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Full Paper

Influence of seed priming and soil water content on growth and yield of two rice cultivars grown under greenhouse conditions

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Abstract: The objective of this research is to investigate the effects of seed priming and short-duration drought on the early growth stages and yields of two rice (*Oryza sativa* L.) cultivars under greenhouse conditions. The experiment was laid out in a split-split plot design with four replications. Two rice cultivars (KDML 105 and RD6) were assigned in the main plots. Four water irrigation treatments, viz. 100% field capacity (100% FC), the control (W0), and three irrigation treatments of 50% FC applied over a 14-day period (10-25, 26-40 and 41-55 days after planting), were assigned in sub-plots. Three treatments of seed priming, assigned in sub-sub plots, consisted of the untreated control, gibberellic acid and wood vinegar. Relative water content (RWC), plant height, leaf area and shoot dry weight under irrigation with 50% FC in all stress periods were significantly lower than those in the 100% FC control, while grain yield was not significantly different. The RD6 cultivar had significantly higher RWC and plant height than did the KDML 105 cultivar, though they were not significantly different in grain yield. The results lead to the conclusion that rice seeds primed with wood vinegar better maintained RWC and crop growth, resulting in an improved grain yield under water-shortage conditions in both rice cultivars.

Keywords: seed priming, gibberellic acid, wood vinegar, rice, soil water content

INTRODUCTION

Throughout Thailand, the rapid growth of urbanisation and industrialisation has created a high consumption of water resources, and has thereby decreased the water resources available for farming [1]. In response to increasing water shortages, farmers, especially rice growers, have changed their cropping patterns [2]. The agronomic practice of transplanting rice seedlings into a flooded area has declined in rainfed regions of Asia because this practice requires additional water and is time-consuming, labour intensive and very costly [3]. Therefore, most farmers in Asia practice more sustainable techniques by shifting conventional transplanting to dry-direct rice seeding, i.e. sowing the dry rice seeds on moist (non-saturated) soil at the start of the rainy season. This method saves more water than does wet-direct rice seeding or water rice seeding [4].

In this sowing period crops are frequently affected by drought stress during the seedbed and vegetative growth stages. This stress causes poor seed germination and erratic crop stand [3]. Short periods of water deficit at the germination stage are highly detrimental to rice farming and productivity [5], and soil moisture stress during the early growth stages may result in high mortality rates, leading to poor crop performance [6], reportedly reducing the yield by 15-35% for rainfed lowland rice [7].

Fast germinating seeds improve seedling growth due to an efficient use of available soil moisture. Seed priming is a technique for enhancing seed germination. The process of seed priming includes partial seed hydration up to the start of the germination process and just before radicle emergence. The seeds are then re-dried to their initial moisture content [8]. Seed priming reduces emergence time, achieves uniform emergence and improves stand establishment [9]. Primed sorghum seeds are more tolerant to abiotic stress conditions [10] by reducing lipid peroxidation, stabilising the cell membrane and increasing stress tolerance under drought or excessive soil moisture environments [11]. On-farm seed priming increases yields of maize and chickpeas (*Cicer arietinum* L.) due to rapid seed germination and growth of seedlings, given a sufficient production of a deep root system before drought [10].

Plant growth regulator hormones such as gibberellic acid (GA_3) and natural plant growth hormones like wood vinegar (pyroligneous acid) are widely used in the field of agriculture to promote seed germination, crop growth and yield. GA_3 is the most important growth regulator as it regulates protein synthesis [12], breaks down seed dormancy, increases leaf size and promotes seed germination, intermodal length, hypocotyl growth, cell division [13] and enzyme production [14]. Watanabe et al. [15] found that rice seeds hydro-primed with GA_3 gave an increased seedling growth. Wood vinegar is a dark liquid by-product from charcoal burned under airless conditions. It consists of hundreds of chemicals such as acetic acid, phenolics, alkones, alcohols and esters [16]. Previous studies reported that wood vinegar promotes growth as well as increases root branching and the catalyst activity of rice roots under laboratory conditions [17]. Soaking rice seeds in 1:300 (v/v) wood vinegar solution before sowing combined with foliar application with the same solution every 14 days during the growing season significantly increases plant height, total root length per plant, root surface, panicle numbers, seed numbers and total seed yield under wet-direct rice seeding conditions [18]. The practice also promotes germination and the radicle growth of lettuce (*Lactuca sativa*), watercress (*Nasturtium officinale*), honewort (*Cryptotaenia canadensis*) and chrysanthe- mum (*Chrysanthemum indicum*) [19].

Rapid germination and rapid shoot and root growth are important seedling vigour-related traits under drought stress conditions [20]. When crops experience water stress, root adaptation is an important mechanism for protecting against drought stress. Root length and root length density have been shown to play a significant role in adapting to drought stress. These traits may be used as criteria for selecting rice genotypes with drought tolerance [21]. Previous studies have found that priming of rice seeds increases root and shoot length, seedling weight, and the number of secondary roots under laboratory conditions [9]. However, different rice varieties are known to respond differently to drought stress at various developmental stages such as during tilling and panicle initiation phases [22], but this response to seed priming and water stress at different growth stages as well as the interactions among these factors has not been thoroughly investigated. Moreover, the information on physiological and morphological traits such as shoot and root development characteristics is important for improving rice yields. Thus, the objective of this study is to evaluate the effects of seed priming treatment and soil water content applied at early growth stages on growth and grain yield of two rice cultivars under greenhouse conditions.

MATERIALS AND METHODS

Location and Experimental Design

The experiment was conducted under greenhouse conditions at the Greenhouse Complex, Faculty of Agriculture, Khon Kaen University from March to December 2014. It was laid out in a split-split plot design with four replications. Two of Thailand's north-eastern rice cultivars, i.e. Khao Dawk Mali 105 (KDML 105) and Rice Division 6 (RD6), were assigned in the main-plots. Four irrigation treatments, contained within 100% field capacity (FC), were assigned in the sub-plots, i.e. the control (W0) and 50% FC applied during a 14-day period at 10-25 days after planting (DAP) (W1), 26-40 DAP (W2) and 41-55 DAP (W3). Three seed-priming treatments, assigned in sub-sub-plots, consisted of no treatment (control), GA_3 treatment and wood vinegar treatment.

Seed Treatment

Seeds of KDML 105 and RD6 cultivars were received from the Agricultural Co-operative, Khon Kaen province. Seed moisture content (SMC) was determined using three seed samples according to the recommendations of Ellis et al. [23]. The average SMC of KDML 105 and RD6 were obtained 1) at initial values of 10.69% and 11.21% respectively; 2) after the priming process, at 30.32% and 31.73% respectively; and 3) after dehydration at11.00% and 11.65% respectively.

All seeds (including the untreated control) were surface-sterilised prior to the start of the experiment, using 5% (v/v) sodium hypochlorite solution (1.25 L per 250 g of seeds) to control fungal diseases. They were then rinsed 3 times with distilled water and dried with tissue paper [24, 25]. For GA_3 hydro-priming treatment, seeds were soaked with 100 ppm of GA_3 (Institute of Biotechnology and Genetic Engineering, Chulalongkorn University) for 48 hr [17]. For wood vinegar hydro-priming treatment, seeds were soaked with wood vinegar (TPI Polene Bio-organic Co., Bangkok) and distilled water (1:300 (v/v)) for 48 hr [26]. All priming treatments were applied at room temperature (25±3°C) [26], after which the seeds were rinsed again 3 times with distilled water. They were re-dried with an air-dryer (SKK 09, Ceres International Co., Bangkok) for 10 hr or until an equilibrial seed moisture content at 30°C was reached. Seeds were sealed in polythene bags and stored in a refrigerator at 15ºC and 50% relative humidity for up to 30 days until the experiment was conducted.

Nursery Husbandry

Plants were grown in plastic pots, 35 cm in height and 14 cm in diameter. The plant setting was divided into four sets for data collection in each treatment. Sets 1-3 consisted of 48 pots, whereas set 4 consisted of 96 pots. Crop growth trait data were collected from the first, second and

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third sets on the last day after the crops experienced water stress at 25, 40 and 55 DAP respectively. The fourth set was collected at harvest (120 DAP).

Soil samples were air-dried, crushed and sieved with a 2-mm wire mesh and randomly collected for a three-point analysis of their physical and chemical properties. Soil textural classes were sandy (91.71%), silt (6.57%) and clay (1.72%) as established through the Pipette method [27]. Soil chemical properties were found follows: 0.006% total nitrogen (Kjeldahl method) [28], 3.46% available phosphorus (Bray II and molybdenum-blue method) [29], 12.2 mg kg^{-1} exchangeable potassium (1N NH_4OAc pH 7 and Flame photometry method) [28], 0.12% organic matter (Walkley and Black method) [28], 1.68% cation exchange capacity (ammonia-electrode method) [28] and pH 4.79 (pH meter). Soil samples were also collected from three positions in the field in order to determine their field capacity (FC) and permanent wilting point (PWP) at depths of 0-10, 10-20, 20-30, 30-40, 40-50 and 50-60 cm below soil surface level (Abbott method) [30]. The average FC and PWP values were 14.52% and 5.42% respectively.

The plastic pots were loaded with 14 kg of dry soil, which were crushed and sieved for uniform bulk density. A chemical fertiliser (46% N_2, 18% P_2O_5 and 50% K_2O) was applied to the pots at planting at a rate of 156 kg ha^{-1} (0.13 mg pot^{-1}). Ten seeds were sown per pot and then irrigated to obtain 100% FC in order to ensure uniform crop emergence until 9 DAP. The seedlings were later thinned to two plants per pot at 7 DAP. Nitrogen fertiliser (46% N_2) was applied again at a rate of 63 kg ha^{-1} in the panicle initiation stage.

Irrigation

Soil moisture content was maintained in the 100% FC control (W0) treatment from 0 to 60 DAP, whereas the other three treatments were controlled at the FC level prior to any water shortage and then irrigated to obtain 50% FC for a 14-day period, at 10-25 DAP (W1), 26-40 DAP (W2) and 41-55 DAP (W3). All plastic pots were weighed daily and any water loss in each pot was replenished.

Upon the completion of the drought stress imposed in each treatment, the crops were re-irrigated at their respective FC level until 60 DAP. All treatments maintained a water level at 5 cm above soil surface from 60 to 100 DAP, after which the plastic pots were irrigated at the required FC levels until harvest (120 DAP).

Soil and Plant Water Status

Soil water content (SWC) was measured by gravimetric method (micro-auger) [31] at 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 cm from soil surface prior to planting and again every seven days until 55 DAP. Wet soil samples were weighed to obtain wet weight and oven-dried at 105°C for 72 hr to determine dry weight. The SWC was calculated using the following formula: SWC (%) = [(Soil wet weight – Soil dry weight) / Soil dry weight] × 100.

Relative water content (RWC) was measured on the last day of drought stress, which occurred at 25, 40 and 55 DAP. Two of the second or third leaves (next to flag leaf) were chosen as leaf samples from each pot. The leaves were cut between 10.00-12.00 a.m. at a length of 15 cm from the leaf tip and then re-cut into three parts, 5 cm in length. The leaves were stored in a plastic bag and put in an ice box to avoid water loss and maintain fresh weight. The leaf samples were then soaked in distilled water in a dark room for 8 hr at 25°C. Water-saturated leaves were wiped with tissue paper, weighed and oven-dried in an air oven (Memmert Universal Oven UF 750, Memmert

Gmblt+Co.KG, Germany) for 48 hr at 80°C or until the weight was constant. RWC was calculated according to Turner [32] through the following the formula: RWC (%) = [(Leaf fresh weight- Leaf dry weight)/ (Leaf turgid weight-Leaf dry weight)] x100.

Shoot and Root Growth Analysis

Shoot and root growth parameters were obtained on the last day of drought stress (with similar plant water status) and at harvest (120 DAP). Plant height was averaged in all plants in each replication. Leaf area was recorded in all leaves in each replication at 25, 40 and 55 DAP using a leaf area meter (LI-3100C Area Meter, LI-COR Inc., USA). The plants were cut at underground level and oven-dried in the air oven for 48 hr at 80°C or until constant dry weight was obtained.

Root length was measured using a root scanner (Epson Perfection V700 Photo, Seiko Epson Co., UK) and analysed using Win RHIZO program (Win RHIZO pro V2004a, Reagent Instruments Inc., Canada). Root samples were oven-dried in the air oven for 48 hr at 80°C or until constant dry weight was obtained. Root-to-shoot (R:S) ratio was calculated from root dry matter and shoot dry matter. Root length density (RLD) was obtained through the following formula: RLD (cm^{-3}) = Total root length (cm) / Plastic pot volume (cm^3).

Yield and Its Components

Yield and its component traits (panicle number per pot, total grain number per panicle and 1000-grain weight) were measured at harvest stage. Grain yield was measured from the total filled grain weight of each pot at 14% seed moisture. Harvest index (HI) was calculated through the following formula: HI = (Total grain weight (g) / Biological yield (g).

Data Analysis

Analysis of variance (ANOVA) was performed according to split-plot design using Statistix, version 8 (STAT 8) software (Analytical Software, USA). Means were separated by the least significant difference at 0.05 probability level.

RESULTS

Soil Water Status

Figure 1 shows the SWC patterns at six soil levels (0-30 cm of each soil profile), irrigated at 100% FC and 50% FC, from 0 to 55 DAP. In the 100% FC control treatment the SWC was gradually reduced with time, but remained near the FC value (14.52%). The lowest SWC (11.00%) was obtained at 55 DAP (Figure 1A). For the 50% FC treatments (0-7 DAP), the SWC in each drought treatment remained close to their respective FC level. While amounts of irrigating water were reduced to create drought at 50% FC at 10 DAP, the SWC in each drought treatment steadily declined and remained close to the PWP level at 23 DAP (three weeks after planting) through 55 DAP. The lowest soil moisture content (5.42%) was obtained at 55 DAP (Figure 1B).

Plant Water Status

Seed priming treatments caused significant difference ($P \leq 0.05$) in RWC at 25 and 40 DAP, yet there was no significant difference at 55 DAP (Table 1). At 25 DAP, wood vinegar (96%) scored significantly higher than the untreated control (89%), while GA_3 (92%) was not significantly higher. The interactions between these sources of variation were not significant.

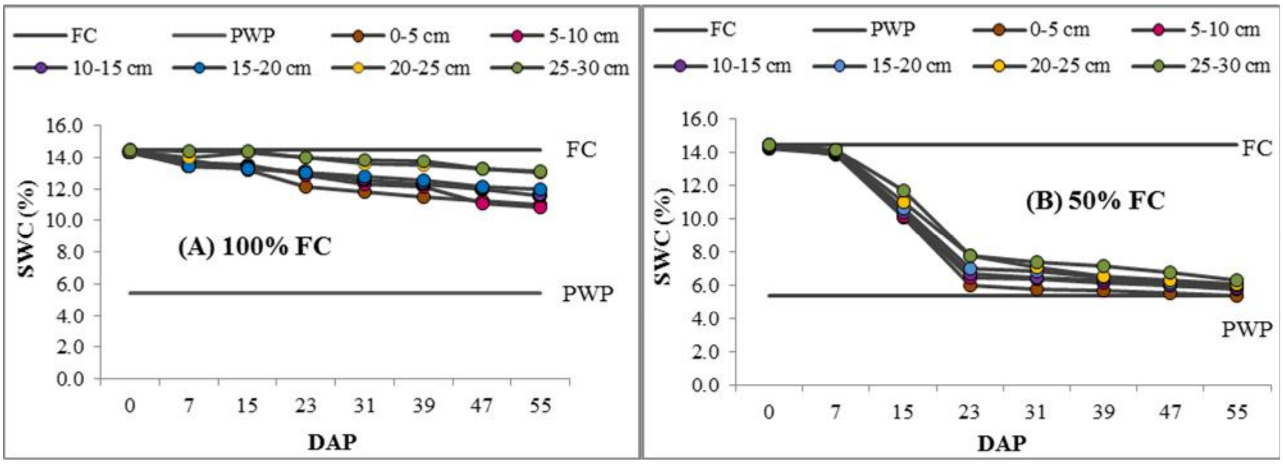

Figure 1. SWC at depth levels of 0-5, 5-10, 10-15, 15-20, 20-25 and 25-30 cm

Irrigation treatments caused significant difference ($P \leq 0.05$) in RWC at 25, 40 and 55 DAP. The irrigation treatments of 50% FC in all periods of the early growth stages gave significantly lower RWC (68-92%) than that from the 100% FC control (91-96%) (Table 1). Rice cultivars did not make significant difference in RWC at 25 and 55 DAP, although they did ($P \leq 0.05$) at 40 DAP, when the RD6 cultivar gave significantly higher RWC (81%) than that by the KDML 105 cultivar (77%). The interactions between these sources of variation were not significant (Table 1).

Plant Height

Plant heights were not significantly different with different seed priming treatments at 25, 40 and 55 DAP, but they were ($P \leq 0.05$) at 120 DAP (Table 1). At 120 DAP, the untreated control (109.5 cm) gave significantly lower height than that by both the GA_3 (112.9 cm) and wood vinegar (113.4 cm) treatments.

Plant heights were not significantly different with different irrigation treatments at 25 and 40 DAP, but they were ($P \leq 0.05$) at 55 and 120 DAP (Table 1). At 55 DAP, the irrigation treatment of 50% FC for 14 days gave significantly shorter plants (60.6 cm) than that from 100% FC control (62.9 cm), whereas at 120 DAP, the 100% FC control gave the highest plant height (114.6 cm), which was significantly higher than those produced by all irrigation treatments of the 50% FC (110.9-111.1 cm).

Rice cultivars did not make significant difference in plant height at 25, 40 and 55 DAP, but they did ($P \leq 0.05$) at 120 DAP, when the RD6 cultivar (114.6 cm) was significantly higher than the KDML 105 cultivar (109.3 cm) (Table 1).

The interactions between cultivar and irrigation treatment and between cultivar and seed priming treatment were significant ($P \leq 0.05$) for plant height at 120 DAP, but not at 25, 40 and 55 DAP (Table 1). Both the RD6 and KDML105 cultivars showed different responses of plant height at 120 DAP under different irrigation and seed priming treatments (data not shown).

Leaf Area

Rice cultivars and seed priming treatments did not gave significant difference in rice leaf areas at 25, 40 and 55 DAP (Table 1), but irrigation treatments did make the difference ($P \leq 0.05$), where the leaf area from the 100% FC control (23.4-210.2 cm^2 pot^{-1}) was significantly larger than that from the irrigation treatments of 50% FC (11.2-85.2 cm^2 pot^{-1}). The interactions between these sources of variation were not significant in these traits.

Shoot Dry Weight

Seed priming treatments differed significantly in shoot dry weight ($P \leq 0.05$) at 25 DAP, but not at 40, 55 and 120 DAP (Table 1). At 25 DAP, wood vinegar gave significantly higher weight (0.24 g pot^{-1}) than that by both the untreated control (0.18 g pot^{-1}) and GA_3 (0.20 g pot^{-1}), whereas the latter two values did not differ significantly.

Irrigation treatments also gave significant difference in shoot dry weight ($P \leq 0.05$) at 25 and 40 DAP, but not at 55 and 120 DAP (Table 1). At 25 and 40 DAP, the weight from the 100% FC control (0.26-1.82 g pot^{-1}) was significantly higher than that from the 50% FC treatments imposed at 10-25 DAP (1.16 g pot^{-1}) and 26-40 DAP (1.22 g pot^{-1}). Rice cultivars did not give significant difference in shoot dry weight at 25, 40, 55 and 120 DAP. The interaction between irrigation treatment and seed priming proved significant ($P \leq 0.05$) only at 25 DAP, yet the interactions among these sources of variation were not significant (Table 1).

Root Growth Traits

Seed priming treatments and rice cultivars did not give significant difference in root length, root dry weight, RLD, or R:S ratio (Table 2).

Irrigation treatments gave significant difference ($P \leq 0.05$) in root length at 25, 40 and 120 DAP, but not at 55 DAP (Table 2). At 25 and 40 DAP, the 100% FC control gave a significantly longer root than that by the 50% FC at both 10-25 DAP and 26-40 DAP. At 120 DAP, the 50% FC treatment at 10-25 DAP gave the highest growth (243 cm), followed by that from the 50% FC at 41-55 DAP (234 cm), the 100% FC control (181 cm) and the 50% FC at 26-40 DAP (144 cm).

Irrigation treatments also gave significant difference ($P \leq 0.05$) in root dry weight at 25 and 40 DAP, but not at 50 and 120 DAP. At 25 and 40 DAP, the 100% FC control gave significantly higher weight than that by the irrigation treatments of 50% FC at 10-25 and 26-40 DAP.

The differences in RLD from different irrigation treatments were significant ($P \leq 0.05$) at 25, 40 and 120 DAP, but not at 55 DAP. The analysis of RLD followed the same pattern as the root length.

The R:S ratio from each irrigation treatment differed significantly ($P \leq 0.05$) at 55 DAP, but not at 25, 40 or 120 DAP. At 55 DAP, the 100% FC control gave a significant higher ratio than that from the 50% FC irrigation treatments at 41-55 DAP.

The interactions between these sources of variation were not significant for root length, root dry weight, RLD, or R:S ratio at 25, 40, 55 and 140 DAP, but they were significant for RLD at 120 DAP only (Table 2).

Grain Yield, Yield Components and HI

Seed priming treatments gave significant difference ($P \leq 0.05$) for grain yield, but not for panicle number per pot, grain number per panicle, 1000-grain weight, or HI (Table 3). Wood vinegar gave the highest grain yield (9.68 g pot^{-1}), which was significantly higher than that from the untreated control (8.02 g pot^{-1}), whereas that by GA_3 (8.74 g pot^{-1}) was not significantly different from that by the untreated control. Wood vinegar also gave the highest grain number per panicle, 1000-grain weight and HI, although the increases were not significant. Irrigation treatments did not give significant difference for panicle number, grain number per panicle, 1000-grain weight, grain yield, or HI (Table 3).

Rice cultivars gave significant difference ($P \leq 0.05$) for grain number per panicle, but not for panicle number, 1000-grain weight, grain yield, or HI (Table 3). The RD6 cultivar produced a significantly higher grain number per panicle (60 seeds panicle^{-1}) than that by the KDML 105 cultivar (52 seeds panicle^{-1}). The interactions between and among these sources of variation were not significant for panicle number per pot, grain number per panicle, 1000-grain weight, grain yield, or HI (Table 3).

DISCUSSION

Seed Priming Treatments

Seeds primed with wood vinegar gave seedlings which were better able to maintain the leaf water status under water shortages than were those from the untreated control, as indicated by the higher RWC values in this study. This might be due to lipid peroxidation reduction, cell membrane stability, or osmotic adjustment, similar to that occurred in sorghum, where an increase in proline resulted in a stress tolerance [11]. Seed priming with GA_3 or wood vinegar did not show significant effects on root growth as compared to the untreated control. Under wet-direct seeding condition, seed priming with wood vinegar did not show any significant effect on root dry weight [18]. The differences in results among different studies would be due to differences in experimental conditions as laboratory experiments were better controlled than were those conducted in the field.

Irrigation Treatments

In this study a water deficit of 50% FC was imposed on the crop at 10, 26 and 41 DAP for 14 days. The drought treatments at all intervals significantly reduced RWC, plant height, leaf area and shoot dry weight as compared to the 100% FC treatment. This was due to the water shortage or drought stress which inhibited the cell elongation and can be explained by the interruption of water flow from the xylem to the surrounding cells [33].

Irrigation treatments of 50% FC at 10-25 DAP and 26-40 DAP significantly reduced root length, root dry weight, RLD and R:S ratio as compared to the 100% FC control at 25 and 40 DAP. These findings agree with those of Manikavelu et al. [34], who reported that drought stress during the vegetative stage greatly reduces plant growth and development in rice. However at harvest, a water shortage at 10-25 DAP significantly increased root length and RLD as compared to the 100% FC control. This can be a result of the crops being subjected to water shortage at an early stage. Thereby young roots of the stressed plants develop more vigorous growth after re-watering.

In the present experiment irrigation treatments of 50% FC at all growth stages did not make significant difference in grain yield, panicle number per pot, grain number per panicle, or 1000-grain weight at harvest as compared to the 100% FC control. A water shortage for a short period at the vegetative growth stage was not detrimental to crop yield as the crop could recover at the end of drought. The 50% FC treatment proved not too severe and the available water was sufficient for the crop to resume growth. Additionally, seed priming resulted in increasing stress tolerance as mentioned earlier. The results indicate that the rice crop could maintain high RWC values (77-94%) under drought stress, provided that the rice seeds were primed before planting.

Table 1. Relative water content (RWC), leaf area, plant height and shoot dry weight of two rice cultivars treated with different water irrigation methods and seed priming methods under greenhouse conditions

	RWC (%)			Plant height (cm)				Leaf area (cm^2 pot^{-1})			Shoot dry weight (g pot^{-1})			
	DAP													
Treatment	25	40	55	25	40	55	120	25	40	55	25	40	55	120
Cultivar (C)														
KDML 105	93	77 b	93	39.9	48.1	61.8	109.3 b	17.0	80.6	141.4	0.20	1.58	1.66	16.70
RD6	92	81 a	94	38.8	50.1	61.8	114.6 a	17.6	80.2	153.8	0.20	1.56	1.80	16.70
F-test	ns	*	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
Water irrigation (W)														
100% FC control	96 a	91 a	95 a	42.3	52.0	62.9 a	114.6 a	23.4 a	123.0 a	210.2 a	0.26 a	1.82 a	16.80	17.01
50% FC at 10-25 DAP	89 b	-	-	36.3	-	-	111.1 b	11.2 b	-	-	0.16 b	-	-	17.00
50% FC at 26-40 DAP	-	68 b	-	-	46.0	-	110.9 b	-	38.0 b	-	-	1.22 b	-	15.80
50% FC at 41-55 DAP	-	-	92 b	-	-	60.6 b	111.1 b	-	-	85.2 b	-	-	1.70	17.21
F-test	**	**	**	ns	ns	*	*	**	**	**	**	*	ns	ns
Seed priming (S)														
Untreated control	89 b	74 b	93	38.6	49.2	62.5	109.5 b	15.4	79.4	145.2	0.18 b	1.54	1.70	16.52
GA_3	92 ab	81 a	94	37.5	46.8	61.5	112.9 a	17.8	80.6	145.8	0.20 b	1.48	1.74	16.66
Wood vinegar	96 a	82 a	93	41.9	51.3	61.5	113.4 a	18.6	79.4	143.0	0.24 a	1.56	1.76	16.92
F-test	*	*	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns
CxW	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
CxS	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns
WxS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
CxWxS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (C) %	7.3	1.2	4.4	11.5	15.8	14.6	6.3	15.2	22.3	53.2	20.0	15.4	13.1	20.5
CV (W) %	0.2	4.3	1.1	13.1	13.1	2.5	4.3	12.3	29.4	23.5	8.1	17.9	11.1	13.4
CV (S) %	6.5	13.3	7.9	12.9	8.9	6.8	5.5	27.3	13.6	18.3	17.1	11.0	14.0	17.8

Notes: Means followed by the same letter in the same column were not significantly different at $P \leq 0.05$ by least significantly difference.
ns, *, ** = non-significant, significant at $P \leq 0.05$ and significant at $P \leq 0.01$ probability levels respectively.
F-test = statistical test with F-distribution under null hypothesis; CV = coefficient of variation

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Table 2. Root length, root dry weight, root length density (RLD) and root-to-shoot (R:S) ratio of two rice cultivars treated with different water irrigation methods and seed priming methods under greenhouse conditions

	Root length (m pot^{-1})				Root dry weight (g pot^{-1})				RLD (cm cm^{-3})				R:S ratio			
	DAP															
Treatment	25	40	55	120	25	40	55	120	25	40	55	120	25	40	55	120
Cultivar (C)																
KDML 105	43	206	55	199	0.12	0.78	1.60	12.60	15.9	74.8	177.1	724.0	0.3	0.2	0.2	0.3
RD6	43	185	55	209	0.14	0.66	1.58	12.90	16.5	67.2	184.0	759.1	0.3	0.2	0.2	0.3
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Water Irrigation (W)																
100% FC control	52 a	240 a	63	181 b	0.16 a	0.86 a	1.86	12.60	19.3 a	86.9 a	219.5	710.4 b	0.3	0.2	0.3 a	0.3
50% FC at 10-25 DAP	34 b	-	-	243 a	0.12 b	-	-	12.68	13.2 b	-	-	880.2 a	0.3	-	-	0.3
50% FC at 26-40 DAP	-	152 b	-	144 c	-	0.58 b	-	12.42	-	55.0 b	-	524.8 c	-	0.2	-	0.4
50% FC at 41-55 DAP	-	-	46	234 ab	-	-	1.32	12.20	-	-	141.6	850.5 ab	-	-	0.2 b	0.4
F-test	**	**	ns	**	**	**	ns	ns	**	**	ns	**	ns	ns	*	ns
Seed priming (S)																
Untreated control	41	203	50	2080	0.14	0.80	1.52	12.50	16.1	73.8	169.7	753.7	0.3	0.2	0.3	0.4
GA_3	44	197	50	2201	0.12	0.70	1.56	13.00	15.6	67.9	168.9	797.5	0.3	0.2	0.3	0.4
Wood vinegar	44	187	63	1859	0.14	0.68	1.70	12.64	16.9	71.3	203.0	673.4	0.3	0.2	0.3	0.4
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CxW	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CxS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
WxS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CxWxS	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
CV (C) %	7.3	16.1	43.5	39.6	8.3	7.1	60.9	16.6	3.0	16.1	45.7	39.6	54.7	22.2	12.0	24.1
CV (W) %	8.9	5.9	38.4	36.0	5.9	11.0	36.6	15.1	12.9	5.9	35.3	36.0	30.3	31.0	22.9	12.2
CV (S) %	7.5	24.0	29.9	41.0	24.5	19.7	17.7	13.6	15.9	24.0	29.9	41.0	15.3	19.4	15.7	19.1

Notes: Means followed by the same letter in the same column were not significantly different at $P \leq 0.05$ by least significantly difference.
ns, *, ** = non-significant, significant at $P \leq 0.05$ and significant at $P \leq 0.01$ probability levels respectively.
F-test = statistical test with F-distribution under null hypothesis; CV = coefficient of variation

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Table 3. Panicle number, grain number per panicle, 1000-grain weight, grain yield and harvest index (HI) of two rice cultivars treated with different water irrigation methods and seed priming methods at harvest (120 DAP) under greenhouse conditions

Treatment	Panicle number (no. pot^{-1})	Grain number per panicle	1000-grain weight (g)	Grain yield (g pot^{-1})	HI
Cultivar (C)					
KDML 105	8	52 b	25.78	8.61	0.34
RD6	7	60 a	24.26	9.02	0.33
F-test	ns	**	ns	ns	ns
Water irrigation (W)					
100% FC control	7	59	24.31	9.03	0.34
50% FC at 10-25 DAP	8	51	25.35	8.82	0.34
50% FC at 26-40 DAP	7	56	24.25	8.04	0.33
50% FC at 41-55 DAP	7	58	26.26	9.35	0.35
F-test	ns	ns	ns	ns	ns
Seed priming (S)					
Untreated control	7	54	24.68	8.02 b	0.32
GA_3	7	54	24.25	8.74 ab	0.34
Wood vinegar	7	60	26.14	9.68 a	0.36
F-test	ns	ns	ns	*	ns
CxW	ns	ns	ns	ns	ns
CxS	ns	ns	ns	ns	ns
WxS	ns	ns	ns	ns	ns
CxWxS	ns	ns	ns	ns	ns
CV (C) %	11.5	7.1	9.8	16.1	18.1
CV (W) %	16.9	26.9	19.3	24.2	14.2
CV (S) %	16.7	33.2	18.6	26.0	19.8

Notes: Means followed by the same letter in the same column were not significantly different at $P \leq 0.05$ by least significantly difference.
ns, *, ** = non-significant, significant at $P \leq 0.05$ and significant at $P \leq 0.01$ probability levels respectively.
F-test = statistical test with F-distribution under null hypothesis; CV = coefficient of variation

Rice Cultivars

KDML 105 and RD6 cultivars were selected for this study as these cultivars are grown extensively across several regions of Thailand. KDML 105 is known as the best cultivar for the production of non-glutinous aromatic rice or fragrant rice (Thai: *'hom mali'*) for local consumption and export. RD6 is a glutinous aromatic rice improved from KDML 105 by gamma radiation (mutation breeding) and selected for its glutinous endosperm and is grown predominantly in Thailand's northern and north-eastern regions [35]. These cultivars are very similar and differ mainly in table quality. Both the KDML 105 and RD6 are classified as medium drought tolerant [36].

In the present experiment the two cultivars maintained relatively high values of RWC (77-94%), indicating their similarity in maintaining the water status in leaves during water shortages. These cultivars were also similar in grain yield and other agronomic traits, although the RD6 tended to produce higher grain yields than those by the KDML 105 due to a significantly higher grain number per panicle.

CONCLUSIONS

All seed priming methods provide higher values for RWC, plant height, shoot dry weight and grain yield than those from the untreated control, except for root growth traits. Wood vinegar is a better seed primer than GA_3. Crop irrigation with the soil water content of 50% FC at all periods in the early growth stage significantly decreases RWC, plant height, leaf area and shoot dry weight, but not grain yield, as compared to the 100% FC control. The RD6 cultivar has significantly higher RWC and plant height than those of the KDML 105 cultivar, although both cultivars do not differ significantly in grain yield. The results lead to the conclusion that rice seeds primed with wood vinegar better maintain RWC and crop growth, resulting in an improved grain yield under water-shortage conditions in both rice cultivars.

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