



Infrared thermometry for drought phenotyping of inter and intra specific upland rice lines

Cleber M. Guimarães¹, Luís F. Stone¹, Mathias Lorieux², Jaison P. de Oliveira¹, Grasielli C. de O. Alencar³ & Rozângela A. A. Dias³

ABSTRACT

The purpose of the present study was to evaluate the use of infrared thermometry in the characterization of inter specific (*Oryza glaberrima* x *Oryza sativa* cv Caiapó) and intra specific upland rice lines for drought tolerance. The experiment, carried out at Porangatu in the State of Goiás, was submitted to adequate soil moisture for up to 30 days following emergence when a moderate water stress treatment was imposed (about 50% of the applied irrigation in a control plot in which adequate conditions of soil moisture were maintained). It has been observed that lines with higher grain yields under water stress produced taller plants with denser panicles and well-formed grains as well as lower spikelet sterility. A positive correlation between canopy temperature and spikelet sterility was observed; and a negative correlation existed between canopy temperature and 100-grain weight, plant height, tiller fertility, and grain yield. Except for tiller fertility, all components showed correlation with grain yield; in the case of spikelet sterility, the relationship was negative. It has been inferred that *O. glaberrima* confers to its lines higher rusticity where water stress is concerned, and that infrared thermometry is an important supporting tool for phenotyping drought tolerance.

Key words: *O. glaberrima*, *O. sativa*, water stress, spikelet sterility

Termometria infravermelha na fenotipagem para resistência à seca de linhagens inter e intraespecíficas de arroz

RESUMO

Propôs-se avaliar, no presente estudo, a técnica da termometria ao infravermelho na caracterização de linhagens interespecíficas (*Oryza glaberrima* x *Oryza sativa* cv Caiapó) e intraespecíficas de arroz para tolerância a seca. O experimento, conduzido em Porangatu, GO, foi submetido a condições adequadas de umidade no solo até 30 dias após a emergência, quando então foi implantado um tratamento com deficiência hídrica moderada (aproximadamente 50% da irrigação aplicada em uma parcela testemunha, com condições adequadas de umidade no solo). Verificou-se que as linhagens mais produtivas em condições de deficiência hídrica apresentaram plantas mais altas, com panículas mais densas e com grãos mais bem formados, com menor esterilidade de espiguetas. Observou-se, também, que a temperatura das folhas se correlacionou positivamente com a esterilidade de espiguetas e negativamente com a massa de 100 grãos, altura das plantas, fertilidade de perfilhos e produtividade. Exceto a fertilidade de perfilhos, os demais componentes se correlacionaram com a produtividade de grãos, sendo que com a esterilidade de espiguetas a correlação foi negativa. Concluiu-se que a *O. glaberrima* confere, às suas progênies, maior rusticidade à deficiência hídrica e que a termometria ao infravermelho é uma técnica auxiliar importante na fenotipagem para tolerância a seca.

Palavras-chave: *O. glaberrima*, *O. sativa*, estresse hídrico, esterilidade de espiguetas

¹ Embrapa Arroz e Feijão, Rod. GO 462, Km 12, CP 179, CEP 75375-000, Santo Antônio de Goiás, GO. Fone: (62) 3533-2178. E-mail: cleber@cnpaf.embrapa.br; stone@cnpaf.embrapa.br; jaison@cnpaf.embrapa.br

² Centro Internacional de Agricultura Tropical, Apartado Aéreo 6713, Cali, Colombia. E-mail: m.lorieux@cgiar.org

³ Departamento de Biologia/Universidade Estadual de Goiás, Unidade Universitária de Porangatu, CEP 76550-000, Porangatu, GO. Fone: (62) 3362-2128. E-mail: grasiellealencar@yahoo.com.br; ataidesarruda@hotmail.com

INTRODUCTION

Water stress causes considerable reduction in upland rice yields even in regions with favorable climate because it is common to have periods when rain water is not enough to meet the crop demands. On the other hand, drought tolerance variability in upland rice lines is a well known fact (Cabuslay et al., 2002; Lafitte & Bennett, 2002; Heinemann & Stone, 2009). This has certainly set up differences in the effectiveness of the mechanisms related to the absorption and contention of water losses. Being triggered by the environment water shortage, these mechanisms define the plant's water status which may be assessed by considering the plant's curled leaves and by its yield (Gupta & O'Toole, 1986), or still inferred by the thermal state of the plant under direct solar radiation (Leinonen & Jones, 2004). According to Jackson et al. (1981), water stress causes the stomata to partially close reducing transpiration and cause leaf temperature to go up when exposed to solar radiation. This is brought about mainly by heat absorption of the environment via the water evaporation process. The higher the transpiration, the higher will be the heat absorption. Rice varieties with deeper root system exhibit lower spikelet sterility rates in areas under stressful air temperature as these varieties present lower leaf temperature as a result of higher transpiration rate (IRRI, 1983). Cabuslay et al. (2002) state that rice varieties with moderate water stress tolerance did present higher relative transpiration rates, i.e. they showed high transpiration under stress as compared to stress free conditions. Hyrayama et al. (2006) have also observed that upland rice varieties with deeper root systems exhibited lower leaf temperature, and that leaf temperature was correlated to transpiration rates and photosynthesis. Zhang et al. (2007) have also stated that the canopy's greatest temperature difference between the water stressed and unstressed treatment occurred at 13:00 h. Su & Yang (1998) verified that during the tillering and panicle formation, smaller variations occur as compared to those that take place during the plant's physiologic maturation.

According to Lafitte et al. (2003) and Guimarães et al. (2006), the use of the canopy temperature measurement technique to select plants that present better water status – if conducted appropriately together with other evaluating methods – will be a useful tool for phenotyping drought tolerant cultivars, for it is fast, non-destructive, and does not call for tissues or intense movement within the plots. It is the purpose of the present work to determine the efficiency of infrared thermometry as a secondary component in the characterization of drought tolerance of the EMBRAPA Rice and Beans lines along with inter specific lines among the *Oryza glaberrima* x *Oryza sativa* cv Caiapó of the International Center of Tropical Agriculture.

MATERIAL AND METHODS

The study was conducted at the SEAGRO Experimental Station in Porangatu, Goiás: latitude 13° 27', longitude 49° 10', altitude 600 m, climate Aw, savanna tropical, mega

thermo, according to Köppen classification. The annual mean air temperature is 26 °C. The month of June presents the lowest minimum air temperature (19.9 °C), while the month of September exhibits the maximum air temperature (35.5 °C). The pluvial regime is well defined, in other words, the rainy period from October to April and the dry period from May to September are very distinct. The predominant soil is the Distrophic Red Latosol.

A 7 x 7 lattice experimental design was used with three replications, in which 49 lines were positioned in the plots, being 11 fixed lines (two selected lines of EMBRAPA Rice and Beans, BRA 1600 and BRA 1618, and nine commercial cultivars: Bonança, Caiapó, CNA 9025, CNA 9045, Curinga, Guarani, Liderança, Primavera and Soberana), and 38 remaining inter specific lines from the crossing between the Caiapó cultivar and the *Oryza glaberrima* species.

The sowing of lines/cultivars was completed on May 9, 2006, in three-rows, 3 m long and 35 cm apart with 80 seeds m⁻¹. When the experiment was conducted, the mean maximum temperature was 34.3 °C, the mean minimum temperature was 19.4 °C, and the mean temperature was 26.2 °C.

Plant requirement of nitrogen, phosphorous and potassium was provided by utilizing 12, 90 and 48 kg ha⁻¹ of N, P₂O₅ and K₂O, respectively. In addition to that, 20 kg ha⁻¹ of zinc sulphate was added to it, and 30 kg ha⁻¹ of N was applied as top dressing at the panicle initiation. Weed control was carried out via oxidation at 1000 g ha⁻¹ as pre-emergency.

The cultivar/lines were submitted to suitable conditions of soil water, -0,025 MPa in the depth of 15 cm (Stone et al., 1986), until the crop got established, 30 days after the emergency period. After that, it was applied a treatment for moderate water deficit, approximately 50% irrigation employed on a control plot that was conducted along the experiment. In this plot, irrigation was controlled by means of tensiometers. Irrigations of approximately 38 mm were applied when the soil water potential at a depth of 15 cm reached the pre-established value.

The following variables were evaluated: grain yield, spikelet sterility, number of grains per panicle, tiller fertility, number of panicles per square meter, 100-grain weight, flowering, considering the number of days after emergency (DAE), and plant height, as established by conventional methods. The water status of plants was obtained through temperature readings of the canopy with the help of a Fluke 66 model infrared thermometer with resolution of 0.1 °C and 1% precision, during the reproductive period, at 70, 71, 84 and 90 DAE, as asserted by Guimarães et al. (2006). Two measurements were taken in each plot in all repetitions during the period of higher atmospheric demand – between 13:00 and 15:00 h – in order to better discriminate the genotypes that are more sensitive to water stress. The harvest index (HI) was determined along a one-meter long row where the $HI = GY / (GY + B)$, being GY the grain yield and B, the dry biomass of shoot biomass determined at harvest time, based on 0,35 m² in all repetitions. The drying of biomass was done in an oven with a forced air circulation at 70 °C until it attained constant mass, as indicated through precision balance.

With the help of multivariable analysis and by using the hierarchical method for grouping via Euclidean distance and considering mainly the grain yield component, the lines were distributed into groups of ten, and then submitted to the t ($p < 0.05$) test for comparison between the means. A correlation analysis was also conducted between all evaluated components

RESULTS AND DISCUSSION

Table 1 shows the distribution of lines into groups of ten, based on multivariable analysis via Euclidean distance, considering the mean grain yield values. It was seen that the groups' mean productivity differed significantly from one another. This was also seen to happen in connection with spikelet sterility and the water state of the groups' lines, which have been inferred from canopy temperature (Table 2).

The most productive group under water stress was made up of inter specific lines CNA 9045 (BRS Monarca) and BRA 1618, and inter specific CT16308-CA-5-M, which produced around $3,071 \text{ kg ha}^{-1}$. The second most productive group consisted of the Curinga, CT16330-1-CA-2-M, CT16333-1-CA-7-M, CT16334-2-CA-11-M and BRA 1600 lines, which produced on average $2,342 \text{ kg ha}^{-1}$ (Table 2); finally, the least productive group was made up of inter specific lines CTI6307-CA-15-M and CTI6346-CA 11 M, and produced on average 192 kg ha^{-1} .

It has been seen that the grain yield of the evaluated lines under water deficit conditions was correlated negatively to spikelet sterility and leaf temperature, and positively to the number of grain per panicle, the 100-grain weight, and plant height (Table 3). This behavior was maintained by most of the groups: group 6 – which was the most productive – presented low spikelet sterility, panicles with a larger number of grains and taller plants when compared to the least productive groups (1, 2 and 3). Therefore, the most productive lines under water deficit conditions are the one that have exhibited much higher height and panicles with more well-formed grains, and with the least sterile spikelet. On the other hand, line productivity under these water conditions was not influenced by the tiller fertility, number of panicles per square meter; neither was it influenced by the flowering date. The cycle of development of the plants had no impact on productive behavior in conditions of water deficit; probably, because of the time and the intensity of water stress.

Arf et al. (2001) and Rodrigues et al. (2004) verified that under water deficit the rice cycle was prolonged, having shown a reduction in the height of the plants, in the number of panicles per m^2 , in grain weight and in productivity. Lafitte & Courtois (2002) and Heinemann & Stone (2009) observed that the occurrence of water deficit close to the flowering period reduces productivity drastically because of an increase in spikelet sterility, which is caused by the minimum water potential in the leaves and in the panicles, developed during the period of water deficit (Cruz & O'Toole, 1984). Fukai & Cooper (1995) confirmed that among the lines examined by Yoshida & Hasegawa (1982), the ones

most adapted under water scarcity exhibited greater height and lesser tillering. Their roots were fewer but far more robust and deeper, with better distribution of secondary and tertiary ramifications, according to the soil profile. These roots have larger external diameter and larger xylem cells and offer less resistance to water flux. These are characteristics that reflect on the water status of the plants and which can be assessed by the relative water content, water potential, or even inferred by the curling level of the leaves or by their temperature. However, plants that produce more tillers are inclined to have more roots, especially in the secondary and tertiary tillers that develop later and in which the roots are shorter (O'Toole & Moya, 1978).

More productive lines under water deficiency conditions presented lower mean temperatures during reproductive period which was evaluated in a period ranging from 70 to 90 days after emergency (Table 3). Similar development was maintained by the groupings. Group 6 – the most productive – presented lower canopy temperature and, consequently, better water status in comparison to those less productive: groups 1, 2 and 3.

Hirayama et al. (2006) have also noticed that canopy temperature showed significant relationships with grain yield, photosynthesis rate and transpiration. The authors have agreed that rice cultivars under lower canopy temperature maintain higher transpiration and higher photosynthetic rates and produce better under upland conditions on account of deeper root system giving rise to better water conditions.

Canopy temperature was also correlated positively with spikelet sterility and negatively with 100-grain weight, plant height and tiller fertility. Similarly, these variables – except for tiller fertility – also correlated with grain yield. As a result, this suggests that the use of canopy temperature for selecting plants with better water status (Guimarães et al., 2006) proves to be a useful tool for the drought tolerance phenotyping, for it is fast, non-destructive and does not require plant tissue or intense mobility in the plots.

The results obtained corroborate with those presented in IRRI (1983) where it was demonstrated that rice cultivars with deeper root systems presented less spikelet sterility on account of lower canopy temperature. Liu et al. (2005) verified that rice plants with higher capability of drought tolerance held higher water potential in their leaves and lower dossel temperature producing less spikelet sterility.

As it can be seen in Figure 1A, the more productive lines under water deficiency, both the inter specific and the non-inter specific, presented lower leaf temperature during the reproductive period – from 68 to 88 days following emergence. It was also verified that both inter specific lines and those non-inter specific pointed towards linear reduction in grain yield with an increase in canopy temperature, but at different intensities. The inter specific population presented a decrease in productivity of $475 \text{ kg } ^\circ\text{C}^{-1}$, whereas with the non-inter specific lines this reduction was of $645 \text{ kg } ^\circ\text{C}^{-1}$; data suggest that the *O. glaberrima* parent confers to its progenies greater rusticity to water deficit, for its productivities were less influenced by the canopy temperature. This was due to greater carbohydrate immobility during the development

Table 1. Grain yield (GY), spikelet sterility (SS), number of grains per panicle (GP), tiller fertility (TF) number of panicles per m² (PN), 100-grain weight (GW), plant height (PH), flowering (F) and leaf temperature (LT) of groups, taking into account the grain yield component under water deficit of the advanced rice lines and the inter specific (*Oryza glaberrima* x *Oryza sativa* cv Caiapó) lines

LINES	GROUP	GY (kg ha ⁻¹)	SS (%)	GP	TF (%)	PN	GW (g)	PH (cm)	F DAS ¹	LT (°C)
CTI6334 1CA-2-M CTI6324-CA-10-M	1	506 i	62.75 b	86.7 a	75.80 a	247.1 a	2.66 a	77.5 a	74 a	33.7 ab
CTI6307-CA-15-M CTI6346-CA 11 M	2	192 j	80.29 a	78.6 a	79.95 a	290.7 a	2.28 a	79.0 a	88 a	34.5 b
CTI6315 1CA-1-M CTI6311 1CA-6-M CTI6353-CA-10-M CTI6338-CA-19-M CAIPO CTI6307-CA-5-M CTI6324-CA-9-M	3	778 h	64.93 b	90.7 a	77.79 a	220.8 a	2.68 a	79.6 a	78 a	33.7 bc
CTI6345-CA-8-M CTI6326-CA-3-M CTI6342-CA-4-M CTI6353-CA-11-M	4	1195 f	49.66 c	92.8 a	80.22 a	200.4 a	2.85 a	84.0 a	79 a	32.9 ac
CTI6312 1CA-1-M LIDERANCA CTI6324-CA-15-M CTI6331-CA-8-M	5	953 g	50.89 c	88.3 a	74.64 a	227.1 a	2.64 a	82.7 a	81 a	33.5 ac
CNA9045 CTI6308-CA-5-M BRA1618	6	3071 a	40.88 e	114.5 a	72.98 a	229.1 a	2.45 a	85.3 a	92 a	32.6 a
CTI6315 1CA-16M CTI6310 2 CA-5M CTI6315 1-CA-5M CTI6307 1CA-4-M CTI6338-CA-28-M PRIMAVERA CTI6344-CA-9-M CTI6337-CA-6-M	7	1667 d	42.10 e	89.2 a	83.49 a	228.6 a	2.59 a	82.3 a	79 a	33.0 ac
CTI6346-CA-10-M CTI6346-CA-20-M GUARANI CTI6329 CA-10-M CTI6338 CA-6-M CTI6329-CA-5-M CTI6333 1CA-22M BONANCA CURINGA CTI6330 1CA-2-M CTI6333 1-CA7-M CTI6334 2 CA11M BRA1600	8	1460 e	47.06 d	89.8 a	80.11 a	224.8 a	2.74 a	83.1 a	78 a	32.8 a
CTI6315(1)CA22M CTI6342-CA-25-M CTI6313-CA-19-M CTI6333 2CA-6-M SOBERANA CNA9025	10	1934 c	34.84 f	90.43 a	79.63 a	225.2 a	2.80 a	84.1 a	73 a	32.6 a

The means followed by the same letter in the column do not differ significantly from one another according to t test

¹ DAS number of days after sowing

Table 2. Summary of the analysis of variance of the groups considering grain yield under water deficit conditions as shown by the multivariable regression analysis for grain yield (GY), spikelet sterility (SS), number of grains per panicle (GP), tiller fertility (TF), number of panicles per m² (PN), 100-grain weight (GW), plant height (PH), flowering (F) and leaf temperature (LT)

Sv	Df	Mean square								
		GY (kg ha ⁻¹)	SS (%)	GP	TF (%)	PN	GW (g)	PH (cm)	F DAS ¹	LT (°C)
Model	9	2548275.71**	664.22**	231.69 ^{ns}	46.80 ^{ns}	1593.6 ^{ns}	0.09 ^{ns}	20.69 ^{ns}	104.00 ^{ns}	1.24**
Error	39	14738.03	149.18	281.17	53.5	1192.8	0.15	69.63	111.59	0.47
Cv (%)		8.15	24.75	18.43	9.21	15.05	14.30	10.13	13.32	2.06

Sv – source of variation, Df – degrees of freedom

¹ DAS – days after sowing; ^{ns} – F non-significant at 5% ** – F significant at 1%

Table 3. Simple correlation coefficient between the mean grain yield (GY) spikelet sterility (SS), number of grains per panicle (GP), tiller fertility (TF), number of panicles per m² (PN), 100-grain weight (GW), plant height (PH), flowering (F) and leaf temperature (LT)

	SS ¹	GP	TF	PN	GW	PH	F	LT
GY	-0.563 0.001	0.312 0.002	0.148 0.145	-0.059 0.564	0.232 0.022	0.407 0.001	-0.025 0.809	-0.619 0.001
SS		0.041 0.685	-0.322 0.001	0.082 0.421	-0.475 0.001	-0.468 0.001	0.354 0.001	0.641 0.001
GP			-0.044 0.665	-0.206 0.042	-0.190 0.060	0.153 0.133	0.293 0.003	-0.036 0.725
TF				0.404 0.001	0.255 0.011	0.318 0.001	0.322 0.001	-0.211 0.037
PN					0.002 0.987	-0.089 0.381	-0.023 0.821	0.122 0.230
GW						0.300 0.003	-0.508 0.001	-0.262 0.009
PH							-0.174 0.086	-0.541 0.001
F								0.188 0.064

¹ In each column, the first value corresponds to the correlation coefficient and the second value refers to level of significance

of root system in spite of grain production. These plants are less productive, but they endure effectively the periods of water deficit, for they possess greater capacity for exploring deeper ground water. Hyrayama et al. (2006) also verified that F4 lines of the cultivar Kantomochi 168, with higher drought tolerance, when compared to the F4 lines of the cultivar Norinmchi, of medium drought tolerance, exhibited lower canopy temperature, a trend similar to that found in F5. The authors concluded that this approach is capable of estimating drought tolerance and has proved superior to the more conventional methods (Guimarães et al., 2006). This method constitutes, therefore, a rather useful tool for selecting lines under drought conditions.

Lines at lower temperatures under water deficit conditions, besides the fact they are taller and present higher productivity, they produce less sterile spikelet, more fertile tillers and greater 100-grain weight. As observed in grain yield, canopy temperature does not correlate with the number of days for flowering. The cycle of plant development did not interfere with its water status not affecting productivity of lines, on the other hand this variable correlated positively with the spikelet sterility, and negatively with tiller fertility and 100-grain weight.

Garrity & O’Toole (1995) observed that the canopy temperature during the reproductive phase correlated significantly with grain yield. They also verified significant differences between the evaluated lines.

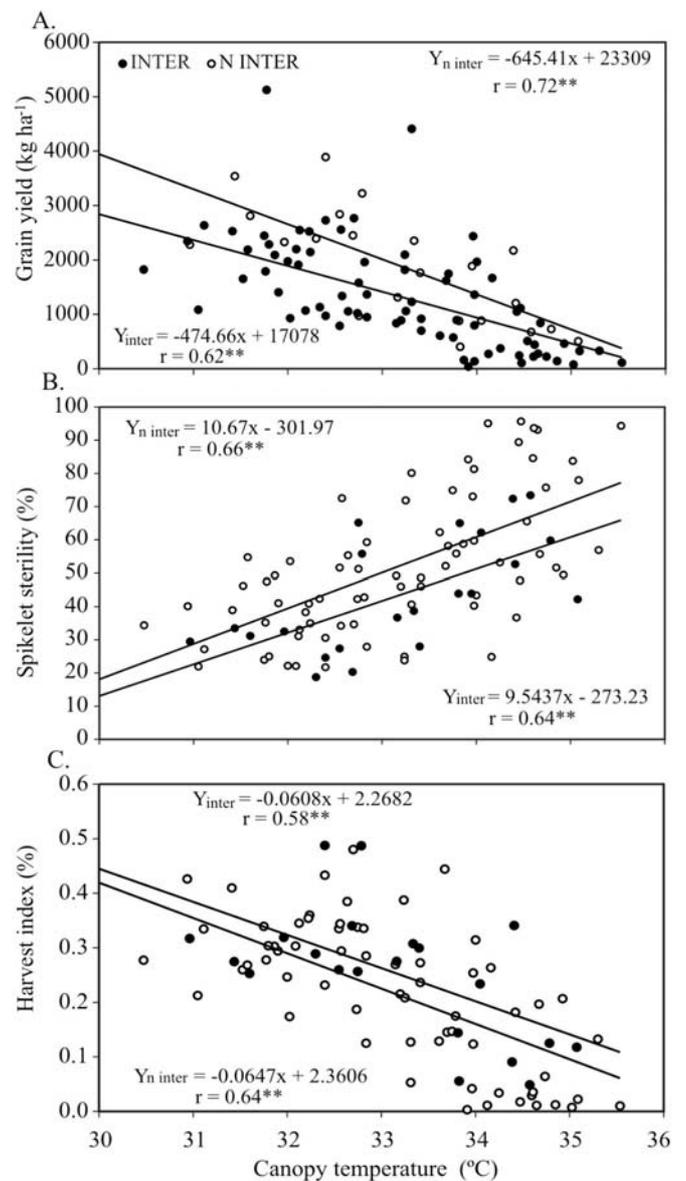


Figure 1. Relation of grain yield (A), spikelet sterility (B) and harvest index (C) of inter specific lines (inter) and non-inter specific (N-inter) under water shortage conditions with canopy temperature

Furthermore, one can add that the infrared thermometry has been a rather useful tool for phenotyping drought tolerance in a number of crops. Positive results have been obtained in assessing the following crops: wheat (Blum et al., 1982), maize (Chaudhuri et al., 1986) and cotton (Hatfield et al., 1987).

The relation between the spikelet sterility of inter specific lines and non-inter specific lines and canopy temperature has been described through linear equations with rather similar angular coefficients (Figure 1B). It has been seen, however, that non-inter specific lines present greater spikelet sterility under the same canopy temperature, possibly because of the non prioritization of carbohydrate translocation to the root system, as has been previously described. Inter specific lines, for presenting lower productivity sensitivity to canopy temperature effect due to smaller spikelet sterility, do present a higher harvest index (Figure 1C).

CONCLUSIONS

1. The most productive lines under water deficiency are those with higher height and panicle with a greater number of better formed grains with lower sterile spikelets.

2. Leaf temperature correlates negatively with grain yield, 100-grain weight, plant height and tiller fertility; and positively with spikelet sterility.

3. If adequately conducted, together with other evaluations, infrared thermometry is a useful tool for phenotyping drought tolerance of inter and intra specific lines because of its fast and non-invasive use.

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