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การคัดเลือกพันธุ์ข้าวต้านทานแล้งภายใต้สภาพอาศัยน้ำฝนในสาธารณรัฐประชาธิปไตยประชาชนลาว

Varietal Screening for Drought Resistance in Rain-Fed Lowland Rice in the Lao PDR

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Abstract

Drought is recognized as a primary constraint for rainfed rice production. A series of experiments were conducted in rainfed lowland conditions to identify drought resistant rice varieties at the Agricultural Research Center (ARC) in Vientiane municipality and Tasano Research and Seed Multiplication center (Tasano) in Savannakhet province in Lao PDR. The study consisted of sixty-six rice genotypes grown under two water treatments, well water (WW/Irrigated control), and water-stress (WS/ imposed drought) conditions. The rice seed were sown on July 25th 2004 and transplanted on August 25th 2004 which is somewhat later than the normal sowing date. The late sowing aimed to increase the likelihood of drought occurring during grain filling. The water was drained from the WS field 25 days after transplanting (DAT) to impose the drought treatment. A large genotypic variation existed for grain yield under both WW and WS conditions, depending on timing, duration and severity of plant water deficit. Grain yield of rice genotypes under WS, in relation to that under WW conditions was reduced approximately 80%, and 60% at ARC and Tasano, respectively. Rice grown under WS reduced leaf water potential (LWP) and delay in flowering at both locations. The genotypic variation in LWP ranged from -0.73 to -2.43 MPa in WW and -1.65 to -3.88 MPa in WS at ARC and -0.80 to -1.70 MPa in WW and -1.53 to -2.73 MPa in WS at Tasano. Some genotypes were able to maintain high LWP and low drought response index (DRI) of grain yield ranged from -0.01 to -1.92 at ARC and 0.01 to 1.71 at Tasano are also an indicator of drought tolerance and associated with other drought tolerance traits during the drought stress period that developed just before flowering produced higher grain yield, and yield components. When water stress occurred prior to flowering, the onset of flowering was delayed. A long delay in flowering is generally considered a disadvantage for rice genotypes grown under WS environments. Therefore, genotypes have a short delay in flowering during WS are one indication of drought tolerance in rice.

Keywords: Drought response index, flowering delay, Lao PDR, leaf water potential, rice.

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บทคัดย่อ

ภัยแล้งเป็นปัญหาพื้นฐานในการผลิตข้าว ศูนย์วิจัยเกษตรได้ทำการทดสอบพันธุ์ข้าวจำนวนมากเพื่อจำแนกสายพันธุ์ที่ทนทานต่อความแห้งแล้งในเขตนาลุ่ม ที่กำแพงนครเวียงจันทร์ และศูนย์วิจัยและขยายเมล็ดพันธุ์ข้าวท่าสะโน แขวงสะหวันนะเขต ประเทศสาธารณรัฐประชาธิปไตยประชาชนลาว การศึกษาครั้งนี้ประกอบด้วยสายพันธุ์ข้าวจำนวน 66 สายพันธุ์ นำไปปลูกภายใต้ระดับน้ำ 2 ระดับ คือ การให้น้ำเต็มที่ (เป็นตัวเปรียบเทียบ) และการปลูกภายใต้สภาวะขาดน้ำ (สภาพแล้ง) ตกกล้าวันที่ 25 กรกฎาคม 2548 และปักดำ วันที่ 25 สิงหาคม 2548 ทั้งนี้เป็นการปักดำช้ากว่าการปลูกข้าวตามปกติ เพื่อให้เกิดความแห้งแล้งในระยะการสร้างเมล็ด การทดสอบในสภาพการขาดน้ำจะทำการปล่อยน้ำออก หลังจากปักดำไปแล้ว 25 วัน เพื่อให้เกิดความแห้งแล้ง เพื่อทดสอบผลผลิตของสายพันธุ์ข้าวเหล่านั้น ภายใต้สภาพที่มีน้ำอย่างสมบูรณ์และภายใต้สภาพที่ขาดน้ำ โดยกำหนดระยะเวลาของการทำให้ขาดน้ำ ช่วงเวลาและความรุนแรงของการขาดน้ำ ผลการศึกษาพบว่าภายใต้สภาพที่ขาดน้ำ ผลผลิตข้าวที่กำแพงนครเวียงจันทน์ และท่าสะโนจะลดลง 80 และ 60 เปอร์เซ็นต์ ตามลำดับ ซึ่งเป็นผลอันเนื่องมาจากใบข้าวมีค่าศักย์ของน้ำในใบ (LWP) ลดลง และข้าวออกดอกล่าช้ากว่าปกติในทั้ง 2 แห่งที่ทำการทดลอง ค่าความแปรปรวนของ LWP อยู่ในช่วง -0.73 ถึง -2.43 MPa สำหรับใบข้าวที่ปลูกภายใต้สภาพที่มีน้ำอย่างสมบูรณ์ และ -1.65 ถึง -3.88 MPa สำหรับใบข้าวที่ปลูกภายใต้สภาพขาดน้ำของแปลงทดลองที่กำแพงนครเวียงจันทน์ และมีค่าระหว่าง -0.80 ถึง -1.70 MPa สำหรับใบข้าวที่ปลูกภายใต้สภาพที่มีน้ำอย่างสมบูรณ์ และมีค่าระหว่าง -1.53 ถึง -2.73 MPa สำหรับใบข้าวที่ปลูกภายใต้สภาพขาดน้ำของแปลงทดลองที่ท่าสะโน พบว่า มีข้าวบางสายพันธุ์ที่สามารถรักษาระดับ LWP ให้มีค่าสูงและมีค่าดัชนีตอบสนองต่อความแห้งแล้งต่ำของลักษณะผลผลิต ซึ่งอยู่ในช่วง -0.01 ถึง -1.92 และ 0.01 ถึง 1.71 ที่กำแพงนครเวียงจันทร์และท่าสะโนตามลำดับ และพบว่าดัชนีความทนทานต่อความแห้งแล้งจะสัมพันธ์กับลักษณะทางการเกษตรบางลักษณะ เช่นเมื่อเกิดสภาวะแห้งแล้งขึ้น ข้าวจะชะลอการออกดอกแต่พันธุ์ข้าวที่ถือว่าทนแล้งจะชะลอการออกดอกเพียงระยะสั้น ๆ เท่านั้น

Introduction

Rice is the single most important crop in the Lao People's Democratic Republic (Lao PDR.). In 2004 the rice growing areas was increased to approximately 667,710 ha representing 89.7% for rain-fed lowland areas (Ministry of Agriculture and Forestry (MAF). The main rain-fed lowland rice area extends from in the upper central region to the southern province and is characterized by erratic rainfall, which can result in drought damage in any given year. The rainfall pattern is typically weakly bimodal with a minor peak in May-June and a major peak in August-September (Fukai et al., 1998). Under such conditions farmers are concerned with risk avoidance rather than optimizing yields. Cultivars currently grown in the rainfed lowland ecosystem are almost exclusively glutinous endosperm types with more than 85% of the area being sown to traditional, photoperiod sensitive rice varieties Therefore, they produce high yields in drought-prone areas and well adapted to these conditions are required. Thus, an agronomic practice is an important factor to minimize drought effects and development of them that yield well even under water-limiting conditions are required for enhancing rice production. Drought is also common problems for rainfed lowland rice in many rice growing areas, estimated to reduced yield of rainfed lowland rice by

15-35% (Jongdee et al., 1997). There is a large genotype by environment (GxE) interaction for yield and can greatly influence the efficiency of the breeding program. These interactions may be caused by phenology differences among genotypes. Other possible reasons causing the large GxE include the genotypic variation in drought resistance. A screening method against late season drought was developed in Thailand (Pantuwan et al., 2002), and early drought in Cambodia (Ouk et al, 2004) utilized in their variety testing programs. The methods of screening for drought resistance in different growth stages have been developed and few drought resistant genotypes are now available in the Lao national breeding program. (Inthapanya et al., 2004). Drought resistant rice varieties may be considered that possess drought resistant traits and produce higher yields than others under drought conditions. If the drought is severe, predictable and terminal, then yield is maintained by escaping the drought through the use of early maturing varieties. If the drought is severe, mid-season and unpredictable, a mechanism for drought tolerance is required. Thus Fukai et al. (1999) indicated that only phenology, high potential yield and ability to maintain high leaf water potential (LWP) were associated directly with higher grain yield (GY) in the target drought environments. Pantuwan et al., (2002) demonstrated the importance of yield potential under mild stress (less than a yield loss of 50%). Rice is highly sensitive to water deficit during the reproductive stage prior to flowering (Lilley and Fukai, 1994). At flowering stage, grain yield reduction due to water deficit is mainly associated with increased spikelet sterility (O'Toole and Namuco, 1983; Sibounheuang et al., 2001). The maintenance of high leaf water potential has been reported to be associated with maintenance of high spikelet fertility during periods of water deficit at the flowering stage (Ekanayake et al., 1989; Garrity and O'Toole,1994; Jongdee,1998). These indicate a role in minimizing the adverse effect of water deficit on grain yield. The main objective of the experiment is to identify drought resistance in rainfed lowland rice varieties for their usage in the development of drought resistant cultivars in the future in the Lao PDR.

Materials and Methods

Experiments were carried out at the Agricultural Research Center (ARC), latitude 18°19´N longitude 102°44, in Vientiane municipality and Tasano Research and Seed Multiplication Center, latitude 16°20´N longitude 105°00´E, in Savannakhet province. The experiments were arranged under WW, and WS conditions. In the WW treatment as control relied on rainfall supplemented with irrigation to provide non-stress conditions. In the WS treatment, the field was drained about 25 days after transplanting (DAT) and onward to simulate drought. In addition, small ditches about

10 cm. deep were dug between replicates in the fields to collect water into 50-cm deep pit in the corner of the fields. The water was pumped from the field during the rain in order to drain water quickly. The level of the soil water table was recorded weekly using PVC tube placed in each corner of the main water treatment plots. Total of sixty-six rice genotypes were tested at two sited over one year, included 61 genotypes that were previously tested for drought screening trial, 1 genotype from International Rice Research Institute (IRRI), and 4 genotypes from Thai breeding program. The seed was sown on 25th July and thirty day-old seedlings were transplanted manually on 25th August 2004 using three seedlings/hill with 20 x 20 cm spacing. After ten days any missing hills were re-transplanted. Irrigation was applied at transplanting to maintain a water level of 3-5 cm. in all treatments and continued at both sites until about 25 days after transplanting (DAT) in the WS treatment, and until harvest in the WW treatment. The experimental design was randomized complete block (RCB) with three replications. The plot size was 1 m. (5 rows) x 4 m. The field was fertilized with 60-30-30 kg/ha of N-P_2O_5-K_2O. N as urea (46%N) was split two times the first half as a basal and the second half at 20 days after transplanting, while the P_2O_5 as triple super phosphate (48% P_2O_5) and K_2O as potassium chloride (60% K_2O) were applied once as a basal application. Weeds were controlled two times by hand both in the WW and WS fields. Pests and diseases were controlled to avoid any yield losses as necessary. Data collection included free water depth above and below soil surface, days to 50% flowering (DTF) and percentage of filled grain. Any grain with less than 75% filled endosperm was considered as an empty grain. Grain yield adjusted to 14 % moisture content was also measured. Leaf water potential (LWP) was measured in WW treatment for mild stress approximately at 85 days after sowing (DAS) and in WS treatment for mild and severe stress approximately at 83 and 93 DAS, respectively at both sites. Drought Response Index (DRI) was calculated by comparing the mean values over replications in the WS and WW treatments that uses threshold values for the upper and lower 10% of the normal distribution (Z = +1.3 and -1.3) to identify the drought tolerant (DRI>1.3) and susceptible (DRI<1.3) genotypes.

Results

Environmental conditions

The rainfall pattern throughout most of Lao PDR is weakly bimodal, with a minor peak in May to early June, and a major peak is in August to September. About 75% of the annual rainfall is received during May and October. The rainfall pattern can be varied from year-to-year, causing large fluctuations in rice production. The potential impact of different management practices on minimizing the impact of both early and late wet-season drought in the rainfed lowland environment is outlined in the following sections. The weekly rainfall and water levels under the WW and WS treatments are presented in Fig. 1. The peak monthly rainfall was observed during July and September in both provinces. The total amount of rainfall during the three months was 19 to 34 % of the rainfall during the wet season in Vientiane municipality and 17 to 43 % in Savannakhet province. The rainfall pattern in Vientiane municipality was similar to that in Savannakhet Province. However, the total amount of rainfall was greater in Vientiane municipality (1442 mm) than in Savannakhet province (1200 mm).

Water level during drained period.

The WW treatment has standing water until maturity, except in early September, when the rain was less and supplementary irrigation was supplied to maintain water level. In the WS treatment the water was drained out 25 DAT and there was no free standing water from the 10th October (vegetative time) onwards. Free water levels were monitored in WW and WS treatments during the experiment Fig. 2. Under WS conditions re-watering occurred twice on 30th October and 10th November 2004 at ARC and at Tasano on 14th October and 8th November 2004 to survive the rice when the leaf show 50% rolled symptom at 85 and 83 DAS at ARC and Tasano, respectively.

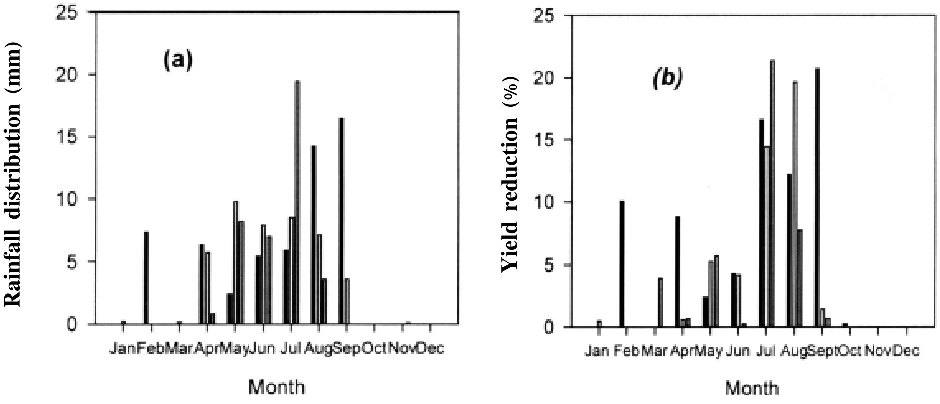

Fig. 1 Rainfall distribution for a 10 days period at ARC, Vientiane municipality (a) and at Tasano, Savannakhet province (b)

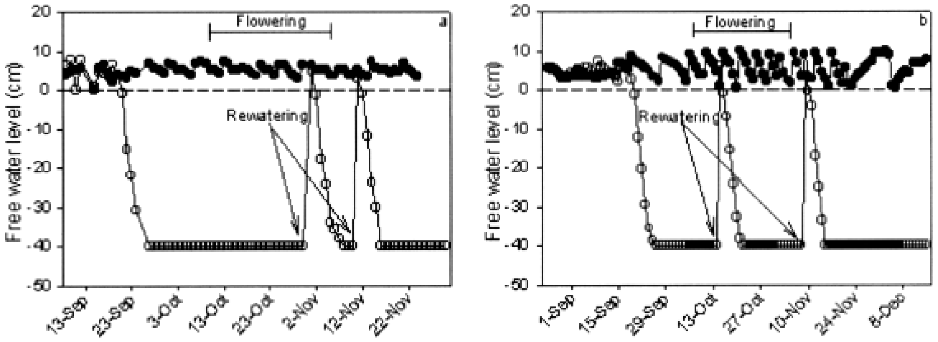

Fig. 2 Free water level at a) ARC, b) TASANO in the well-watered (WW) (●) and water stressed (WS) treatment (O). Re-watering of the WS treatment occurred twice at ARC and Tasano

Rice grains yield and yield component.

In this study, the mean responses of genotypes in all experiments are summarized in Table 1, i.e., mean of rice grain yield, days to 50% flowering, and delay in flowering. The genotypic variation for those characters was highly significant difference under WW and WS conditions at both sites. Mean grain yield under WW (1770 kg/ha) was higher than of those WS (360 kg/ha) ($P<0.01$) and there was a positive relationship (R^2 = 0.19 **) between grain yield under WW and WS conditions at ARC. Similarly, mean grain yield of WW (2620 kg/ha) condition was higher than of those WS (1040 kg/ha) ($P<0.01$) and there was a positive relationship (R^2 =0.26**) between grain yield under WW and WS conditions at Tasano. The effect of severe WS was imposed in 2004 wet season with a yield reduction of 80% at ARC and 60% at Tasano. There was lower spikelet fertility and subsequently lower grain yield in the WW treatments at ARC compared to Tasano (Table 1).

Rice genotypes in this study were identified into 3 groups based on date of maturity by drought exposure (Early<85, Medium 86-95 and late >96 days) from sowing date to flowering date. In general, the WS reduced LWP and increased the delay in flowering time in most genotypes. The genotypic variation in LWP for both WW (-2.15 MPa), and WS for mild (-2.24 MPa) and for severe stress (-2.9 MPa) was highly significant ($P<0.01$). High LWP is also an indicator of drought tolerance and is associated with other drought tolerance traits. There was no association between grain yield and LWP at 83 and 93 DAS in WS treatment (Table 2). The measurement of LWP at 83 DAS in WS treatment was on the average of 2, 16 and 29

Table 1 The analysis of variance on days to flower (DTF), spikelet sterility, grain yield and plant height of rice under WW and WS conditions at ARC and Tasano in 2004 WS

	Well water (WW)		Water stress (WS)	
	Mean	P-value	Mean	P-value
ARC (Vientiane municipality)				
DTF (Days)	87	P<0.001	98	P<0.001
Spikelet sterility (%)	38	P<0.001	73	P<0.001
Grain yield (kg/ha)	1,778	P<0.001	360	P<0.001
Plant height (cm)	102	P<0.001	76	P<0.001
Tassano (Savannakhet)				
DTF (Days)	89	P<0.001	98	P<0.001
Spikelet sterility (%)	27	P<0.005	39	P<0.001
Grain yield (t/ha)	2,620	P<0.001	1,040	P<0.001
Plant height (cm.)	105	P<0.001	82	P<0.001

Table 2 Leaf water potential at various days after sowing (DAS) range of days to flowering in WW and WS treatments at ARC and Tassano

Location	DAS	DTF range	Leaf water potential (MPa)		
			WW	WS	
				Mild	severe
ARC	83	73-123	-	-2.24**	-
	85	77-103	-1.51*	-	-
	93	73-123	-	-	-2.91**
Tasano	79	81-114	-	-2.14**	-
	81	74-104	-1.18**	-	-
	95	85-125	-	-	-2.79**

** p<0.01, * p<0.05, ns - not significant

days before flowering of early, medium and late flowering rice group, respectively. When WS occurred prior to flowering, the onset of flowering was delayed. A long delay in flowering is generally considered a disadvantage for rice genotypes grown under WS environments. Therefore, genotypes that have a short delay in flowering during WS are one indication of drought tolerance in rice.

Delay in flowering and grain yield

The relationship between days to flowering under WS and flowering delay were examined at ARC and Tasano (Table 3 and 4). At ARC the early flowering genotypes had a shorter flowering delay than medium and late flowering genotypes under the WS conditions. The medium and late flowering genotypes have a greater delay in flowering, enabling them to take benefit from the second re-watering during flowering and grain filling. At Tasano the medium flowering genotypes had the longest delay in flowering due to flowering of early and late genotypes occurred during re-watering. The WS conditions generally delayed flowering time in most genotypes compared to WW conditions. The delay ranged from 6 to 12 days in early group, 2 to 14 days in medium group and 2 to 23 days in late maturity group at ARC and delay ranged from 0 to 17 days in early group, 7 to 19 days in medium group, and 4 to 15 days in late maturity group at Tasano. The early group flowering experienced less water deficit at the flowering stage because they flowered during the period when sufficient water was still available. The medium and late flowering genotypes, which flowered close to the time of relieving the water deficit, experienced greater WS stress and generally greater delays in flowering. However, the delay in flowering was not so great in the very late flowering genotypes as they were irrigated just prior to flowering in WS treatments. The delay in flowering time was negatively associated with grain yield reduction percentage (r^2=0.25**) for the three groups under WS at ARC (Fig 3a) but the delay in flowering was not associated with grain yield reduction percentage was not significantly difference among three groups of maturity at Tasano. Relationships between grain yield and days to flowering were positive at ARC and Tasano for WS mainly because of re-watering during the stress period. The late flowering genotypes had more opportunity to recover from drought before flowering at ARC and Tasano. The early flowering genotypes were not exposed to WS than that of the late maturity genotypes. Therefore, the genotypes were grouped into early, medium and late exposure to drought based on their flowering under WW conditions. The capacity to drought resistance among genotypes was compared within these groups. The relationship between grain yield under WS conditions and delay flowering was investigated at ARC. Delay in flowering was estimated by taking the days difference for flowering of each genotype under WS and WW conditions. There was a positive association between delay flowering and grain yield. The late maturing varieties had more advantage of re-watering during the stress cycle and were able to produce relatively higher yield than the early flowering genotypes. The yield reduction was low in long delay flowering for late maturing genotypes (Fig 3 b). However, the relationship between flowering delay and yield reduction was not so strong at Tasano (data not shown).

Table 3 Grain yield, days to flowering and maturity of rice under well-water (WW) and water stress (WS) at agricultural research center (ARC) in Vientiane municipality

Genotype	Mat$^{1/}$	Yield(kg/ha)		YR (%)	Days to flowering		Delay in Flowering
		WW	WS		WW	WS	
IR74371-3-1-1	E	1,729	254	85.33	78	84	6
Namheng 1	E	1,463	403	72.45	78	81	3
Nam heng 2	E	1,131	204	81.93	78	75	-3
Angdo 1	E	711	41	94.21	79	74	-5
Angdo 2	E	1,324	83	93.71	79	83	4
Eaphon 2	E	2,342	261	92.45	79	89	10
Hangvi	E	829	44	94.64	79	85	6
Hom keo	E	1,868	171	90.83	79	88	9
I Khao	E	1,962	148	86.29	79	89	10
Leng 1	E	1,599	136	91.49	79	81	2
Mackmouy	E	1,241	146	88.23	79	91	12
Noon soung 2	E	2,274	293	95.34	79	86	7
Peud nam 3	E	941	327	65.26	79	83	4
Peud nam 4	E	2,199	171	90.37	79	85	6
Peud nam 5	E	2,193	208	90.53	79	86	7
Eaphon 8	E	2,182	102	87.12	80	86	6
Noon soung 1	E	1,960	456	76.75	80	87	7
Eaphon 1	E	1,352	203	84.99	81	87	6
Eaphon 3	E	1,773	112	93.66	81	87	6
Eaphon 5	E	1,382	133	92.23	82	85	3
IR77298-5-6	E	2,410	330	88.85	82	89	7
Eaphon 6	E	1,627	148	90.93	83	95	12
Eaphon 9	E	1,836	141	92.3	83	90	7
Peud nam 1	E	1,738	234	86.53	83	92	9
Chao america	E	1,417	147	89.62	84	98	14
Chaodeng	E	1,974	168	91.47	84	99	15
Eaphon 7	E	1,279	53	95.83	84	89	5
TDK 114-4B88-B2	E	2,517	592	76.46	84	96	12
B6144F-MR-6-O-O	E	1,698	414	75.64	85	95	10
Chao	E	1,137	333	96.52	85	97	12
Eaphon 4	E	2,019	108	94.63	85	98	13
Chaodeng	M	1,324	100	86.05	86	99	13
Hom lai	M	1,470	51	70.67	86	97	11
TDK5	M	2,717	379	92.48	87	99	12

Table 3 Grain yield, days to flowering and maturity of rice under well-water (WW) and water stress (WS) at agricultural research center (ARC) in Vientiane municipality (Cont.)

Genotype	Mat[1/]	Yield(kg/ha)		YR (%)	Days to flowering		Delay in Flowering
		WW	WS		WW	WS	
IR55423-01	M	1,942	578	70.23	88	96	8
IR74590-67-1-1-3-1	M	2,514	387	84.61	88	103	15
IR57514-PMI-5-B-1-2	M	1,647	712	56.79	89	105	16
Hom 1	M	2,046	344	83.17	90	103	13
Kham15	M	1,744	607	61.34	90	106	16
Meuang nga	M	2,774	799	71.19	90	106	16
Kam19	M	1,485	299	79.84	91	109	18
KK12	M	2,243	329	79.08	92	115	23
IR57514-TDK-9-1-2	M	1,389	537	65.18	92	106	14
IR74371-3-1-1	M	1,382	382	52.91	92	114	22
Kam11	M	2,005	419	85.32	92	115	23
KDML105	M	1,800	675	65.13	92	109	17
Hom 3	M	1,994	461	68.41	93	111	18
Kam14	M	981	342	62.51	93	109	16
TDK 114-4B-5	M	1,954	749	61.66	93	108	15
TDK4	M	1,224	500	59.16	93	103	10
Eabok	M	475	205	56.86	94	92	-2
TDK 47-6-1-2-3	M	2,385	819	65.65	94	116	22
BL6	M	1,948	547	71.92	95	123	28
IR 68101-TDK-31-1	M	2,677	846	76.87	95	111	16
TDK 37-1-2-51	M	1,269	403	68.27	95	109	14
TDK42-4-1-1-2	M	2,417	501	79.26	95	114	19
IR69502-6-SRN-3-UBN	L	2,021	617	69.44	96	112	16
BL2	L	1,710	294	82.78	96	113	17
NTN1	L	2,296	580	74.76	96	115	19
TDK21-B-6-2-1-B	L	2,577	925	64.09	97	111	14
TDK 114-4B-88-B1	L	1,564	276	82.35	99	130	31
TDK1	L	1,750	793	54.7	99	116	17
TDK 114-4B-79	L	1,925	122	93.67	101	130	29
TDK 27-13-131-1-1-1	L	1,645	594	63.87	102	118	16
TDK21-B-24-19-1-B	L	1,812	853	72.35	102	114	12
BL1	L	1,616	227	85.95	105	111	6
Mean		1,770	360	79.47	87	100	12
F-test		**	**	**	**	**	

[1/] Mat = Maturity, E = Early, M = Medium, L = Late, YR(%) = Yield reduction

** indicate significant difference

Table 4 Grain yield, days to flowering and maturity of rice under well-water (WW) andwater stress (WS) at Tassano Rice Research and Seed Multiplication center in Savannakhet province

Genotype	Mat$^{1/}$	Yield(kg/ha)		YR (%)	Days to flowering		Delay in
		WW	WS		WW	WS	Flowering
ANG DO	E	1,263	508	60	74	78	4
Nam heng 2	E	2,455	536	78	78	82	4
Hangvi	E	2,457	545	78	79	86	7
Nam heng 1	E	3,266	540	83	80	84	4
Eaphon 1	E	1,965	965	51	81	82	1
Eaphon 5	E	1,800	600	67	81	94	13
Mack mouy	E	4,182	519	88	81	84	3
Peud nam 3	E	1,850	682	63	81	84	3
Eaphon 3	E	1,801	1,144	36	82	88	6
Eaphon 7	E	1,876	247	87	82	94	12
Eaphon 8	E	2,739	804	71	82	99	17
IR74371-3-1-1	E	2,378	1,110	53	82	84	2
Leng 1	E	2,306	748	68	82	85	3
Angdo	E	2,165	682	68	83	84	1
Chao	E	2,666	1,033	61	83	86	3
Hom lai	E	2,722	319	88	83	94	11
I Khao	E	2,659	642	76	83	97	14
Noon Soung 2	E	2,496	753	70	83	88	5
Peud Nam 1	E	2,799	362	87	83	94	11
Eabok	E	1,512	467	69	84	84	0
Eaphon 2	E	2,338	1,112	52	84	89	5
Hom Keo	E	2,590	1,167	55	84	99	15
Noon Soung 1	E	1,742	505	71	84	87	3
Peud nam 5	E	2,654	942	64	84	92	8
Chao america	E	2,163	926	57	85	86	1
Chao deng 1	E	2,347	597	75	85	96	11
Chao deng 2	E	2,395	535	78	85	102	17
Eaphon 4	E	1,908	342	82	85	99	14
Eaphon 6	M	2,378	907	62	86	98	12
Hom 1	M	2,649	981	63	86	96	10
IR77298-5-6	M	2,348	1,251	47	86	102	16
Peud Nam 4	M	2,690	1,094	59	86	91	5
IR74590-67-1-1-3-1	M	2,826	1,297	54	87	99	12
Kam14	M	2,151	448	79	87	102	15

Table 4 Grain yield, days to flowering and maturity of rice under well-water (WW) andwater stress (WS) at Tassano Rice Research and Seed Multiplication center in Savannakhet province (Cont.)

Genotype	Mat[1/]	Yield(kg/ha)		YR (%)	Days to flowering		Delay in
		WW	WS		WW	WS	Flowering
Kam19	M	2,120	401	81	87	91	4
TDK4	M	3,293	1,101	67	87	100	13
B6144F-MR-6-O-O	M	3,956	769	81	88	102	14
IR55423-01	M	3,155	1,652	48	89	102	13
Kham15	M	1,851	992	46	89	102	13
Meuang nga	M	2,899	1,445	50	89	108	19
TDK 114-4B88-B2	M	3,373	1,319	61	90	99	9
TDK5	M	3,249	1,339	59	90	99	9
Hom 3	M	2,998	982	67	91	105	14
TDK 47-6-1-2-3	M	3,059	1,625	47	91	105	14
KDML105	M	1,908	674	65	92	99	7
TDK 37-1-2-51	M	2,460	1,609	35	92	103	11
Eaphon 9	M	1,868	703	62	93	86	-7
KK12	M	3,770	1,469	61	94	106	12
IR74371-3-1-1	M	2,515	895	64	94	107	13
IR57514-TDK-9-1-2	M	2,612	1,328	49	95	101	6
BL6	L	3,120	1,940	38	96	107	11
IR69502-6-SRN-3-UBN	L	2,575	1,110	57	96	107	11
BL2	L	2,925	836	71	96	111	15
TDK 114-4B-5	L	3,046	1,699	44	96	111	15
IR 68101-TDK-31-1	L	2,485	2,126	14	97	100	3
IR57514-PMI-5-B-1-2	L	2,553	1,662	35	98	102	4
TDK42-4-1-1-2	L	2,225	1,109	50	99	105	6
TDK21-B-6-2-1-B	L	3,093	1,413	54	100	111	11
TDK 114-4B-79	L	2,634	1,693	36	101	110	9
Kam11	L	1,583	404	74	102	105	3
NTN1	L	3,601	1,470	59	102	107	5
TDK 27-13-131-1-1-1	L	3,740	1,409	62	102	111	9
TDK21-B-24-19-1-B	L	4,279	1,849	57	102	111	9
BL1	L	3,820	1,885	51	103	111	8
TDK 114-4B-88-B1	L	2,835	1,435	49	103	113	10
TDK1	L	3,477	1,828	47	104	108	4
Mean		2,630	1,022	61.22	89	98	9
F-test		**	**	**	**	**	**

[1/] Mat = Maturity, E = Early, M = Medium, L = Late, YR(%) = Yield reduction

** indicate significant difference

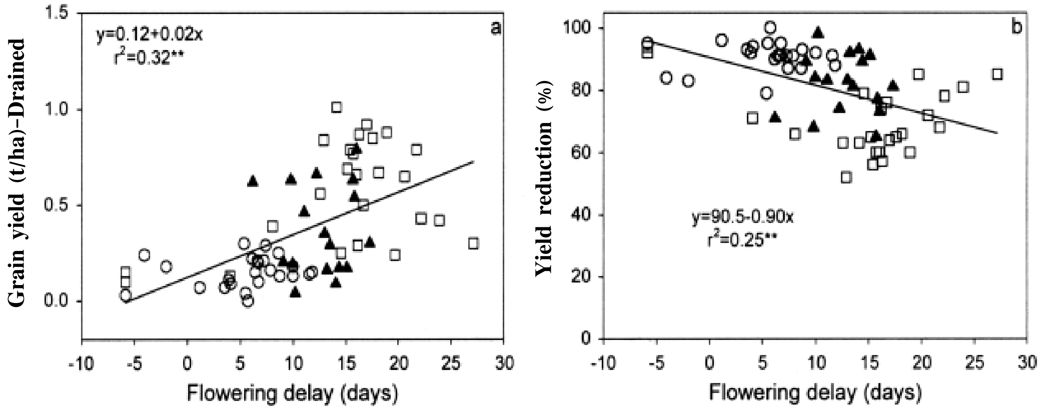

Fig. 3 Relationship between flowering delay and grain yield (a) and yield reduction (b)

Days to flowering and spikelet fertility.

There was a positive relationship between days to flower and spikelet fertility in WS conditions at ARC and Tasano. The relationship was stronger at ARC than at Tasano, indicating the severity of prolonged drought on spikelet fertility in early flowering genotypes at ARC. The early flowering group had higher spikelet fertility because they used the available soil moisture during flowering and early grain filling, which may not have been available for medium and late flowering genotypes.

Drought response index for grain yield

Results of these experiments showed the ability of rice performance under WS conditions. At ARC genotypes IR57514-PMI-5-B-1-2 performed very well and maintained high DRI yield, but had a low LWP. On the other hand BL1, TDK 114-4B, IR57514-PMI-5-B-1-2, I Khao, Hom 1, and Kham15 had low LWP. IR69502-6-SRN-3-UBN-B-22 and Ephon 1 had low DRI and TDK114-4B-5 had a high DRI yield, but maintained low LWP. The two genotypes TDK21-B-6-2-1-B, TDK21-B-24-19-1-B matured late but they maintained relatively high LWP compared to the mean LWP. Angdo1 flowered early but spikelet fertility was badly affected by drought conditions at ARC (Table 5). There were 12 genotypes also performed badly in LWP, days to flowering, spikelet fertility (%), DRI for grain yield at Tasano such as genotypes Eaphon 3, Eaphon 1 Eaphon 2, Peud nam 3, TDK 37-1-2-51, IR77298-5-6, IR74590-67-1-1-3-1, TDK114-4B88-B2, BL6, TDK 114-4B-5, KK12, TDK 114-4B-79 and IR57514-PMI-5-B-1 (Table 6).

Table 5 Leaf water potential (LWP) of rice under well-water (WW) and water stress (WS) and drought response index (DRI) at ARC, Vientiane municipality

Genotype	Mat$^{1/}$	Leaf water potential (MPa)			DRI for GY
		WW	WS(mild)	WS(severe)	
IR74371-3-1-1	E	-1.13	-1.88	-3.10	0.24
Nam heng 1	E	-1.78	-1.95	-3.73	0.99
Nam heng 2	E	-2.23	-2.33	-3.28	0.47
Ang do 1	E	-1.19	-1.93	-3.10	0.02
Angdo 2	E	-1.13	-2.15	-2.40	-0.18
Eaphon 2	E	-1.63	-2.03	-3.20	-0.22
Hangvi	E	-1.31	-2.20	-3.10	-0.05
Hom keo	E	-1.88	-1.98	-2.98	-0.25
I Khao	E	-1.19	-2.13	-2.60	-0.36
Leng 1	E	-2.19	-2.10	-2.68	-0.16
Mack mouy	E	-1.38	-2.13	-2.48	0.11
Noon soung 2	E	-1.29	-2.08	-2.68	-0.01
Peud nam 3	E	-1.88	-1.53	-3.63	0.96
Peud nam 4	E	-1.53	-1.65	-2.73	-0.47
Peud nam 5	E	-1.82	-1.78	-3.03	-0.28
Eaphon 8	E	-2.00	-2.00	-2.95	-0.74
Noon soung 1	E	-1.69	-2.05	-2.53	0.73
Eaphon 1	E	-1.56	-2.15	-2.63	0.11
Eaphon 3	E	-1.69	-2.45	-3.28	-0.52
Eaphon 5	E	-1.81	-2.25	-2.65	-0.25
IR77298-5-6	E	-1.38	-2.18	-3.28	-0.17
Eaphon 6	E	-1.88	-2.03	-2.75	-0.44
Eaphon 9	E	-1.06	-1.75	-2.93	-0.60
Peud nam 1	E	-1.75	-2.05	-2.88	-0.14
Chao America	E	-1.69	-1.85	-2.63	-0.37
Chaodeng 1	E	-1.85	-2.25	-3.68	-0.65
Eaphon 7	E	-1.94	-1.83	-3.00	-0.59
TDK 114-4B88-B2	E	-1.38	-2.23	-3.35	0.65
B6144F-MR-6-O-O	E	-1.56	-2.13	-2.63	0.42
ChaoE	-	1.06	-2.03	-2.80	0.49
Eaphon 4	E	-1.75	-1.95	-3.05	-0.95
ChaodengM	-	1.53	-2.08	-2.50	-0.57
Hom lai	M	-1.98	-2.00	-2.88	-0.90

Table 5 Leaf water potential (LWP) of rice under well-water (WW) and water stress (WS) and drought response index (DRI) at ARC, Vientiane municipality (Cont.)

Genotype	Mat[1/]	Leaf water potential (MPa)			DRI for GY
		WW	WS(mild)	WS(severe)	
TDK5	M	−1.31	−1.93	−3.15	−0.52
IR55423-01	M	−1.50	−1.70	−2.33	0.71
IR74590-67-1-1-3-1	M	−1.19	−2.73	−3.98	−0.39
IR57514-PMI-5-B-1-2	M	−1.31	−2.15	−2.33	1.35
Hom 1	M	−0.06	−2.33	−2.88	−0.40
Kham15	M	−0.94	−1.88	−3.13	0.80
Meuang nga	M	−1.25	−2.00	−3.18	0.85
Kam19	M	−0.88	−2.25	−3.33	−0.24
KK12	M	−1.83	−2.05	−3.08	−0.69
IR57514-TDK-9-1-2	M	−1.56	−2.25	−2.53	0.62
IR74371-3-1-1	M	−1.44	−2.05	−2.28	0.06
Kam11	M	−0.81	−2.13	−3.00	−0.21
KDML105	M	−1.53	−1.95	−2.93	0.89
Hom 3	M	−1.42	−2.05	−3.25	−0.14
Kam14	M	−1.96	−2.35	−3.28	0.13
TDK 114-4B-5	M	−1.25	−2.05	−3.15	0.99
TDK4	M	−1.25	−2.20	−3.48	0.52
Eabok	M	−1.50	−2.05	−2.35	−0.15
TDK 47-6-1-2-3	M	−1.44	−2.08	−2.95	0.93
BL6	M	−1.31	−2.05	−2.68	0.14
IR 68101-TDK-31-1	M	−1.06	−1.83	−2.73	0.75
TDK 37-1-2-51	M	−1.06	−2.25	−2.95	0.04
TDK42-4-1-1-2	M	−1.19	−2.15	−3.00	−0.39
IR69502-6-SRN-3-UBN	L	−1.98	−2.56	−3.35	0.27
BL2	L	−1.75	−2.20	−2.70	−0.78
NTN1	L	−1.81	−2.23	−2.80	−0.06
TDK21-B-6-2-1-B	L	−0.75	−1.80	−2.80	1.01
TDK 114-4B-88-B1	L	−1.31	−1.85	−2.63	−0.90
TDK1	L	−1.75	−1.98	−3.08	0.92
TDK 114-4B-79	L	−1.45	−2.25	−3.18	−1.88
TDK 27-13-131-1-1-1	L	−1.00	−2.18	−2.50	0.02
TDK21-B-24-19-1-B	L	−1.44	−2.00	−2.68	0.94
BL1	L	−1.13	−2.08	−2.63	−1.51
Mean		−1.46	−2.07	−2.93	
F-test		**	**	**	

Table 6 Leaf water potential (LWP) of rice under well-water (WW) and water stress (WS) and drought response index (DRI) at Tasano in Savannakhet province

Genotype	Mat[1/]	Leaf water potential (MPa)			DRI for GY
		WW	WS(mild)	WS(severe)	
Angdo	E	−0.19	−1.93	−3.10	0.02
Nam heng 2	E	−1.55	−2.33	−3.28	0.47
Hangvi	E	−1.69	−2.08	−2.68	−0.01
Nam heng 1	E	−1.50	−1.53	−3.63	0.96
Eaphon 1	E	−1.98	−2.10	−2.68	−0.16
Eaphon 5	E	−1.38	−2.13	−2.48	0.11
Mackmouy	E	−1.81	−2.25	−2.65	−0.25
Peud nam 3	E	−1.15	−2.15	−2.40	−0.18
Eaphon 3	E	−1.69	−2.45	−3.28	−0.52
Eaphon 7	E	−1.76	−1.75	−2.93	−0.60
Eaphon 8	E	−1.69	−1.85	−2.63	−0.37
IR74371-3-1-1	E	−1.13	−1.88	−3.10	0.24
Leng 1	E	−1.96	−1.65	−2.73	−0.47
Angdo	E	−1.13	−2.20	−3.10	−0.05
Chao	E	−1.30	−1.78	−3.03	−0.28
Hom lai	E	−1.75	−2.05	−2.88	−0.14
I Khao	E	−1.38	−2.23	−3.35	0.65
Noon Soung 2	E	−1.88	−1.98	−2.98	−0.25
Peud Nam 1	E	−1.50	−2.05	−2.35	−0.15
Eabok	E	−1.44	−1.95	−3.73	0.99
Eaphon 2	E	−1.63	−2.03	−3.20	−0.22
Hom Keo	E	−1.93	−2.00	−2.88	−0.90
Noon Soung 1	E	−1.56	−2.15	−2.63	0.11
Peud Nam 5	E	−1.94	−1.83	−3.00	−0.59
Chao America	E	−1.63	−2.05	−2.53	0.73
Chao deng 1	E	−1.88	−2.03	−2.75	−0.44
Chaodeng 2	E	−1.25	−2.00	−3.18	0.85
Eaphon 4	E	−1.06	−2.03	−2.80	0.49
Eaphon 6	M	−1.50	−1.70	−2.33	0.71
Hom 1	M	−1.26	−2.13	−2.63	0.42
IR77298-5-6	M	−1.25	−2.05	−3.15	0.99
Peud Nam 4	M	−1.49	−2.13	−2.60	−0.36
IR74590-67-1-1-3-1	M	−1.25	−2.25	−3.68	−0.65

Table 6 **Leaf water potential (LWP) of rice under well-water (WW) and water stress (WS) and drought response index (DRI) at Tasano in Savannakhet province (Cont.)**

Genotype	Mat$^{1/}$	Leaf water potential (MPa)			DRI for GY
		WW	WS(mild)	WS(severe)	
Kam14	M	-1.31	-2.15	-2.33	1.35
Kam19	M	-1.38	-2.18	-3.28	-0.17
TDK4	M	-1.25	-2.20	-3.48	0.52
B6144F-MR-6-O-O	M	-0.94	-1.88	-3.13	0.80
IR55423-01	M	-0.88	-2.25	-3.33	-0.24
Kham15	M	-0.56	-2.25	-2.53	0.62
Meuang nga	M	-1.19	-2.15	-3.00	-0.39
TDK 114-4B88-B2	M	-1.31	-1.93	-3.15	-0.52
TDK5	M	-1.13	-2.08	-2.50	-0.57
Hom 3	M	1.00	-2.05	-3.25	-0.14
TDK 47-6-1-2-3	M	-0.75	-1.80	-2.80	1.01
KDML105	M	-1.75	-1.95	-3.05	-0.95
TDK 37-1-2-51	M	-1.50	-1.95	-2.93	0.89
Eaphon 9	M	-2.00	-2.00	-2.95	-0.74
KK12	M	-2.13	-2.08	-2.63	-1.51
IR74371-3-1-1	M	-1.56	-1.98	-3.35	0.27
IR57514-TDK-9-1-2	M	-1.19	-2.73	-3.98	-0.39
BL6	L	-1.44	-2.05	-2.28	0.06
IR69502-6-SRN-3-UBN-B	L	-1.75	-2.20	-2.70	-0.78
BL2	L	-1.85	-2.05	-3.08	-0.69
TDK 114-4B-5	L	-1.75	-1.98	-3.08	0.92
IR 68101-TDK-31-1	L	-1.06	-2.33	-2.88	-0.40
IR57514-PMI-5-B-1-2	L	-1.69	-2.35	-3.28	0.13
TDK42-4-1-1-2	L	-1.06	-1.83	-2.73	0.75
TDK21-B-6-2-1-B	L	-1.44	-2.08	-2.95	0.93
TDK 114-4B-79	L	-0.81	-2.13	-3.00	-0.21
Kam11	L	-1.06	-2.25	-2.95	0.04
NTN1	L	-1.44	-2.00	-2.68	0.94
TDK 27-13-131-1-1-1	L	-1.00	-2.18	-2.50	0.02
TDK21-B-24-19-1-B	L	-1.45	-2.25	-3.18	-1.88
BL1	L	-1.50	-2.05	-2.68	0.14
TDK 114-4B-88-B1	L	-1.31	-1.85	-2.63	-0.90
TDK1	L	-1.83	-2.23	-2.80	-0.06
Mean		-1.39	-2.06	-2.93	
F-test		**	**	**	

** indicate significant difference

Discussions

There is a clear difference between varieties for the expression of yield and yield component under WS conditions. The result of these experiments suggested that Vientiane and Savannakhet provinces which in the upper central region need different rice genotypes due mostly to different soil type and rainfall pattern. Late maturity was affected by long drought period. Therefore, the genotypes that had an ability to maintain high LWP had a short period of delay in flowering and low levels of unfilled grain (%) which can be escaped from drought. Thus high LWP is also important to identify the genotypes during stress period. The effects of drought can be reduced by appropriate cropping practices, including by matching crop phenology with water availability (Fukai, et al., 1999). Pantuwan (2000) suggested that genotypes with larger yield reduction due to drought were those that flowered late and had larger delay in flowering time. Delay in flowering time was approximately 1 to 15 days under WS conditions. Fukai and Cooper (1995) have demonstrated that late-season drought alone can reduce grain yields by an average of 30%. In the study, drought environments were established successfully by draining paddies at different crop growth stages so different types of drought environments were available for screening genotypes. The types of drought varied in timing with crop development from prolonged drought being affected from the vegetative stage or being restricted to a short duration in the grain filling stage. However, the actual stress mainly developed late in the season as such presents the target environments. The drought effect ranged from a 12-46% reduction in grain yield (GY). Similarly, Wonprasaid et al. (1996) reported that 40% yield reduction was obtained when draining the paddies about one month before flowering, while Pantuwan et al. (2002) reported that yield reductions ranged from 19-80%. The DRI was used to determine drought resistant/susceptible genotypes with DRI greater than 1.3 were considered drought resistant and those with less than -1.3 were drought susceptible. In general, LWP declined continuously with time after imposition of water deficit. Significant genotypic variation in maintenance of LWP was observed for midday measurements. Although development of water deficit was different between experiments, genotypic variation in maintenance of LWP was generally consistent. Boonjung and Fukai (1996) found that genotype with small canopies used water more slowly and were able to maintain higher midday LWP, while Lilley and Fukai (1994) found that a few lines of similar canopy size differed in midday LWP.

Leaf water potential is shown to be a promising character and can be used for selection to improve tolerance against late season drought. Genotypic ranking is consistent for water deficit at vegetative, booting and flowering stages and across experiments and therefore can be determined at either vegetative or reproductive stages using midday values. Grain yield under water deficit at flowering stage is negatively associated with spikelet sterility. Some mechanisms involved in maintenance of LWP have been identified but further research is required to fully understand the morphological and physiological reasons for breeding program in Lao PDR.

Conclusions

Development of a drought screening methodology it was then used to identify drought resistant varieties which can be crossed with current varieties to develop drought resistant with high yield potential and good grain quality when grown by the farmers under various growing conditions. As a result of drought resistance screening experiment in Lao PDR, a number of rice varieties are currently in different stages of development in the rice-breeding program. They have the potential to be released as new varieties in the future.

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