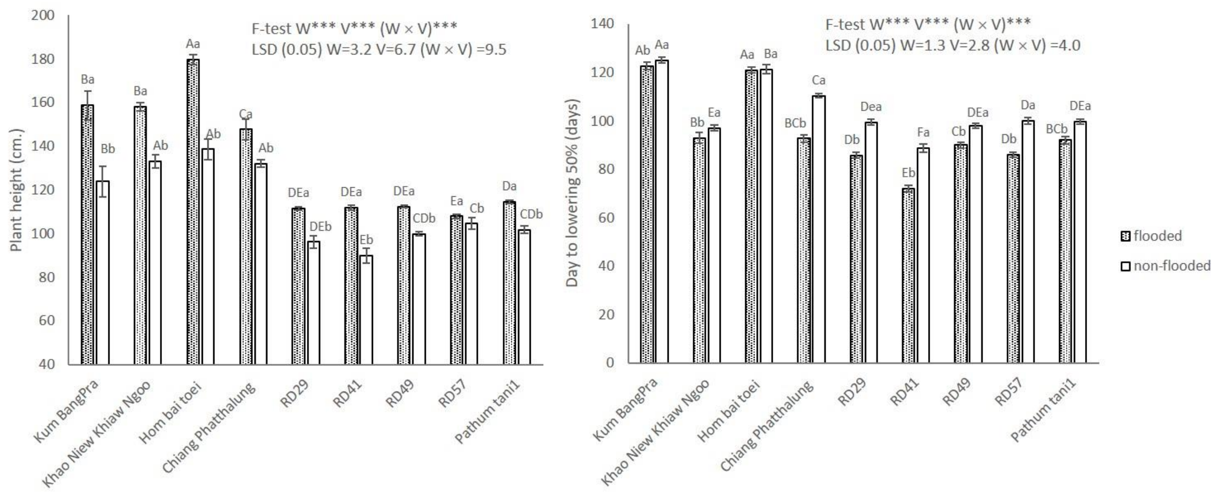

Fig 1. Plant height (a) and day to flower 50% (b) of nine rice varieties under flooded and non-flooded conditions. F-test of soil water level (W), variety (V) and interaction between soil water level and variety (W x V) were presented at the top of figure. *** = significant difference at $p< 0.001$. Bars indicate mean ± SE. Different upper case later indicate significant difference between variety and lower case indicate significant difference water condition according to LSD Fisher test in a confidence interval of 95%.

density, mulching, and minimum tillage. Rice variety is one of the most important factors when using the aerobic rice system. Some rice varieties have been grown for a long period under flood conditions. Therefore, they cannot adapt to aerobic soil. Differences in responses to aerobic soil may be a result of photosynthesis and the transpiration efficiency of each variety (Gu et al., 2012). In China, a new rice variety (Han Dao 502) has been specifically developed for aerobic rice system (ARS), which showed lower water use all season and relatively high yield compared to the lowland rice variety (Bouman et al., 2002). However, breeding new rice varieties requires a long period. Therefore, using germplasm within the country is an easy and rapid way to cope with drought or water limitations in the future.

Thailand is a country with significant rice diversity due to variation in ecology (Vejchasarn et al., 2021). Therefore, different improvements in location and different parents may result in varying adaptation to aerobic soil. Moreover, most of the varieties used during the in-season are local varieties, while the off-season uses modern rice varieties. These varieties are affected by water shortages. Therefore, this project aimed to determine the responses of modern and local Thai rice varieties under aerobic soil.

Results

Maximum and minimum temperature in greenhouse

The average temperature throughout the season was 30°C, while the maximum and minimum temperatures were 35°C and 24°C, respectively.

Responses of modern and local Thai rice varieties under aerobic and anaerobic soil

Water level, variety, and interaction between water level and variety significantly affected plant height, flowering date, number of tiller plants^{-1}, number of panicle plants^{-1}, number of spikelet panicles^{-1}, number of filled grain panicles^{-1}, number of empty grain panicles^{-1}, percentage of filled grain and grain yield plants^{-1} (Table 2). Plant height under anaerobic soil varied between 108-180 cm, while aerobic soil varied between 90 -139 cm (Figure 1a). The highest reductions in plant height were found in Hom bai toei and Kum BangPra at 22% compared to anaerobic soil followed by RD41 at 20%, while the lowest was found in RD57 at 3% and the other ranged between 10-15%. In the aerobic soil, the number of day to 50% flowering was delayed for almost all varieties except for Hom bai toei. Under aerobic soil, Chiang Phatthalung and RD41 flowered about 16-17 days later compared to anaerobic soil, followed by RD57 at 14 days, while the others were between 2-8 days (Figure 1b). The number of tiller plants^{-1} was decreased in all varieties growing under aerobic soil compared to anaerobic soil (Figure 2a). Under anaerobic soil, the number of tiller plants^{-1} varied from 11-19, while it was 6-10 under aerobic soil. The highest reduction was found in RD41 (57%) followed by PTT1, Hom bai toei, and Chiang Phatthalung at 54%, while the lowest was found in RD57 and Khao Niew Khiaw Ngoo at 42%. Under aerobic soil, modern rice varieties provided 8-10 tiller plants^{-1} which were higher than the local rice varieties providing 5-7 tiller plants^{-1}. The panicle plants^{-1} under anaerobic soil varied between 11 -17, while it was

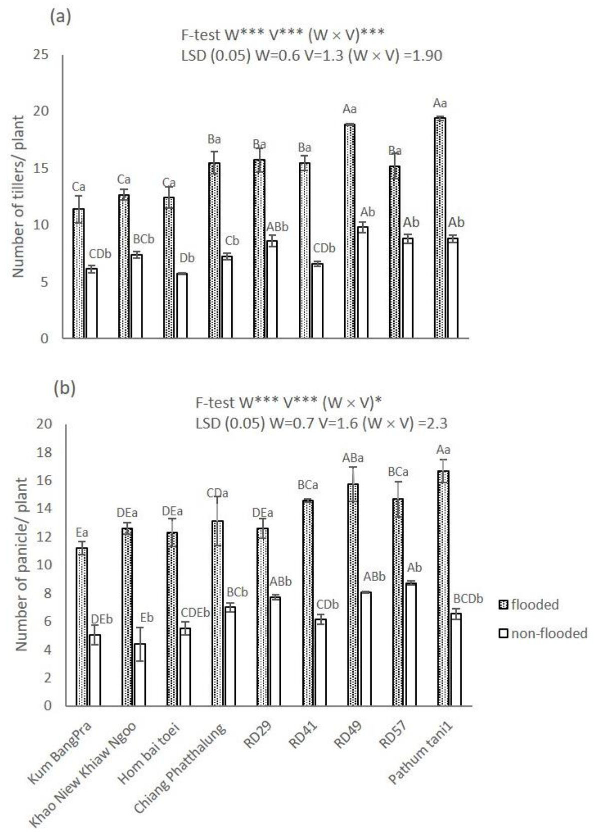

Fig 2. Number of tiller plant^{-1} (a) and number of panicle plant^{-1} (b) of nine rice varieties under flooded and non-flooded conditions. F-test of soil water level (W), variety (V) and interaction between soil water level and variety (W x V) were presented at the top of figure. *, *** = significant difference at *p*< 0.05 and 0.001, respectively. Bars indicate mean ± SE. Different upper case later indicate significant difference between variety and lower case indicate significant difference water condition according to LSD Fisher test in a confidence interval of 95%.

4-9 panicle plants^{-1} under aerobic soil (Figure 2b). The highest reduction was found in Khao Niew Khiaw Ngoo (65%) followed by PTT1 (60%), while the lowest was found in RD29 and RD57. Under anaerobic soil, the number of spikelet panicles^{-1} varied between 150 -232 spikelet panicles^{-1}, while it was 120-203 spikelet panicles^{-1} under aerobic soil (Figure 3a). Increasing spikelet panicles compared to aerobic soil were found in RD57 and RD49 (2-8%), while the others were reduced. The lowest reduction was found in Hom bai toei at 39%. The number of filled grain panicles^{-1} varied between 42 - 218 under anaerobic soil, while it was 23 -161 grain panicles^{-1} under aerobic soil (Figure 3b). The highest reduction was found in Kum BangPra (63%) followed by Hom bai toei (54%), while the lowest was found in RD49 (10%) and RD57 (3%). The number of unfilled grain panicles^{-1} was lower under anaerobic compared to aerobic soil, except for Chiang Phatthalung (Figure 3c). The number of empty grain panicles^{-1} under anaerobic soil varied between 20-107 grain panicles^{-1}, while it was 28-112 grain panicles^{-1} under aerobic soil. The highest increase of empty grains was found in PTT1 and RD41 (60%). For the percentage of filled grains, all varieties provided a lower percentage of filled grains under aerobic soil conditions, except Chiang Phatthalung (Figure 3d). Under anaerobic soil, the percentage of filled grain varied between 28-95%, while it was 17-83% under anaerobic soil. The highest reduction was found in Kum BangPra (54%) followed by PTT1 (40%). For the harvest index (HI), we found that HI was higher in most varieties in aerobic soil than anaerobic, except for PTT1, which was lower than anaerobic soil (Figure 4a). Three varieties showed no difference between aerobic and anaerobic soil, including Kum BangPra, Hom bai toei, and RD41. Grain yield plants^{-1} under anaerobic soil varied between 22-46 gram plants^{-1}, while it was 11- 22 gram plants^{-1} under anaerobic soil (Figure 4b). Under aerobic soil conditions, grain yield plants^{-1} were lower than anaerobic soil for all varieties. The largest reduction was found in Hom bai toei (69%) followed by Kum BangPra and PTT1 at 60%, while the lowest was found in Khao Niew Khiaw Ngoo (34%). However, it showed the lowest grain yield compared to others.

Correlation analysis

Correlation between yield and 8 agronomic characteristics was analysed. We found that grain yield was highly correlated with the percentage of filled grain (R=0.8***) under anaerobic soil, while grain yield was highly correlated with the number of panicle plants^{-1} (R=0.75***) under aerobic soil (Table 3).

Discussion

The growth and development of rice was lower under aerobic soil than anaerobic soil. However, the response to aerobic soil was varied between variety and growth stage. Growth under aerobic soil significantly reduced the plant height of all local rice varieties except Chiang Phatthalung, while slightly reducing modern rice varieties.

In terms of yield components, the reduction of the number of tiller plants^{-1} and panicle plants^{-1} including grain yield plants^{-1} of modern rice varieties was larger than local rice varieties. However, they still provided a higher number of tiller plants^{-1} than the local rice varieties, especially RD29, RD49, and RD57. These results were consistent with the number of spikelet panicles^{-1}, number of filled grain panicles$^{-1,}$ and percentage of filled grain. Most of the modern rice varieties were not affected in aerobic soil except for PTT1, which showed a lower number of spikelet panicles^{-1}

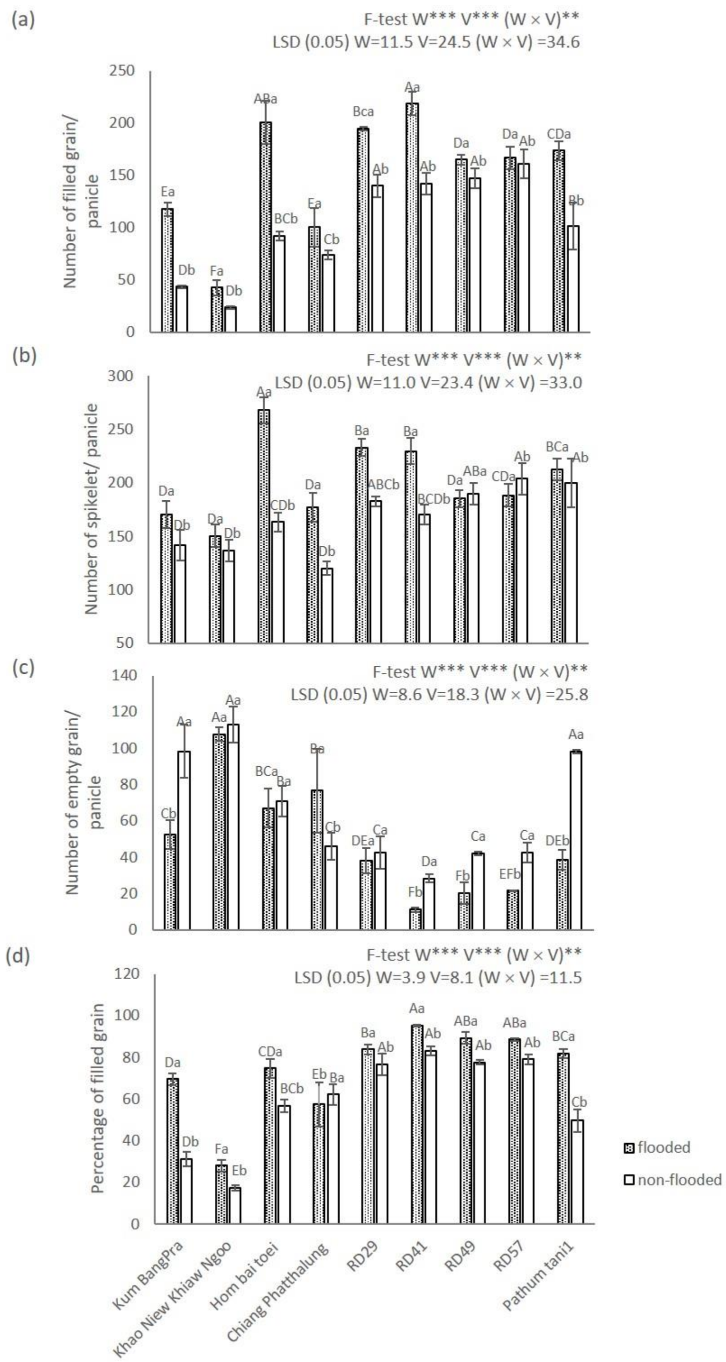

Fig 3. Number of spikelet panicle^{-1} (a) number of filled grain panicle^{-1} (b), number of unfilled grain panicle^{-1} and (c) percentage of filled grain (d) of nine rice varieties under flooded and non-flooded conditions. F-test of soil water level (W), variety (V) and interaction between soil water level and variety (W x V) were presented at the top of figure. **, *** = significant difference at p< 0.01 and 0.001, respectively. Bars indicate mean ± SE. Different upper case later indicate significant difference between variety and lower case indicate significant difference water condition according to LSD Fisher test in a confidence interval of 95%.

and percentage of filled grain as well as higher empty grain panicles^{-1}. This result was in accordance with some studies that reported PTT1 is the drought-sensitive variety at the reproductive stage (Yooyongwech et al., 2013). The large reduction of spikelet panicles^{-1} and filled grain panicles^{-1} in Hom bai toei and Kum BangPra and lower number of panicle plants^{-1} in Khao Niew Khiaw Ngoo may be a result of the location of improvement. Hom bai toei and Kum BangPra were selected for cultivating in lowland areas during the wet season, especially the Central plain and East of Thailand. Most of this area faces flooding in the wet season. Therefore, these genotypes are well adapted to anaerobic soil. Meanwhile, Khao Niew Khiaw Ngoo was selected for cultivation in northern Thailand. However, they were suggested for the area without water shortage, indicating that this variety has not faced drought stress under the selection program.

There was an interesting local rice variety: Chiang Phatthalung. This variety provided higher HI under aerobic soil compared to anaerobic soil, which was a result of the lower plant height and number of tiller plants^{-1}, while the percentage of filled grain was high. Lodging is a problem in some varieties with higher plant heights (Pimratch et al., 2019). Therefore, the lower plant height in Chiang Phatthalung may be more suitable for cultivation. This variety is a local rice variety improved by mass selection and adaptation under flood and drought conditions in southern Thailand. Bouman (2006) reported that different HI was varied depending on the response to soil moisture. HI of the modern rice varieties was higher than local both under anaerobic and aerobic soil except for Chiang Phatthalung, indicating that modern rice variety and Chiang Phatthalung had high water use efficiency. Li-ka and Bua-bor-bae are local rice varieties in the north of Thailand that are recommended for growing under non-flooded conditions (Rungcharoen et al., 2014). Therefore, there will be other local rice varieties that provide better growth and yield when grown under aerobic soil.

The yield and yield components of modern rice varieties RD29, RD49, and RD57 were higher than others under aerobic soil because most RD rice varieties were generated from the IR variety (Table 1). The IR rice variety was developed to cope with environmental fluctuations such as drought tolerance and heat tolerance (Khush, 2005). Donor heat tolerance genes in rice are IR22, IR2307-247-2-2-3, IR6, IR8, and MRC603-838 (Ali and Wani, 2021). For modern rice varieties RD10, CNT1, and SPR1 were heat-tolerant varieties at the anthesis stage (Sukkeo et al., 2017). Therefore, RD rice varieties should be considered for rice production in Thailand during the off-season, having lower water availability.

Table 1. Description of 9 rice varieties used in this experiment.

Varieties	Pedigree	Ecosystem	Sensitivity to photoperiod
Kum BangPra	Local rice	Rainfed lowland	Photoperiods sensitivity
Khao Niew Khiaw Ngoo	Local rice	Rainfed lowland	Photoperiods sensitivity
Hom bai toei	Local rice	Rainfed lowland	Photoperiods sensitivity
Chiang Phatthalung	Local rice	Rainfed lowland	Photoperiods sensitivity
RD29	SPR 60/ IR29692-99-3-2-1// IR11418-19-2-3	Irrigated lowland	Photoperiods insensitivity
RD41	CNT85059-27-1-3-2/ SPR60// RP217-635-8	Irrigated lowland	Photoperiods insensitivity
RD49	IR66738-118-1-2 / IR68544-29-2-1-3-1-2 //PSL00508-3-1-1-4	Irrigated lowland	Photoperiods insensitivity
RD57	SPR1/IR64	Irrigated lowland	Photoperiods insensitivity
PTT1	BKNA6-18-3-2 / PTT85061-86-3-2-1	Irrigated lowland	Photoperiods insensitivity

Table 2. Analysis of Variance of 9 agronomic traits of 9 rice varieties grown under flooded and non-flooded conditions.

Characteristic	Water level (W)	Variety (V)	W x V
Plant height (cm.)	***	***	***
Flowering date	***	***	***
Number of tiller/ plant	***	***	***
Number of panicles/ plant	***	***	*
Number of spikelets/ panicle	***	***	**
Number of filled grain/ panicle	***	***	**
Number of empty grain/ panicle	***	***	**
Seed set (%)	***	***	**
Grain yield/ plant (g.)	***	***	***
Harvest Index	ns	***	**

ns = non-significant at $P<0.05$

*,** and *** = significant different at $P<0.05$, 0.01 and 0.001, respectively

Table 3. Correlation between yield and 8 agronomic characteristics of 9 rice varieties under flood and non-flood condition.

characteristics	Flooded		Non-flooded	
	Correlation (C)	P-value	Correlation (C)	P-value
Day to flowering 50%	-0.30	ns	-0.58	<0.001
Plant height	-0.62	<0.001	0.69	<0.001
Number of tiller plant^{-1}	0.42	<0.05	0.63	<0.001
Number of panicle plant^{-1}	0.49	<0.001	0.75	<0.001
Number of spikelets panicle^{-1}	0.46	<0.05	0.56	<0.001
Number of filled grain panicle^{-1}	0.75	<0.001	0.71	<0.001
Number of empty grain panicle^{-1}	-0.74	<0.001	-0.51	<0.001
Percentage of filled grain	0.8	<0.001	0.63	<0.001

* ns=non-significant at $P<0.05$

The highly significant correlation between grain yield and percentage of filled grain under anaerobic soil, and number of panicle plants^{-1} under aerobic soil indicated that the productivity of panicle initiation depended on fertilisation and grain filling under sufficient water. Meanwhile, grain yields depended on panicle initiation under insufficient water. A lower number of panicle plants^{-1} results in lower grain yield for rice growing under aerobic soil. Therefore, the panicle initiation stage should be focused first when there is a water shortage. This result was consistent with Yan (2010), who reported that panicle number was the main factor limiting grain yield in rice. Akram (2013) reported that, under a water deficit, all yield components positively correlated with grain yield except empty grain panicle^{-1}.

Materials and methods

Plant materials

Rice materials used in this study consisted of 9 lowland rice varieties (Table 1). Kum BangPra, Khao Niew Khiaw Ngoo, Hom bai toei, and Chiang Phatthalung are local rice

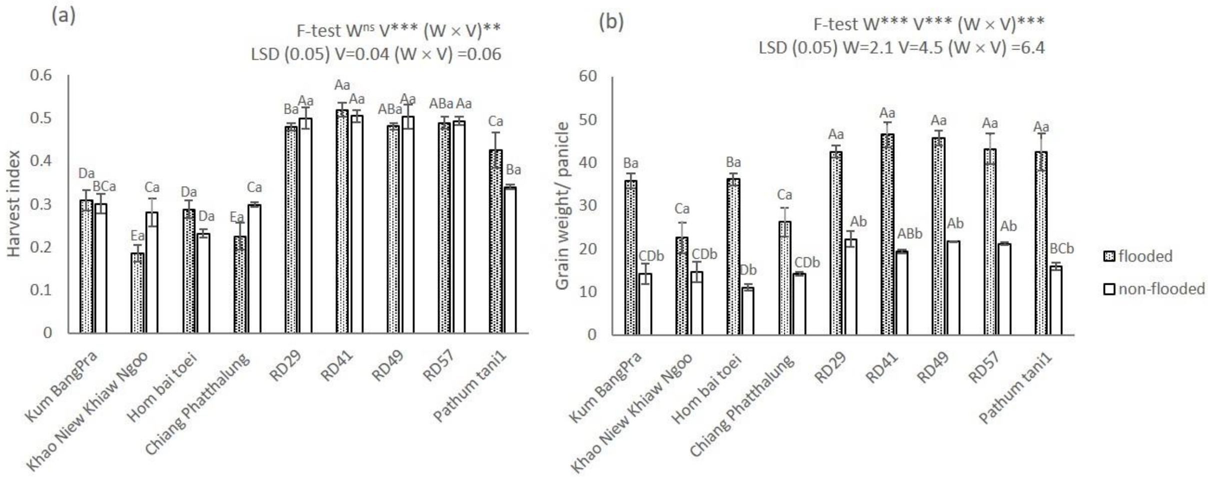

Fig 4. Harvest index (a) and grain weight plant^{-1} (b) of nine rice varieties under flooded and non-flooded conditions. F-test of soil water level (W), variety (V) and interaction between soil water level and variety (W x V) were presented at the top of figure. ns = non significant. **, *** = significant difference at *p*< 0.01 and 0.001, respectively. Bars indicate mean ± SE. Different upper case later indicate significant difference between variety and lower case indicate significant difference water condition according to LSD Fisher test in a confidence interval of 95%.

varieties with photoperiod sensitivity, while RD29, RD41, RD49, RD57, and Pathum Tani1 are modern rice varieties with photoperiod insensitivity.

Soil water management

Soil water levels were divided into two treatments: aerobic and anaerobic soil. The aerobic soil is in a flooded state, while the anaerobic soil is in a non-flooded state. In the aerobic soil, soil was well-drained, not saturated and irrigation was applied when the plant required water. For anaerobic soil, the water level was increased gradually after transplanting until the seedling was well-established and maintained for 30 days before harvesting.

Experimental design

This experiment was conducted in factorial design arranged in completely random design (CRD) with three replications. The first factor was rice variety, consisting of nine varieties, and the second was soil water level, composed of two levels (aerobic and anaerobic). Seeds were soaked for 1 night then incubated at room temperature for 48 hrs. Seeds were placed in a petri-dish for 7 days to allow for germination. Uniform seedling of each variety was transplanted on 1 June 2020 in plastic pots size 30 cm in diameter and 30 cm in depth containing 10 cm soil sandy loam leaves from the top of the pot. Each pot contained 5 plants (1 plant/ hill) representing 1 replication. All pots were placed in a greenhouse covered with plastic to protect the soil from rain. Ammonium phosphate fertiliser (16-20-0) 20 kg/rai and urea fertiliser (46-0-0) 10 kg/rai were applied at 30 and 45 days after transplanting, respectively.

Data collection and data analysis

Temperature and humidity were recorded throughout the season. Day to flowering at 50% was recorded when rice flowered at 50% of the pot. At physical maturity, plant height, number of tiller plants$^{-1,}$ and number of panicle plants^{-1} were collected. Two panicles were randomised and collected to determine the number of spikelet panicles^{-1}, number of filled grain panicles^{-1}, number of empty grain panicles$^{-1,}$ and seed setting (%). Harvest index (HI) and grain yield plants^{-1} were collected. All data were analysed by Analysis of Variance (ANOVA) according to the experimental design, and mean values were compared by Least Significant Difference (LSD) using Statistix V.8.0; Analytical software. Correlation analysis was used to test the relationship between yield and agronomic characteristics.

Conclusion

From the results, it can be concluded that there were different responses to aerobic soil. The rice varieties that were well adapted in aerobic soil tended to be found in modern rice varieties containing the IR gene compared to the local rice varieties. Modern rice RD29, RD49, and RD57 and local rice Chiang Phatthalung were the varieties that tended to be more tolerant to drought. These rice varieties were suggested as suitable for growing in areas with limited water. During a water shortage, panicle initiation or boot staging should be executed. Irrigation should be applied in this stage. However, Thailand is located in the centre of rice diversity. Therefore, this method should be expanded to other varieties, which will provide a larger database of rice varieties that can grow under drought conditions or water shortages in the future.

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