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Growth performance of selected Malaysian rice germplasm under drought stress environment

(Prestasi pertumbuhan germplasma padi Malaysia terpilih dalam sekitaran tegasan kemarau)

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Abstract

The rice accessions reached the 50% flowering stage at the end of March, indicating that the crops underwent severe stress for about 2 weeks during panicle development and pre-flowering stages. All traits were drastically affected by the drought stress and significant reduction in their performance was also observed. Analysis of variance showed significant differences for all phenotypic and agronomic traits observed under stress environment. Heritability showed four phenotypic and agronomic traits, namely, days to 50% flowering, plant height, flag leaf length and flag leaf width. These traits showed high heritability both under non-stress (control) (67.7 – 82.6%) and stress (64.1 – 89.7%) environments. Grain yield had high heritability under non-stress environment (62.5%) but moderate heritability under stress environment (50.0%). Several significant positive as well as negative correlations under stress environment were observed among the traits. Similar trends of correlation were also observed under non-stress environments.

Introduction

Rice is the world's most important food crop and a primary food source for more than half of the world's population. The global rice area and production during the year 2008 was 155.7 million ha and 661.8 million tonnes with a productivity of 4.2 t/ha (USDA 2009). More than 90% of the world's rice is grown and consumed in Asia. It has been estimated that more than 200 million tonnes of rice are lost every year due to environmental stresses, diseases, and pests (Herdt 1991; Chen and Murata 2002). Drought is a major constraint to rice production and yield stability especially in rain-fed areas and causes large yield losses in many Asian countries (Jearakongman et al. 1995; Pantuwan et al. 2002a; Jongdee et al. 2006).

Drought is defined by plant breeders as a shortfall of water availability sufficient to cause loss in yield, or a period of no rainfall or irrigation that affects crop growth (Fukai and Cooper 1995). In Malaysia, the first severe drought occurred in 1977 and its impact continued up to 1978. Consequently, the rice production of 0.36 million tonnes, worth RM180 million was lost (Teoh and Chua 1989). To meet the growing rice demand and for stable

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rice production during the years of *El Niño*, improvement of existing varieties for drought tolerance is necessary. Identification of drought resistant varieties can be done either by selecting directly based on yield under drought conditions, or indirectly based on physiological or morphological characteristics associated with drought tolerance, or combination of both of these selection strategies (Fukai et al. 1999).

In Malaysia, many studies have been carried out on the biochemical and physiological responses of rice germplasm under controlled drought environments. However, there are only a few studies on growth performance and morphological changes under water stress environments at different stages of crop growth particularly at the reproductive stage. This study was undertaken to evaluate 80 Malaysian rice germplasms to identify tolerant rice accessions based on selected morphology and agronomy traits. The study would give a better understanding on relationships and responses of the particular traits of the accessions to drought stress environment. This information would be useful to rice breeders in selecting the potential lines for developing drought tolerant rice varieties based on morphological characteristics associated with drought tolerance. Besides, the data collected from this study will be compiled in the information system in MARDI's Gene bank for future use.

Materials and methods

Rice accessions

A total of 80 rice accessions were selected from the MARDI Rice Genebank in Seberang Perai, Pulau Pinang. The selected materials consist of Malaysian landraces, breeding lines, varieties, cultivars and introduced varieties or accessions. Six check varieties with a broad range of drought tolerance namely Vandana, Apo, PSBRC-82, UPLRi7, Mokwoo and IR77298-14-1-2-10 and two check varieties susceptible to drought, IR64 and MTU1010, were included in the experiment. These check varieties were commonly used by the drought group at the International Rice Research Institute (IRRI), Los Baños, Philippines.

Planting procedure

The rice accessions were grouped into three groups based on their maturity days, namely, short maturity (<130 days), intermediate (131 – 149 days) and long maturity (>150 days). The accessions were sown and transplanted according to the maturity days. This is important to ensure all the accessions experienced drought stress at the same stages i.e. vegetative to pre-flowering stages.

Experimental design

The field evaluation was conducted under upland conditions at Quarantine Area in IRRI, Los Baños. The soil of the IRRI upland farm consists of Maahas clay loam (isohyperthermic mixed Typic Tropudalf) (Zhao et al. 2006; Bernier et al. 2007).

The rice accessions were planted in two replications with 11 plants in each replication in both drought stress and non-stress (control) environments. Alpha-Lattice Experimental Design (Patterson and Williams 1976) was followed for laying out the experiment. It is a replicated design with incomplete blocks that contains a fraction of the total number of entries. Genotypes are arranged among the blocks so that all pairs occur in the same incomplete-block in nearly equal frequency (Anon. 2005). Spacing between the rows was 0.2 m with 2 m single-row plots.

Drought stress imposition

The 80 Malaysian rice accessions and eight check varieties were evaluated under stress (*Plate 1*) and non-stress (control) (*Plate 2*) environments. The stress trial plots were irrigated normally for the first 4 weeks after transplanting and stress was then imposed by draining out water until maturity by reducing the frequency of irrigation to create the reproductive stage drought in the field. Perforated PVC pipes were placed at 1.0 m soil depth at 6 different points in the field

Plate 1. Crops under stress environment: A. After transplanting; B. Seedling at 3 weeks after transplanting; C. At maturity stage

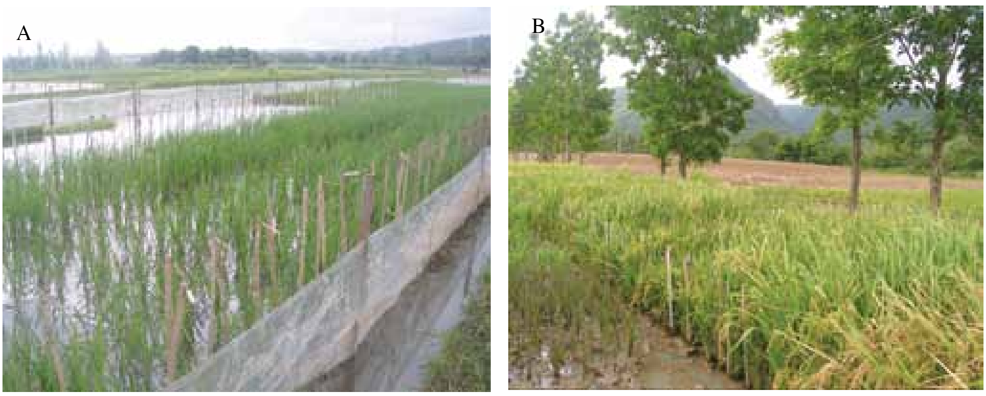

Plate 2. Crops under non-stress environment: A. At vegetative stage; B. At maturity stage

of 500 m^2. The water table was measured daily after draining the field until maturity. When the water table reached below 100 cm and remained so for more than 2 weeks, irrigation was provided and the field was drained after 24 h for the next stress cycle to continue. This irrigation was provided to avoid the plants from dying (Venuprasad et al. 2007).

Continuous stress cycles were created during vegetative to early flowering stage to ensure that all entries experience stress during flowering. Stress imposition was started on 7 February 2011 at the vegetative stage. Daily rainfall data during the cropping season was taken from the IRRI website under Climate Unit, Crops and Environmental Science Division and presented as cumulative rainfall for every 10 days interval (*Figure 1*). In the non-stress (control) trial, a 5.0 cm water level was maintained until the paddy plants reached physiological maturity.

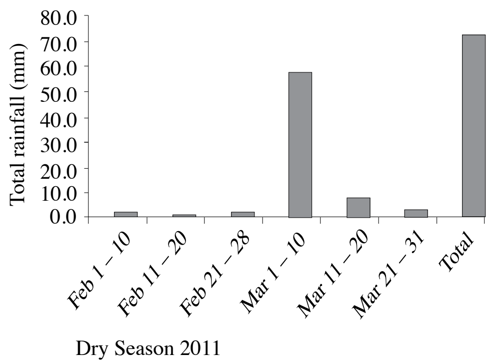

Figure 1. Total cumulative rainfall during vegetative and reproductive stages of paddy in dry season 2011

Basal application of P and K equivalent to 40 kg/ha each were applied in the form of single super phosphate and potassium chloride, and 120 kg/ha of N in the form of ammonium sulfate (Bernier et al. 2007) was applied in three even splits around 10, 25 and 45 days after transplanting. The planting date was 14 January 2011 for both stress and non-stress trials. Furadan, a systemic insecticide, was applied once on 1 February 2011 to control Tungro virus infestation. Weeds were controlled by hand weeding.

Phenotypic and morphological data collection

Observations were recorded at different stages of crop growth until maturity from both treatments. Phenotypic data recorded were as follows: days to 50% flowering (DTF) = Number of days from sowing until 50% of the plants in a plot had flowering tillers; plant height (PH) = Distance from the ground to the tip of the panicle on the main tiller at maturity from three random plants in each plot; flag leaf length (FLL) = Length of the flag leaf from the ligule to the tip of the blade; flag leaf width (FLW) = Width at the widest portion of the flag leaf; tiller number (TN) = Total number of grain-bearing and non-bearing tillers of five plants; panicle number (PN) = Number of panicles per plant at early ripening stage; panicle length (PL) = Length of main axis of panicle measured from the panicle base to the tip; and grain yield (GY) = Paddy was harvested at physiological stage of maturity and grain moisture content adjusted to 14%.

Visual scores of leaf rolling (LR) were recorded after 2 weeks exposure to stress. The evaluation for drought stress was done at the reproductive stage following the Rice Evaluation Standard developed by IRRI (Anon. 1996) using scores of 1 to 9. Score 1 was given to accessions showing green and normal leaves indicating tolerance to drought and score 9 to accessions with completely rolled leaves indicating high susceptibility to drought.

Statistical analysis

The phenotypic observations were analysed using Crop Stat (v7.2) to determine the mean, range, LSD values, broad sense heritability (H^2) and F values. The significance levels were verified from the F values at p <0.05. Correlations among the traits under stress and non-stress (control) were estimated using SPSS (v17.0).

Results and discussion

Drought imposition for the stress trials

The drought screening experiment was successful due to the absence or minimal rainfall during the cropping season, except for the first week of March (*Figure 1*). The water table in the experimental plot of stress trial is shown in *Figure 2*. According to Manneh and Ndjiondjop (2008), effective rooting depth of most rice varieties is the top 20 cm of soil. This indicates that the rice plants may experience stress when the ground water table is lower than 20 cm. In this study, the ground water table reached below 70 cm after 2 weeks of imposing stress.

Bernier et al. (2007) reported that paddy plants wilted and exhibited leaf drying when the soil water potential was below –50 kPa or at 30 cm soil depth. This showed that the rice accessions under stress environment experienced severe drought stress during their growth stages. The most severe stress occurred about 2 weeks during late vegetative and panicle development or pre-flowering stages. This also indicated that the stress period during the crop growth stages was successfully developed. Moreover, the lesser amount of rainfall and longer dry spells are the key components for successful drought screening at IRRI during the dry season (Vikram et al. 2011).

O'Toole (1982) and Boojung and Fukai (1996) stated that drought affected rice yield most severely if the crops were exposed to drought just prior to flowering. Jennings et al. (1979) reported that exposure to at least 2 weeks of drought stress due to rainless days during vegetative stage and at least one week during the reproductive stage can differentiate susceptible and drought resistant genotypes.

Performance of Malaysian rice germplasm under stress environment

The mean, range, standard deviation and test of significance for the different traits under stress and non-stress environments are presented in *Table 1*. All the eight

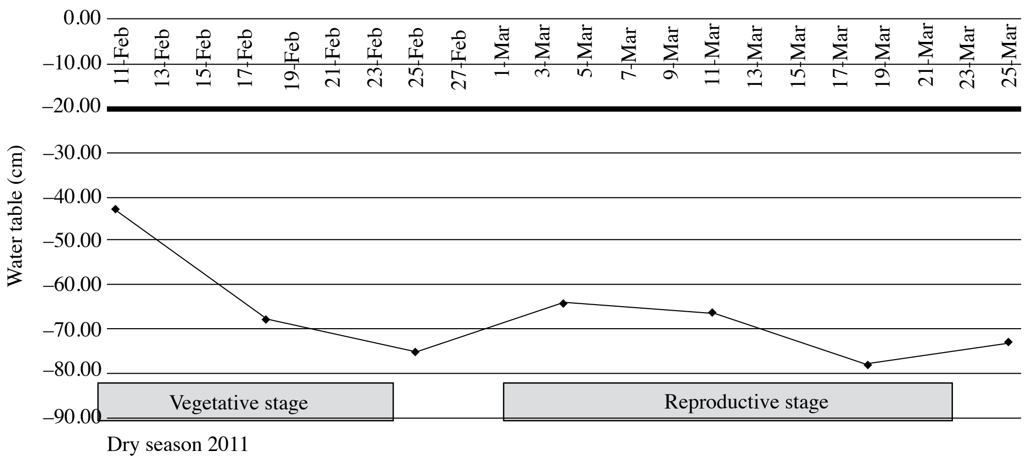

Figure 2. Water table in stress trial during dry season 2011. The trial was conducted under upland conditions at Quarantine Area in IRRI, Los Baños, Philippines. The bold black line shows the level of effective rooting depth of the rice. Plants are water stressed when the water table is below the bold black line

phenotypic and agronomic traits differed significantly among the genotypes under non-stress and stress environments. However, only leaf rolling showed non-significant difference in this study (data not shown). Scores of leaf rolling was not strongly correlated with performance under stress (Price et al. 2002), thus leaf rolling is not an effective trait in selecting drought tolerance variety.

All the traits were drastically affected by the drought stress. DTF was delayed by 5 days under stress compared to non-stress plants (*Table 1*). However, for all the other traits, there were significant reductions in their performance under stress. PH was reduced by 21.0%, FLL by 35.3%, FLW by 16.7%, TN by 35.5%, PN by 40.2%, PL by 17.8% and GY by 60.4% (*Table 1*). The standard deviation and test of significance clearly showed that there were wider variation for agronomic traits under non-stress condition and greater differential response of genotypes under drought stress.

The delayed flowering observed under stress condition in the present study is in agreement with earlier reports by several workers (Lafitte and Courtois 2002; Pantuwan et al. 2002b; Atlin et al. 2006; Jongdee et al. 2006; Zhao et al. 2010; Vikram et al. 2011). According to Pantuwan et al. (2002b), delayed flowering under drought stress could be a good measurement of plant responses and adaptability to drought tolerance, and also an efficient selection criterion for distinguishing drought susceptible and resistant genotypes.

The negative effect of drought on performance of many traits including yield has been reported (Fukai and Cooper 1995; Pantuwan et al. 2002b). Even mild stresses during flowering causes severe reduction in plant height, biomass, spikelet fertility and grain yield. The reduction is mainly because of water shortage in the plant causing more respiration and reduced photosynthesis, leading to less biomass accumulation and less grain yield (O' Toole 1982; Boojung and Fukai 1996; Fukai et al. 1999).

One of the major causes of yield loss under drought is poor panicle exertion especially in the late flowering genotypes. Panicles unable to exert fully resulted in parts or whole panicles to still remain in the flag leaf sheath causing reduction in grain yield (O'Toole and Namuco 1983; Cruz and O'Toole 1984; Ekanayake et al. 1989; Pantuwan et al. 2002a). Kim and Kim (2009) stated that exposure to stress environment during the panicle development

Table 1. Mean, range, and standard deviation for phenotypic and agronomic traits of 80 Malaysian rice accessions observed under stress and non-stress environments

Trait	Mean		Range		Std Dev		LSD		F Value		P>F	
environment	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
DTF	93.8	94.8	60 – 127	55 – 124	12.1	12.8	12.3	12.3	7.64	8.48	<0.001	<0.001
PH	74.7	94.6	55.3 – 121.3	68.7 – 148.7	12.1	19.5	8.7	18.6	16.34	8.99	<0.001	<0.001
FLL	22.2	34.3	13.6 – 40.8	21.6 – 58.5	4.6	6.5	5.1	8.0	6.20	4.84	<0.001	<0.001
FLW	1.5	1.8	0.9 – 1.9	1.2 – 2.7	0.2	0.3	0.2	0.3	4.14	5.58	<0.001	<0.001
TN	10.0	15.5	3 – 19	8 – 31	2.9	4.4	4.7	7.4	2.60	2.41	<0.001	<0.001
PN	7.9	13.2	2 – 18	6 – 30	2.7	4.3	4.3	7.3	2.62	2.33	<0.001	<0.001
PL	19.4	23.6	15.0 – 23.5	17.5 – 31.8	1.4	2.2	2.2	3.3	3.34	3.33	<0.001	<0.001
GY	687.7	1,736.0	57.0 – 1,577.0	633.8 – 3,689.0	327.1	684.6	470.4	942.4	2.48	3.96	<0.001	<0.001

DTF = Days to 50% flowering; PH = Plant height (cm); FLL = Flag leaf length (cm); FLW = Flag leaf width (cm); TN = Tiller number; PN = Panicle number; PL = Panicle length (cm); GY = Grain yield (kg/ha)
S = Stress environment; NS = Non-stress environment

Table 2. Broad-sense heritability (H^2) (%) of phenotypic and agronomic traits of 80 Malaysian rice accessions under stress and non-stress environments

Trait	Stress	Non-stress
DTF	79.4	81.0
PH	89.7	82.6
FLL	73.6	67.7
FLW	64.1	73.4
TN	41.1	40.2
PN	44.7	38.0
PL	48.2	53.5
GY	50.0	62.5

DTF = Days to 50% flowering;
PH = Plant height (cm);
FLL = Flag leaf length (cm);
FLW = Flag leaf width (cm);
TN = Tiller number;
PN = Panicle number;
PL = Panicle length (cm);
GY = Grain yield (kg/ha)

stage can result in delayed flowering time, reduced number of spikelets and poor grain filling.

Heritability of agronomic traits

The broad-sense heritability (H^2) of the phenotypic and agronomic traits under different environments was estimated and presented in *Table 2*. Broad-sense heritability is defined as $H^2 = V_G/V_P$, estimates the proportion of phenotypic variation due to genetic values that may include effects due to dominance and epistasis (Wray and Visscher 2008). Heritability values of agronomic traits were classified based on Hanson et al. (1956) as follows: 0 – 30% (low), 30 – 60% (moderate), and >60% (high).

All the traits showed moderate to high heritability under non-stress (control) and stress environments. Traits such as DTF, PH, FLL and FLW were highly heritable under both environments. Heritability values under non-stress (control) and stress environments were 81.0% and 79.4% for DTF; 82.6% and 89.7% for PH; 67.7% and 73.6% for FLL;

and 73.4% and 64.1% for FLW respectively. For GY, high heritability (62.5%) was obtained under non-stress (control) condition and moderate heritability (50.0%) under stress environment. The rests of the traits namely TN, PN, and PL showed moderate heritability ranging from 38.0 – 53.5% under non stress (control) condition and 41.1 – 48.2% under stress environment. This indicated that the phenotypic variation observed in this study was contributed by the genotypes with minimal environmental effects.

Moderate heritability in grain yield under drought stress environment was also observed in many studies (Babu et al. 2003; Atlin et al. 2004; Lafitee et al. 2004; Yue et al. 2005; Kumar et al. 2007; Kamoshita et al. 2008). High heritability in plant height and days to 50% flowering under drought stress environment were also observed in several studies (Lafitee et al. 2004; Lanceras et al. 2004; Bernier et al. 2007). Other secondary traits also showed high heritability such as number of spikelets per panicle and total grain weight (Lafitte et al. 2004), leaf drying, canopy temperature and leaf chlorophyll content (Gomez et al. 2006).

It was concluded that the high heritability traits were due to preponderance of additive gene action and suitable for direct selection in improving drought resistance in rice (Gomez et al. 2006). In this study, the moderate to high heritability values for yield and yield related traits indicated that they were genetically controlled by additive gene action and can be used as a selection parameter under non-stress as well as stress environments.

Correlation of agronomic traits

Correlation coefficient was estimated for all eight phenotypic and agronomic traits under non-stress (control) (*Table 3*) and stress environments (*Table 4*). Under stress environment, GY showed significant negative correlation with DTF. This was an indication that genotypes with early flowering time may have smaller yield reduction. This negative correlation was also observed in earlier studies by Zhao et al. (2010) and Vikram et al. (2011). The genotypes with early flowering time normally have higher yield than the genotypes that flowered later (Pantuwan et al. 2002b). High yield observed in early maturing genotypes was due to lesser number of stress cycles during the reproductive stage as a drought escape mechanism. Early flowering is an important character to escape from severe drought stress (Jearakongman et al. 1995; Wonprasaid et al. 1996; Cooper and Somrith 1997; Rajatasereekul et al. 1997; Fukai et al. 1999; Pantuwan et al. 2002b; Kamoshita et al. 2008; Guan et al. 2010).

Significant positive correlation was observed between GY with both TN and PN under stress environment (*Table 4*). This showed that increasing the TN and PN will consequently increase grain yield. Significant positive correlation between GY with PN under stress was also observed by Gomez et al. (2006). Significant positive correlation was also observed between TN with PN. These traits appeared to be promising secondary traits for selection to improve the yield under stress and consequently develop high-yielding drought tolerant rice varieties.

Under stress environment, FLL and FLW had negative correlations with TN and PN. However, PH showed strong significant positive correlation with FLL, but it was negatively correlated with GY. Negative correlation between PH and GY was also observed by Lafitte et al. (2004). This indicated that plants which have shorter plant height will produce higher grain yield compared to taller plants which are prone to lodging, thus reducing the grain yield (Zhao et al. 2010).

Some traits under non-stress environment showed similar trends of correlation with traits under stress environment. The PH showed negative correlation with GY; and strong positive

Table 3. Correlation coefficients of phenotypic and agronomic traits of 80 Malaysian rice accessions under non-stress environment

TRAIT	DTF	PH	FLL	FLW	TN	PN	PL	GY
DTF	1.00							
PH	0.27**	1.00						
FLL	0.01	0.34**	1.00					
FLW	0.65**	0.39**	0.03	1.00				
TN	–0.10	–0.14	–0.12	–0.18*	1.00			
PN	–0.09	–0.17*	–0.15	–0.17*	0.98**	1.00		
PL	0.32**	0.53**	0.31**	0.36**	–0.12	–0.16	1.00	
GY	–0.03	–0.15	–0.11	–0.09	0.03	0.02	–0.19*	1.00

*Correlation is significant at 0.05 level ($p < 0.05$)
**Correlation is significant at 0.01 level ($p < 0.01$)

Table 4. Correlation coefficients of phenotypic and agronomic traits of 80 Malaysian rice accessions under stress environment

TRAIT	DTF	PH	FLL	FLW	TN	PN	PL	GY
DTF	1.00							
PH	0.05	1.00						
FLL	–0.03	0.51**	1.00					
FLW	0.46**	–0.04	0.02	1.00				
TN	–0.10	–0.26**	–0.06	–0.14	1.00			
PN	–0.11	–0.28**	–0.08	–0.13	0.94**	1.00		
PL	0.21*	0.05	0.14	0.11	–0.10	–0.10	1.00	
GY	–0.17*	–0.01	–0.17*	0.07	0.28**	0.27**	–0.15	1.00

* Correlation is significant at 0.05 level ($p < 0.05$)
** Correlation is significant at 0.01 level ($p < 0.01$)

correlation with FLL; while, FLL has negative correlation with TN and PN; positive correlation was observed in TN and PN, FLW and DTF. The grain yield under well-watered environment is important in determining the grain yield under stress environment. Although there is no genetic relationship between yield potential and drought tolerance, the trait contributed towards higher grain production under stress environment (Lanceras et al. 2004). Similar trends in correlation among the traits observed under stress and non-stress environments indicated that grain yield under drought can be improved without affecting its yield potential under normal situations. It is also possible to simultaneously increase the yield under non-stress and stress environments.

Conclusion

This study provides a better understanding on the responses of Malaysian rice germplasm to drought stress environment. Many yield component traits such as days to flowering, plant height, tiller number, panicle number, panicle length and grain yield showed potential traits for direct selection in improving drought resistance in rice. These traits have high and medium heritability with strong correlations among them. Selection based on these yield component traits is important for selecting donor parents for developing drought tolerance varieties.

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Abstrak

Aksesi padi yang dikaji mencapai peringkat 50% berbunga pada penghujung Mac, menunjukkan semua tanaman mengalami keadaan tekanan kurang air yang teruk selama 2 minggu semasa peringkat pembentukan tangkai hingga ke peringkat awal pembungaan. Semua sifat yang dikaji terjejas secara drastik oleh tegasan kemarau dan didapati kemerosotan ketara berlaku terhadap prestasi pertumbuhan pokok. Analisis varians menunjukkan perbezaan yang signifikan untuk kesemua sifat fenotip dan agronomi yang dikaji dalam keadaan tegasan air. Keterwarisan menunjukkan empat sifat fenotip dan agronomi iaitu jumlah hari sehingga 50% berbunga, ketinggian pokok, panjang dan lebar daun pengasuh. Sifat-sifat ini menunjukkan keterwarisan yang tinggi di kedua-dua keadaan sama ada untuk keadaan normal (67.7 – 82.6%) atau dalam keadaan tegasan air (64.1 – 89.7%). Hasil padi menunjukkan keterwarisan yang tinggi dalam keadaan normal (62.5%) tetapi keterwarisan adalah sederhana dalam persekitaran tegasan air (50.0%). Beberapa corak korelasi yang positif dan negatif didapati signifikan antara sifat dalam keadaan tekanan kurang air. Corak korelasi yang sama juga turut dilihat dalam keadaan persekitaran bertakung air.

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