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Research Article

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Morphological and yield responses to drought of several inbred rice varieties (*Oryza sativa* L) in mountainous areas in North Central, Vietnam

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Abstract Greenhouse and field experiments were carried out in 2016 and 2017 to study the morphological and yield responses of eight inbred rice varieties to drought stress. In the greenhouse experiment, drought tolerance of rice varieties was measured based on leaf rolling and leaf drying score under water-stressed condition. Yield components were also evaluated in both water-stressed and well-irrigated conditions. The growth and yield of the rice varieties were then estimated in rain-fed field experiments in Thanh Hoa, Nghe An and Ha Tinh provinces. Results showed that drought has affected morphological and yield of these varieties. Drought occurred at the vegetative stage which effected the number of tillers but did not result in significant yield losses, drought in the reproductive stage resulted in substantial yield losses, mainly caused by large percentages of unfilled grains and a reduction in a number of particles. Among the rice varieties, Lam Son 8 and BC 15 were superior tolerant to drought. These rice varieties showed less damaged in leaves and were able to produce yields under water-stressed. Lam Son 8 and BC 15 also gave the highest yields of 66.33 and 62.25 quintal/ha; 65,67 and 61,27 quintal/ha in Spring and Summer seasons under the rain-fed system, respectively. Thuan Viet 1, Hong Duc 9, Thien Uu 8 and Bac Thom were moderately drought tolerant while Huong Thom 1 and Q5 were the least tolerant to drought.

Keywords Drought-tolerance, yield response, rice, stress

1. Introduction

Rice (*Oryza sativa* L.) is grown in more than 114 countries of the world, taking up about 11% of the world's cultivated land [1-3]. Rice is considered one of the most water-intensive and drought-susceptible because of its small root system, thin cuticular wax, and swift stomatal closure [4]. To produce 1 kilo of rice, 2,500 litres of water needs to be supplied to a rice field [5]. In fact, 90% of rice is grown in Asia, which consumes about 80% of the total irrigated freshwater resources around the world [1,5]. The growing scarcity of irrigation water because of competition among agricultural, industrial and other sectors is an alarming problem for sustainable rice production in the future. The impact of climate change leads to more and more rice farmers are facing drought and shortages of freshwater. Water shortage is one of the major environmental constraints severely reducing rice yields [6]. According to Kumar et al. [7], rice yields under severe drought conditions can be reduced up to 65% in comparison to non-drought conditions. The results reported by Pantuwan et al [8] also showed that grain yield of rice could be decreased by up to 81% underwater deficit depending on timing, duration, and severity of the drought condition. Being considered one of the most vulnerable to climate change countries, Vietnam rice production is severely affected by the drought [9]. Rice growing areas is estimated 7,7 million ha, of which 1.5 – 1.8 million ha are often lack of irrigation [10,11]. The North Central of Vietnam is among the country's poorest regions. Agriculture production in upland areas of the North Central tend to produce lower yields and profits yet it has not been the focus of research and development efforts. Often, many of the poorest farmers live in un-irrigated, drought-prone mountainous areas where significant increasing of irrigation is generally not a viable option for alleviating drought problems in rainfed rice-growing systems. Given the difficulty in irrigation, selection of drought-tolerant rice varieties is a potential strategy for agriculture production in upland areas. The objective of this study was to evaluate the drought tolerance and agronomic characteristics of rice varieties selected in different regions of the North Central of this country.

2. Materials and methods

Greenhouse and field experiments were carried out to evaluate drought-tolerance and agronomic characteristics of 8 inbred rice varieties collected from different locations (Table 1). These varieties have been considered drought-resistant varieties according to their producers.

Table 1: Tested varieties and their origin

Variety	*Origin*
Q5	Imported from China
Thuan Viet 1	Selected and produced by Thanh Hoa Seed Joint Stock company
Bac Thom	Imported from China
BC15	Selected and produced by Thai Binh Seed Group Joint Stock Company
Thien Uu 8	Selected and produced by Vietnam National Seed Joint Stock Company
Hong Duc 9	Selected and produced by Hong Duc University
Huong thom 1	Imported from China
Lam Son 8	Selected and produced by Thanh Hoa Seed Joint Stock company

Greenhouse experiment

The experiment was conducted in a greenhouse at Hong Duc University in 2016 using 8 inbred rice varieties and two irrigation regimes (well irrigated and water-stressed). Ten pre-germinated rice seeds were planted in a 30 cm diameter pot containing clay loam soil. Water was maintained at 5 cm above the soil surface. Water stress condition was imposed by withholding irrigation at the beginning of the booting stage. Soil moisture content and visual drought sensitivity were assessed when the soil moisture content decreased to 15%. The drought treatments were not stopped until severe leaf rolling and tip damage occurred when the soil moisture content was decreased to 10%. Then water was added to the pot and survival plants continued to develop. Non-drought control pots continued to be irrigated, and plants in them were evaluated for the same traits on the same days as were the drought-stressed plants. All of the measurements were completed in one day. Leaf rolling and drought score was recorded at mid-day using the scale described by IRRI [12] (Table 2). Thirty plants per replication were measured for seed setting rate as a number of panicles per plant, spikelets per panicle and 1000-grain weight at harvesting.

Table 2: Evaluation of drought sensitivity by leaf rolling and drying scores

Score	*Leaf rolling*	*Leaf drying*
0	Leaves healthy	No symptoms
1	Leaves start to fold	Slight tip drying
3	Leaves folding (deep V-shape)	Tip drying extended up to ¼ length in most leaves
5	Leaves fully cupped (U-shape)	One-fourth to ½ of all leaves dried
7	Leaves margin touching (O-shape)	More than 2/3 of all leaves fully dried
9	Leaves tightly rolled	All plants apparently dead

Field experiment

The field experiment was carried out in three provinces of the North Central Coast, Thanh Hoa, Nghe An and Ha Tinh. The experiment was conducted in two pronounced crop seasons, Spring and Summer season in 2017. Spring crop season started from January to May, where it received 68.9 mm rainfall per month on average. Drought period was from January to March. Summer crop season had an average rainfall of 223.6 mm per month. However, there was a short dry period occurred for a few weeks at the tillering stage (Table3). The experiment was set up using a randomized complete block design with three replications, 20m^2 for each plot.

Rice seedlings were transplanted at a density of 40 seedlings/m^2 (10 cm x25cm). Fertilizers were applied at a dose of 10 tons of manure, 90 kg N, 80 kg P_2O_5 and 80 kg K_2O per hectare. Data were taken on the growth time (day), plant height (cm), total tillers per plant, number of spikelets per panicle, seed setting rate (%), 1,000-grain weight (g) and yield (quintal/ha). Ten plant samples/replication were measured.

Table 3: Monthly rainfall in 2017 recorded by North Central meteorological and hydrological stations

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total rainfall (mm)	16.5	18.7	53.3	68.0	188.6	149.7	203.3	245.0	310.5	209.5	93.1	33.5

Statistical analysis

All data were analyzed using IRRISTAT 5.0 software. The least significant difference (LSD) range test was used to compare differences among treatment means at 5% level.

3. Results and discussion

3.1. Evaluation of visual drought sensitivity and yield of rice varieties under well –water and water stress conditions

Leaf rolling and drying is a significant indicator of the plant under water stress. Leaf rolling and tip drying eventually leads to reduced light interception, transpiration and rice yield [13]. In this experiment, soil water content dropped to 15% on the 12th day and to 10% at 17th day after withholding water.

Table 4: Leaf rolling and drying score of rice varieties at different levels of water stress

Variety	**Soil moisture content 15%**		**Soil moisture content 10%**	
	Leaf rolling (Score)	**Leaf drying (Score)**	**Leaf rolling (Score)**	**Leaf drying (Score)**
Q5	3-5	3-5	7-9	7
Thuan Viet 1	1-3	3	7	5
Bac Thom	3	3	5-7	5-7
BC15	0	0	5-7	3
Thien Uu 8	0	0	7	3-5
Hong Duc 9	1	0	5-7	3-5
Huong thom 1	5	3	7-9	7
Lam Son 8	0	0	5	3

Without drought stress treatment, the 8 varieties did not show any symptoms of rolling or dried leaf tips. When soil moisture content decreased to 15% recorded on the 12th day after withholding water, leaves of the variety Q5 and Huong Thom 1 were folded into deep V-shape or U-shape, whereas other varieties showed little (Hong Duc 9, Thuan Viet and Bac Thom) or not affected (BC15, Thien Uu 8, Lam Son 8) indicating Huong Thom 1 and Q5 were less resistant to drought. No symptoms of leaf tip drying were observed. When soil moisture content reduced to 10%, occurring on the day 17th after drought imposed, leaves of varieties Q5, Huong Thom 1 were rolled tightly and dried. Among the tested varieties, BC15 and Lam Son 8 showed less damage at this stage, suggesting that they are the most tolerant to drought stress. While Bac Thom, Thuan Viet, Thien Uu 8 and Hong Duc 9 were moderately drought tolerant.

Table 5: Yield components under well-irrigated and water stress conditions

Variety	**Water-stressed condition**				**Well-irrigated condition**			
	No. of effective panicles	**No. of spikelet per panicles**	**Seed setting rate (%)**	**1000 grain weight (g)**	**No. of effective particles**	**No. of spikelet per panicles**	**Seed setting rate (%)**	**1000 grain weight (g)**
Q5	1.47c	121.3ab	33.4	23.1	4.53cde	145.4bc	86.7	24.8
Thuan Viet 1	1.17b	109.2a	35.9	22.5	4.37cd	140.8b	90.2	23.4
Bac Thom	1.03a	127.4cd	36.3	17.7	3.70a	147.5bc	85.6	19.7
BC15	1.25b	134.6de	50.2	21.3	4.64e	140.2b	89.7	24.2
Thien Uu 8	1.53c	127.6cd	47.1	21.7	4.31c	145.9bc	91.2	22.9
Hong Duc 9	1.17b	116.8ab	37.3	19.3	4.03b	149.7c	87.7	19.2
Huong thom 1	1.14b	108.2a	28.7	22.7	4.57de	123.8a	86.4	23.8
Lam Son 8	2.10d	137.2e	53.8	21.1	4.63e	150.2c	87.2	22.6
CV%	*0.11*	*8.81*			*0.25*	*7.45*		
$LSD_{0.05}$	*4.8*	*4.1*			*4.5*	*3.8*		

Means with different letters indicate significant differences according to Least Significant Difference test

Rice is considered one of the crops that most susceptible to drought, especially at the reproductive stage [14]. In this study, rice yield components were strongly affected by drought stress started at booting stage. Under the drought – stress, all the varieties showed significantly decreased in yield criteria as compared with the well-watered controls. Seed setting rate has been used in studies as the most important criterion for evaluation of drought tolerance in rice [15,16]. In this study, seed setting rate of the rice varieties in drought stress treatments was significantly different. Lam Son 8 had the highest seed setting rate with 53.8%, followed by BC15. Other varieties had seed setting rates varying from 50.2% to 28.7%. The number of panicles and spikelets were also severely affected by drought. Under drought treatment, the number of spikelets per panicle of all the varieties was remarkably reduced compared to those of the well-irrigated treatments (table 5). The number of panicles per plant ranged from 3.70 to 4.64 panicles/plant in irrigated treatment while in drought treatment it was only from 1.03 to 2.10 panicles/plant. Similarly, total spikelets per panicle were also decreased under drought condition. It was noted that Lam Son 8 had the highest number of panicles and spikelets (2.10 panicles/plant and 137.2 spikelets/particle), while the lowest was observed in Bac Thom (1.03 panicles/plant) and Huong Thom 1 (108,2 spikelets/panicle). With the same variety, the weight of 1000 full grains did not significantly differ between the two water regimes. It seems that drought stress occurring at the beginning of the booting stage has led to the reduction of important yield components of the rice plant. According to Kumar et al. [17], the reproductive stage is the most sensitive period for rice; any biotic or abiotic stress during this period can cause severe loss of rice yield. Maisura et al [18] stated that drought stress at the booting and flowering stages disrupts floret initiation, leads to asynchrony between female and male flowering and maturation and therefore results in slow grain filling and spikelet sterility. Similar rice yield loss tendency under drought stress treatment was also found in studies by Fen et al., [19], Zu et al [20]. Results from research by Yanbao and Ingrain [21] also showed that 15-day water stress period in the reproductive phase resulted in yield reduction up to 88% due to a reduction in the number of spikelets per plant and an increase in the percentage of unfilled spikelets.

3.2. Morphological characteristics and yields of rice varieties in rain-fed condition

Table 6: Agronomic characteristics of the tested varieties

Variety	**Spring 2017**			**Summer 2017**		
	Growth duration (days)	**Plant height (cm)**	**No. of tillers per plant**	**Growth duration (days)**	**Plant height (cm)**	**No. of tillers per plant**
Q5	135	106.3c	7.48a	112	105.4c	6.67a
Thuan Viet 1	133	108.5c	8.49de	105	109.8c	7.49b
Bac Thom	137	97.4a	7.63ab	109	95.5a	7.76b
BC15	125	104.5bc	8.92e	106	107.2c	8.22c
Thien Uu 8	127	106.6c	8.41d	104	103.9bc	8.19c
Hong Duc 9	123	96.3a	7.53a	94	94.7a	7.47b
Huong thom 1	130	99.1ab	7.97bc	106	97.7ab	7.64b
Lam Son 8	126	107.6c	8.31cd	105	108.2c	8.32c
CV%	-	5.74	0.41	-	6.93	0.3
LSD $_{0.05}$	-	3.2	2.9	-	3.9	2.2

Different letters within a column denote significant differences according to the Least Significant Difference test

The growth time of all the varieties in Summer season (94-112 days) was shorter than in Spring season (123 – 137 days). Spring crop season often has the least amount of total rainfall in North Central Coast. Dry and cold weather during the first months of the Spring season inhibits rice growth. In both seasons, the Bac Thom and Q5 varieties had the longest growth time. Longer duration crops are difficult to fit into crop rotation patterns and to avoid dry periods. The plant height varied from low to moderate and was in a range from 96.3 to 108.5 cm and from 94.7 to 109.8 in Summer and Spring, respectively. According to Yoshida [22], low and moderate plant heights are favourable where it is difficult to provide sufficient water to plants. The number of tillers was significantly different among the tested varieties. The highest number of tillers was obtained by variety BC15 in Spring season (8.92 tillers/plant) and Lam Son 8 in Summer season (8.32 tillers/plant). There was a trend of reduction in a number of tillers in Summer season as most of the varieties had fewer tillers than in Spring season except Lam Son 8. According to Yoshida [22], the variation in the number of tillers is influenced by planting distance, environmental conditions, cultivation techniques and nutrient supply. In this experiment, the reason could be that a drought period occurred during the tillering stage in Summer season inhibited tiller development. Only Lam Son 8 did not decrease in the number of tillers, suggesting that this variety was good tolerant to drought.

Table 7: Yield and yield components of rice varieties under rain-fed cultivation system in North Central

Variety	Spring 2017				Summer 2017			
	No. of spikelets per panicle	**Seed setting rate (%)**	**1000 grain weight (g)**	**Yield (quintal/ha)**	**No. of spikelet per panicle**	**Seed setting rate (%)**	**1000 grain weight (g)**	**Yield (quintal/ha)**
Q5	153.43bcd	78.25	24.2	55.69a	148.2d	76.51	23.5	51.57a
Thuan Viet 1	147.96bcd	80.20	23.0	61.00b	112.7a	80.34	22.0	57.5c
Bac Thom	156.25cd	84.35	19.1	59.00ab	144.8d	81.35	20.1	55.43bc
BC15	138.55b	83.06	23.7	65.67c	128.5c	80.06	23.1	61.27d
Thien Uu 8	142.85bc	80.18	23.0	61.10b	116.2b	78.18	22.8	57.72c
Hong Duc 9	158.08d	78.00	19.2	56.57a	150.2d	76.30	19.0	52.82ab
Huong thom 1	119.54a	79.62	24.0	57.33a	113.2a	79.23	22.0	53.43ab
Lam Son 8	160.2d	85.54	21.7	66.33c	146.2d	86.42	22.3	62.25d
CV%	*15.1*			*3.41*	*8.86*			*3.37*
LSD $_{0.05}$	*6.0*			*3.2*	*3.9*			*3.4*

Different letters within a column denote least significant differences

The number of spikelets per panicle was significantly different among the rice varieties in both crop seasons (table 7). The high number of spikelets and highest seed setting rate obtained with variety Lam Son 8 result in the highest yield of 66.33 quintals/ha in Spring season and 62.25 quintals/ha in Summer season, respectively. Its achievement in yield was statistically comparable to BC15. On average of the two seasons, Hong Duc 9 had the highest number of spikelets, yet low seed setting rate and grain weight led to its low yield (56.57 quintals/ha in Spring and 52.82 quintals/ha in Summer, respectively) and was comparable to Q5 and Huong Thom 1. Thien Uu 8 and Bac Thom had moderate yields of 61.10 and 59.00 quintal/ha; 57.72 and 55.43 quintal/ha in Spring and Summer season, respectively. The 1000- grain weight were the most stable component between two seasons, varied from 19.1 to 24.2 g and 19.0 – 23.5 g in Spring and Summer season. It was noted that yields and yield components of the rice varieties were generally higher in Spring season than those in Summer season. According to Gana [23], drought duration and crop growth stage are two determinants of grain yield loss. It seemed that dry period in the Spring season (January to February) happened at the germination stage did not strongly affect rice yield as the rice plants have time to recover before entering the reproductive stage. Furthermore, the weather in Spring season is more favourable for rice growth than in Summer season. This could contribute to higher rice yields observed in this study.

4. Conclusions

In this study, the drought-tolerant rice varieties were selected based on the evaluation of agronomic characteristics and leaf rolling and drought score. Drought in the vegetative phase delayed phenological events but did not result in significant yield losses if drought occurred at early stages. However, a drought occurred at reproductive phase resulted in substantial yield losses, mainly caused by large percentages of unfilled grains and a reduction in the number of panicles. This study indicated that Lam Son 8 and BC 15was superior drought tolerant. Thien Uu 8, Thuan Viet 1, Hong Duc 9 and Bac Thom were moderately tolerant varieties while Q5 and Huong Thom 1 were droughts sensitive. These traits may have greater relevance and benefit to the future for the breeding program, particularly for screening drought tolerance at early stage.

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