Acta Scientiarum
http://www.uem.br/acta
ISSN printed: 1679-9275
ISSN on-line: 1807-8621
Doi: 10.4025/actasciagron.v38i2.27164

Drought tolerance in upland rice: identification of genotypes and agronomic characteristics

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ABSTRACT. This study aimed to identify upland rice cultivars and elite lines that are tolerant to drought and the agronomic traits associated with this tolerance. Forty-one genotypes were evaluated in a randomized block design with three replications in experiments with and without water stress at the Experimental Station of Emater, in Porangatu, Goiás State, in 2011 and 2012. The first experiment was well-irrigated throughout plant development and the second experiment was irrigated only up to 40 days after emergence, after which water stress was imposed. A multivariate analysis using Ward's method was applied, and the genotypes with and without water stress were classified into six and seven clusters, respectively, based on the average yield in the two years of experimentation. The most productive cluster under water stress comprised the genotypes AB062041, Douradão, Guarani, BRS Aimoré, and Tangará. The first four genotypes of this cluster were also ranked in the second most productive cluster under well-irrigated conditions. In the selection for drought tolerance, the genotypes that exhibit precocity, less dense panicles, low sterility and greater 100-grain weight under water stress should be prioritized.

Keywords: *Oryza sativa* L., spikelet sterility, earliness, grain weight.

Tolerância à deficiência hídrica em arroz de terras altas: identificação de genótipos e características agronômicas

RESUMO. O objetivo do trabalho foi identificar a tolerância à deficiência hídrica de cultivares e linhagens elites de arroz de terras altas e as características agronômicas relacionadas com essa tolerância. Avaliaram-se 41 genótipos no delineamento de blocos ao acaso, com três repetições, em experimentos com e sem deficiência hídrica, na Estação Experimental da Emater em Porangatu, Goiás, em 2011 e 2012. O primeiro foi irrigado adequadamente durante todo o desenvolvimento das plantas e o outro apenas até aos 40 dias após a emergência, quando foi aplicada a deficiência hídrica. Aplicou-se a análise multivariada e pelo método de Ward classificaram-se os genótipos em seis e sete grupos, considerando-se os valores médios das produtividades nos dois anos de condução dos experimentos, com e sem deficiência hídrica, respectivamente. O grupo mais produtivo sob condições de deficiência hídrica foi composto pelos genótipos AB062041, Douradão, Guarani, BRS Aimoré e Tangará. Os quatro primeiros genótipos desse grupo foram também classificados no segundo grupo mais produtivo sob condições de irrigação adequada. Na seleção para tolerância à deficiência hídrica deve-se priorizar genótipos que apresentem, sob essa condição, precocidade e panículas menos densas, porém com baixa esterilidade e com maior massa de 100 grãos.

Palavras-chave: *Oryza sativa* L., esterilidade de espiguetas, precocidade, massa dos grãos.

Introduction

Rice (*Oryza sativa* L.) is one of the most-produced and consumed grains worldwide (Walter, Marchezan, & Avila, 2008). It is a part of the basic diet of the population in many regions and is the staple food of poor farm families in several Asian countries (Kamoshita, Babu, Boopathi, & Fukai, 2008). It is also a product of great economic importance in many developing countries, such as Brazil. Additionally, it presents broad adaptation to different soil conditions and climate (Parent, Suard, Serraj, & Tardieu, 2010).

Rice ecosystems are generally classified into four types: irrigated, rain-fed lowland, deep-water and rain-fed upland. Upland rice ecosystems constitute 12% of the global rice production area and have a proportionally greater importance in Africa and Latin America, where they account for approximately 40 and 45% of the rice-growing areas, respectively (Bernier, Atlin, Serraj, Kumar, & Spaner, 2008).

In Brazil, most of the rice grown in upland ecosystems is grown in the Cerrado region, where the soils are characterized by a low water storage capacity, low natural fertility and elevated acidity, factors that limit yield (Crusciol, Soratto, Arf, & Mateus, 2006). This region presents a mostly irregular rainfall distribution, with the occurrence of dry spells, which are periods lacking rainfall during the rainy season (Guimarães, Stone, Oliveira, Rangel, & Rodrigues, 2011).

According to Pinheiro (2003), during these periods a negative water balance in the soil occurs, which causes plant water stress and therefore compromises growth, transpiration, photosynthesis, carbohydrate translocation and grain yield in rice. These dry spells are unpredictable; thus, the drought tolerance in rice genotypes should be treated as an aggregate parameter. Therefore, a deep root system with higher root density is likely to be useful if the growing conditions permit root development at depth (Kamoshita et al., 2008).

The scenario of the water deficit due to irregular rainfall distribution may be aggravated by climate change. Increasing temperatures and the worsening distribution of rainfall is a great possibility, thus further restricting the areas with potential for planting if measures are not taken to moderate its effects. The development of drought-tolerant cultivars can be a solution.

According to Lafitte et al. (2006), the challenge for breeders is to combine the high-yield potential of modern cultivars with strong drought tolerance. Jongdee, Pantuwan, Fukai, and Fischer (2006) stated that rice varieties that respond well to favorably watered conditions can be developed for improved yield under drought stress if there is early selection for yield under both drought and well-watered conditions. This statement is feasible for mild water stress, when the reduction in productivity is less than 50%.

Plant breeders rely on direct selection for grain yield as the main criterion for selection. That process might be made more efficient by the use of indirect traits associated with drought (Jongdee et al., 2006). Thus, the objective of this work is to identify upland rice cultivars and elite lines tolerant to drought and also identify the agronomic traits associated with this tolerance.

Material and methods

The experiments were conducted on soil classified as Oxisol at the Experimental Station of Emater in Porangatu, Goiás State, located at 13° 18' 31" S latitude and 49° 06' 47" W longitude and at an altitude of 391 m. This area has an Aw climate and is classified as a megathermic tropical savanna according to the Köppen's classification. The rainfall data and maximum and minimum temperatures are shown in Figure 1. The rainfall was minimal during the experimental period.

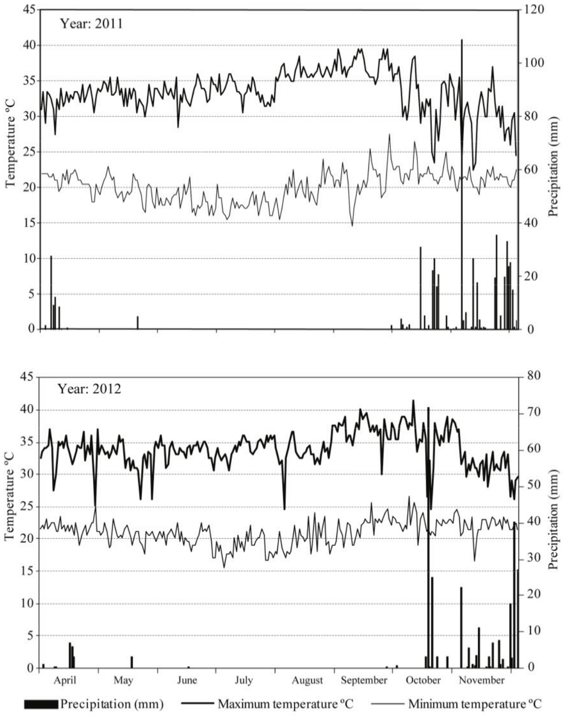

Figure 1. Rainfall, maximum (Tmax) and minimum (Tmin) temperature obtained during the experimental period in the years 2011 and 2012 at the Experimental Station of Emater, Porangatu, Goiás State.

Sowing was performed on 5/17/2011 and 5/12/2012 in plots of four rows, 4 m long and 0.4 m spaced. The seeding rate was 70 seeds per meter. It was applied 16, 120, and 64 kg ha^{-1} of N, P_2O_5, and K_2O, respectively. The topdressing fertilization was performed with 40 kg ha^{-1} of N 45 days after emergence in the form of ammonium sulfate. The weed control was implemented with oxadiazon at a dose of 1,000 g a.i. ha^{-1} during early post-emergence. Forty-one genotypes of upland rice were evaluated in a randomized block design with three replications. Two experiments were conducted each year; the first was well irrigated throughout plant development, and the other was irrigated only up to 40 days after emergence, after which water stress was imposed. Irrigation was performed in the first experiment and during the phase prior to the water deficit in the second experiment to maintain the soil water potential at a 0.15 m depth above -0.025 MPa (Pinheiro, Castro, & Guimarães, 2006). During the water deficit, irrigation was applied when the soil water potential reached -0.06 MPa. The irrigation control was performed by tensiometer sets. The grain yield, spikelet sterility, number of grains per panicle, plant height, number of days to flowering, and 100-grain weight were evaluated by conventional methods. The genotypes were clustered in each experiment by multivariate analysis according to Ward's method (Ward Jr., 1963) based on the grain yield in the two years. The clusters were subjected to an analysis of variance, and the means were compared by a t-test at 5%. Additionally, a correlation analysis among the variables was performed for genotypes in G1 and G2 clusters.

Results and discussion

The genotypes were classified using Ward's method (Ward Jr., 1963) based on the average yield observed in the two years of experimentation into six clusters under water stress (Table 1) and seven clusters without water stress (Table 2). The mean yield of the clusters differed significantly in both water treatments (Table 3). Lafitte et al. (2006) and Guimarães, Stone, Rangel, and Silva (2013) also observed variability in the grain yield of the rice genotypes subjected to water stress.

The mean yield of the two years were 1,618 and 2,915 kg ha^{-1} for the experiments with and without water stress, respectively. Thus, the genotypes experienced an average reduction of 44.5% in yield due to the water stress (Tables 1 and 2).

Under conditions of water stress, the six clusters of genotypes yielded an average of 2556, 2248, 1842, 1,484, 1,155; and 845 kg ha^{-1} (Table 1). G1, the most productive, comprised the genotypes AB062041, Douradão, Guarani, BRS Aimoré, and Tangará. Under these same conditions, the least productive cluster, G6, comprised the genotypes AB062008, Maravilha, BRS Soberana, and Carreon.

The average yields of the seven clusters of genotypes under well-irrigated conditions were 4,479; 3,804; 3,458; 2,840; 2,407; 1,722; and 844 kg ha^{-1} (Table 2). The G1, the most productive, comprised the genotypes BRS Colosso and BRA 01600, and the least productive cluster comprised the genotypes Acrefino and Maravilha.

For the conditions of a climate with irregular rainfall distribution, such as the Cerrado region, tolerance to drought must be an aggregate characteristic of the cultivars because in most cases adequate rainfall is available. In this sense, the grain yield under both water conditions, with and without water stress, should be considered in the selection.

Table 1. Yield, spikelet sterility (SpiSte), number of grains per panicle (GrPan), plant height (Hght) and flowering date (Flower) of the rice genotypes and cluster mean according to Ward's method, considering grain yield under water stress[1].

Cluster	Genotype	Yield (kg ha^{-1})		SpiSte (%)	GrPan (nº)	Hght (cm)	Flower (DAS[2])
		Genotype mean	Cluster mean				
G1	AB062041	2631	2556a	25.5	86	77.7	70
	Douradão	2579		39.9	92	87.7	66
	Guarani	2558		15.5	79	84.7	65
	BRS Aimoré	2512		33.0	70	75.7	65
	Tangará	2502		34.1	73	69.9	67
G2	Rio Paranaíba	2369	2248b	47.8	101	96.7	105
	IRRI 2	2361		61.3	113	77.6	104
	AB062138	2216		30.8	94	75.1	89
	IRRI 33	2195		56.2	115	79.5	101
	Rio Paraguai	2098		49.4	77	89.1	106
G3	Canastra	1946	1842c	51.3	84	74.9	90
	AB062037	1945		32.9	84	80.4	78
	Centro América	1903		25.5	73	78.3	67
	Cabaçu	1795		45.9	63	83.5	115
	Caiapó	1770		46.8	104	86.9	100
	BRS Talento	1695		56.5	101	70.3	96
G4	BRS Monarca	1610	1484d	44.7	67	72.7	78
	Mearin	1566		67.5	90	64.2	118
	BRS Carisma	1562		52.1	106	74.0	89
	Cutack 4	1551		43.9	70	84.3	127
	BRS Colosso	1532		33.0	100	76.1	82
	BRS Pepita	1511		44.1	78	79.5	75
	Carajás	1442		32.1	57	76.6	70
	BRS Sertaneja	1431		43.8	79	79.6	80
	Xingu	1413		44.4	81	76.5	122
	Araguaia	1377		47.3	93	86.9	92
	Rio Verde	1329		41.2	113	72.5	100
G5	Confiança	1222	1155e	54.5	101	79.5	98
	BRSMG Curinga	1219		56.1	79	77.2	100
	BRS Bonança	1218		44.3	71	67.2	80
	BRA 01600	1211		41.9	102	80.5	86
	BRS Aroma	1179		65.7	88	76.1	73
	Caripuna	1164		76.6	92	74.9	108
	BRS Progresso	1133		64.2	78	79.3	123
	Acrefino	1092		73.8	73	87.0	116
	BRS Primavera	1077		60.6	107	91.1	85
	Vencedora	1035		45.8	89	78.1	68
G6	AB062008	928	845f	55.0	76	78.3	84
	Maravilha	914		75.0	131	85.0	102
	BRS Soberana	914		54.8	74	81.5	66
	Carreon	625		65.6	62	78.3	88
	Mean	1618		46,8	87	79.0	91

[1] Means followed by the same letter in the column do not differ significantly (t test 5%).
[2] DAS - Days after sowing.

According to Jongdee et al. (2006), cultivars with a high grain yield that respond well to favorable soil moisture can be developed under conditions of water stress provided they are evaluated under both environments. In this study, four of the five most productive genotypes under water stress, AB062041, Douradão, Guarani, and BRS Aimoré, were also classified in the second-most productive cluster under well-irrigated conditions. These genotypes yielded an average of 3,825 kg ha^{-1} when well irrigated and 2,570 kg ha^{-1} under water stress. A reduction in yield of 32.8% under water stress was observed, but compared with the average yield of all well-irrigated genotypes, the reduction in yield was 11.8% (Table 1 and 2).

Table 2. Yield, spikelet sterility (SpiSte), number of grains per panicle (GrPan), plant height (Hght) and flowering date (Flower) of the rice genotypes and cluster mean according to Ward's method, considering grain yield under well-irrigated conditions[1].

Cluster	Genotype	Yield (kg ha^{-1})		SpiSte (%)	GrPan (n^{o})	Hght (cm)	Flower (DAS[2])
		Genotype mean	Cluster mean				
G1	BRS Colosso	4569	4479a	23.0	150	87.8	80
	BRA 01600	4389		22.9	131	95.3	84
G2	Guarani	4129	3804b	13.1	83	92.9	65
	AB062037	3928		21.8	99	90.3	72
	Douradão	3774		22.2	98	93.7	66
	BRS Primavera	3745		45.3	135	104.9	80
	AB062041	3725		18.9	98	86.5	69
	BRS Aimoré	3670		15.2	89	82.4	65
	Centro América	3656		12.3	96	95.6	66
G3	AB062008	3572	3458c	44.8	146	93.5	82
	Canastra	3544		51.7	98	86.3	91
	BRS Monarca	3533		24.6	100	82.3	73
	BRS Sertaneja	3503		37.7	132	91.4	79
	BRS Carisma	3492		36.4	114	91.5	85
	IRRI 2	3475		39.8	142	86.3	101
	BRS Aroma	3443		40.1	111	86.1	74
	Tangará	3391		18.3	73	80.1	66
	Carreon	3325		37.6	118	89.8	90
	BRS Pepita	3306		34.4	119	92.0	73
G4	Cabaçu	3071	2840d	48.2	82	92.4	110
	Rio Paranaíba	2959		44.9	143	106.0	103
	AB062138	2935		23.0	106	84.7	88
	Caiapó	2919		40.4	142	104.9	92
	Rio Verde	2911		31.7	156	89.2	91
	Vencedora	2794		28.4	119	89.6	68
	BRSMG Curinga	2763		44.2	121	88.3	93
	Rio Paraguai	2748		37.2	120	105.6	98
	Carajás	2690		32.0	77	78.3	70
	BRS Bonança	2614		36.7	85	76.2	80
G5	Confiança	2493	2407e	48.5	144	89.4	93
	BRS Talento	2470		54.8	123	77.5	88
	BRS Soberana	2257		44.9	85	92.2	66
G6	IRRI 33	1944	1722f	34.9	138	85.3	97
	Xingu	1859		54.3	99	77.7	113
	BRS Progresso	1799		51.3	113	84.3	107
	Caripuna	1759		50.5	109	73.8	102
	Araguaia	1630		31.2	89	97.4	92
	Mearin	1600		62.3	113	66.2	114
	Cutack 4	1462		42.5	119	88.5	116
G7	Acrefino	994	844g	69.9	74	85.8	117
	Maravilha	694		62.7	150	82.5	96
	Mean	2915		37.4	113	88.4	87

[1] Means followed by the same letter in the column do not differ significantly (t test 5%).
[2] DAS - Days after sowing.

Table 3. Summary of analysis of variance of clusters established according to Ward's method based on the mean values of grain yield observed in conditions with and without water stress.

Source of variation	DF	Mean square	DF	Mean square
	With water stress		Without water stress	
Cluster	5	2283588.07**	6	5458259.84**
Error	35	8751.09	34	20169.15
CV (%)		5.78		4.87

**Significant at 1% probability by F test.

In addition, among the genotypes classified in the two most productive clusters under water stress, G1 and G2, the flowering date exhibited negative correlation with grain yield (Table 4). AB062041, Douradão, Guarani, BRS Aimoré, and Tangará, all classified in G1, the most productive cluster, showed flowering prior to 70 days after sowing (DAS) (Table 1). Moreover, under well-irrigated conditions, among the genotypes classified in the cluster G1 and G2 the flowering date showed positive correlation, although without significance, with the grain yield; the opposite effect was observed under water-stressed conditions (Table 4).

Table 4. Correlation coefficient (r) among grain yield (Yield), spikelet sterility (SpiSte), number of grains per panicle (GrPan), plant height (Hght), flowering date (Flower) and 100-grain weight (100G) of rice genotypes without (above the diagonal line) and with (below the diagonal line) water stress.

	Yield	SpiSte	GrPan	Hght	Flower	100 G
Yield	1	0.012	0.621	-0.055	0.636	-0.541
SpiSte	-0.600	1	0.649*	0.646*	0.653*	-0.606
GrPan	-0.359	0.677*	1	0.340	0.919**	-0.832**
Hght	-0.160	0.212	0.181	1	0.383	-0.186
Flower	-0.833**	0.799**	0.649*	0.391	1	-0.911**
100 G	0.692*	-0.621*	-0.629*	0.249	-0.657*	1

*,**Significant at 5 and 1% probability, respectively.

According to Blum (2005), the successful and effective selection of plants under water stress conditions is likely to involve genetic changes to prevent plant dehydration. Additionally, Blum (2011) adds that it can be correctly assumed, unless the options are proven otherwise, that among the hundreds and thousands of dehydration-responsive genes identified by the genomics, only a very small proportion actually have any real significance towards drought response and drought resistance in terms of whole-plant growth and productivity. The genotypes that prevent dehydration present plants with higher water potential and can present earliness in flowering, lower height, lower leaf area or lower tillering. All these characteristics may be related to a lower yield potential. Additionally, Fukai, Pantuwan, Jongdee, and Cooper (1999) stated that the maintenance of a high water potential in the plant during pre-flowering is associated with a higher panicle water potential, reducing the delay in flowering and lowered spikelet sterility, which contribute to higher yield. On the other hand, Yang, Zhang, Liu, Wang, and Liu (2007) observed that the panicle water potential remained constant during the water-stress treatment despite the great reduction in leaf water potential. Therefore, spikelet sterility in rice induced by water stress at the meiosis stage is not attributed to the panicle water status. For these authors, overproduced ethylene under water stress plays a role in inducing spikelet sterility. Barnabás, Jäger, and Fehér (2008) stated that panicle exsertion and anther dehiscence are among the events known to be drought-sensitive at flowering. The failure of panicle exsertion alone accounts for approximately 25 - 30% of spikelet sterility because the unexserted spikelets cannot complete anthesis and shed pollen even when development is otherwise normal. As a consequence of water deficiency, the spikelets may dry out or fail to open at anthesis. The anthers may shrivel, rendering insufficient pollen to be available for fertilization.

The spikelet sterility showed a tendency of negative correlation with grain yield among the most productive genotypes, G1 and G2, when they were subjected to water stress (Table 4). Similar results were described by Yue et al. (2006) and Guimarães et al. (2010). These authors stated that the spikelet fertility under water stress is not only a highly informative indicator for the severity of water stress but also the most important determinant of yield under water stress conditions. In the well-irrigated treatment the variability of spikelet sterility caused no effect on the rice yield (Table 4). According to Barnabás et al. (2008), water stress during flowering may reduce yield drastically, largely as a result of a reduction in grain set. It was observed that under conditions of water stress, the Guarani cultivar had the lowest spikelet sterility at 15.5%, followed by the genotype AB062041 at 25.5%. The genotypes IRRI 33 and IRRI 2 of the *indica* subspecies showed the highest spikelet sterilities, 56.2 and 61.3%, respectively (Table 1).

Additionally, the precocity of the most productive genotypes under water stress conditions was associated with lower spikelet sterility because the correlation coefficient between these variables was 0.799 ($p < 0.01$); in other words, the later the flowering, the greater the spikelet sterility. Among the most productive genotype clusters, under water stress, G1 and G2, those flowering after 100 DAS, Rio Paranaíba, IRRI 2, IRRI 33, and Rio Paraguai showed high spikelet sterility at 47.8; 61.3; 56.2, and 49.4%, respectively, and were significantly less productive compared with the genotypes classified in the cluster G1 (Table 1).

A positive correlation was found between the number of grains per panicle and the grain yield of the upland rice genotypes classified in the two most productive clusters under well-irrigated conditions. Moreover, the influence of the variability of the number of grains per panicle on the grain yield of these genotypes under water stress was negative (Table 4).

It was also observed that the genotypes with fewer grains per panicle had the earliest flowering date. The correlation coefficient between these variables was 0.649 ($p < 0.05$) under water stress, and 0.919 ($p < 0.01$), without water stress (Table 4). In other words, the longer the cycle of the genotypes, the greater the number of grains per panicle. Additionally, it was observed that the genotypes with a higher number of grains per panicle had a higher spikelet sterility. Guimarães et al. (2013) also observed that under water stress the panicles with a higher number of spikelets presented higher sterility. This suggests that for the climate and soil conditions where the experiments were conducted, the immobilization of carbohydrates by the genotypes does not adequately meet the demand of the storage sites for carbohydrates.

The grain yield was also found to significantly correlate with the 100-grain weight under water stress conditions (Table 4). The results suggest that the increase in grain weight offset the reduction in the number of grains per panicle in effecting the rice yield in the two most productive clusters, G1 and G2, under water stress conditions. This is confirmed by the negative correlation coefficient between these variables, the number of grains per panicle and the 100-grain weight, - 0.629 ($p < 0.05$).

The water stress caused a reduction in the number of grains per panicle, consequently causing the reduction in storage sites of carbohydrates in the panicles, which contributed to the accumulation of carbohydrates in the few formed grains.

Water stress during the early formation of panicles can completely inhibit booting and panicle development or even the number of grains per panicle (Yang, Liu, Wang, Du, & Zhang, 2007). The critical points of susceptibility of rice to water deficit occurs in the division of the pollen mother cell (meiosis) and from booting to the early stage of grain formation. The formation of pollen grains is highly vulnerable to water stress (Nguyen & Sutton, 2009). Water stress at meiosis causes sterility of the pollen, pollination failure and abortion of the zygote, all contributing to a reduction in the number of grains per panicle.

According the observed data, the selection of genotypes for water stress conditions should consider the earliest flowering genotypes having panicles with fewer grains but with low sterility and higher 100-grain weight.

Conclusion

The genotypes AB062041, Douradão, Guarani, BRS Aimoré, and Tangará are the best suited for cultivation in areas with the possibility of periods of water stress. Under these same conditions, the least productive cluster, G6, comprised the genotypes AB062008, Maravilha, BRS Soberana, and Carreon.

In the selection for drought conditions the genotypes showing precocity and less dense panicles but with low sterility and greater 100-grain weight should be prioritized.

Acknowledgements

We thank Franciel Gonçalves dos Reis and Ramatis Justino da Silva for their assistance in conducting this research and the Experimental Station of Emater in Porangatu for the provision of infrastructure.

References

Barnabás, B., Jäger, K., & Fehér, A. (2008). The effect of drought and heat stress on reproductive processes in cereals. *Plant, Cell and Environment, 31*(1), 11-38.

Bernier, J., Atlin, G. N., Serraj, R., Kumar, A., & Spaner, D. (2008). Breeding upland rice for drought resistance. *Journal of the Science of Food and Agriculture, 88*(6), 927-939.

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential-are they compatible, dissonant, or mutually exclusive? *Australian Journal of Agricultural Research, 56*(11), 1159-1168.

Blum, A. (2011). Drought resistance – is it really a complex trait? *Functional Plant Biology, 38*(10), 753-757.

Crusciol, C. A. C., Soratto, R. P., Arf, O., & Mateus, G. P. (2006). Yield of upland rice cultivars in rainfed and sprinkler-irrigated systems in the Cerrado region of Brazil. *Australian Journal of Experimental Agriculture, 46*(11), 1515-1520.

Fukai, S., Pantuwan, G., Jongdee, B., & Cooper, M. (1999). Screening for drought resistance in rainfed lowland rice. *Field Crops Research, 64*(1-2), 61-74.

Guimarães, C. M., Stone, L. F., Lorieux, M., Oliveira, J. P., Alencar, G. C. O., & Dias, R. A. A. (2010). Infrared thermometry for drought phenotyping of inter and intra specific upland rice lines. *Revista Brasileira de Engenharia Agrícola e Ambiental, 4*(2), 148-154.

Guimarães, C. M., Stone, L. F., Oliveira, J. P., Rangel, P. H., & Rodrigues, C. A. P. (2011). Sistema radicular do arroz de terras altas sob deficiência hídrica. *Pesquisa Agropecuária Tropical, 41*(1), 126-134.

Guimarães, C. M., Stone, L. F., Rangel, P. H. N., & Silva, A. C. L. (2013). Tolerance of upland rice genotypes to water deficit. *Revista Brasileira de Engenharia Agrícola e Ambiental, 17*(8), 805-810.

Jongdee, B., Pantuwan, G., Fukai, S., & Fischer, K. (2006). Improving drought tolerance in rainfed lowland rice: an example from Thailand. *Agricultural Water Management, 80*(1-3), 225-240.

Kamoshita, A., Babu, R. C., Boopathi, N. M., & Fukai, S. (2008). Phenotypic and genotypic analysis of drought-resistance traits for development of rice cultivars adapted to rainfed environments. *Field Crops Research, 109*(1-3), 1-23.

Lafitte, H. R., Li, Z. K., Vijayakumar, C. H. M., Gao, Y. M., Shi, Y., Xua, J. L., ... Mackill, D. (2006). Improvement of rice drought tolerance through backcross breeding: Evaluation of donors and selection in drought nurseries. *Field Crops Research, 97*(1), 77-86.

Nguyen, G. N., & Sutton, B. G. (2009). Water deficit reduced fertility of young microspores resulting in a decline of viable mature pollen and grain set in rice. *Journal of Agronomy and Crop Science, 195*(1), 11-18.

Parent, B., Suard, B., Serraj, R., & Tardieu, F. (2010). Rice leaf growth and water potential are resilient to evaporative demand and soil water deficit once the effects of root system are neutralized. *Plant, Cell and Environment, 33*(8), 1256-1267.

Pinheiro, B. S. (2003). Integrating selection for drought tolerance into a breeding program: the Brazilian experience. In K. S. Fisher, R. Lafitte, S. Fukai, G. Atlin, & B. Hardy (Eds.), *Breeding rice for drought-prone environments* (p. 75-83). Los Baños, PH: IRRI.

Pinheiro, B. S., Castro, E. M., & Guimarães, C. M. (2006). Sustainability and profitability of aerobic rice production in Brazil. *Field Crops Research, 97*(1), 34-42.

Walter, M., Marchezan, E., & Avila, L. A. (2008). Arroz: composição e características nutricionais. *Ciência Rural, 38*(4), 1184-1192.

Ward Jr., J. H. (1963). Hierarchical clustering to optimize an objective function. *Journal of the American Statistical Association, 58*(301), 236-244.

Yang, J., Liu, K., Wang, Z., Du, Y., & Zhang, J. (2007). Water-saving and high-yielding irrigation for lowland rice by controlling limiting values of soil water potential. *Journal of Integrative Plant Biology, 49*(10), 1445-1454.

Yang, J., Zhang, J., Liu, K., Wang, Z., & Liu, L. (2007). Abscisic acid and ethylene interact in rice spikelets in response to water stress during meiosis. *Journal of Plant Growth Regulation, 26*(4), 318-328.

Yue, B., Xue, W., Xiong, L., Yu, X., Luo, L., Cui, K., ... Zhang, Q. (2006). Genetic basis of drought resistance at reproductive stage in rice: separation of drought tolerance from drought avoidance. *Genetics, 172*(2), 1213-1228.

Received on March 30, 2015.
Accepted on August 13, 2015.