Photosynthesis and panicle growth responses to drought stress in F_1 hybrid rice (Oryza sativa L.) from a cross between thermo-sensitive genic male sterile (TGMS) line 103S and upland rice IR17525

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https://doi.org/10.5109/1467627

出版情報：九州大学大学院農学研究院紀要. 59 (2), pp.273-277, 2014-08-29. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **59** (2), 273–277 (2014)

Photosynthesis and panicle growth responses to drought stress in F_1 hybrid rice (*Oryza sativa* L.) from a cross between thermo–sensitive genic male sterile (TGMS) line 103S and upland rice IR17525

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(*Received April 25, 2014 and accepted May 12, 2014*)

An F_1 hybrid rice combination from a cross between a thermo-sensitive genic male sterility (TGMS) '103S' line and an upland rice 'IR17525' were investigated for physiological response traits under drought stress and recovery at the heading time by comparing with its parents. The F_1 and parental plants were planted in pots in a net house at different times for synchronizing flowering. At the stage of 5-3 days before heading, water was withdrawn from the pot. When the soil water potential in the pot reached -60 kPa, photosynthetic rate and dry matter accumulation were measured. Recovery traits including photosynthetic rate and dry weight of panicle were measured at 5 days interval until harvesting. The results showed that the photosynthetic rate was lower in the F_1 hybrid than that in the parents during drought treatment, in contrary it was higher during recovery stage. The grain yield was maintained in the F_1 hybrid under drought treatment as much as under the control condition, whereas it significantly reduced as drought treatment in the male parent. The grain yield was higher in the F_1 hybrid than that in the male parent under the well-irrigated condition, and even much higher under drought treatment. It is suggested that such advantageous characters, including the shorter ripening duration, the longer panicle exertion, the higher recovery photosynthetic rate as well as the faster of dry matter translocation into panicle at the ripening stage, contribute drought tolerance in rice. Thus, the F_1 hybrid rice 103S/IR17525 would be a promising rice with high yield potential under drought stress.

Key words: F_1 hybrid rice, heterosis, panicle growth rate, photosynthesis, TGMS line

INTRODUCTION

Water is an important factor for crops, affecting their overall growth and development (Boonjung and Fukai 1996; Kato *et al.*, 2007), which include accumulation and revolution of dry matter and photosynthetic characteristics (Kumar *et al.*, 2006; Li *et al.*, 2008; Wang *et al.*, 2008), along with their yield and quality (Wang *et al.*, 2004; Yang *et al.*, 2002). In addition, water stress at heading time had a negative effect on the yield of rice, even moderate water stress at the heading and filling stages significantly promoted the grain filling and increased the seed setting rate and grain weight (Wang *et al.*, 2004).

Rice is most susceptible to water stress at reproductive stage, particularly heading time was an important determinant of grain yield under prolonged and severe drought. In rice, over 80% of the sugars accumulated in grains is produced by the top two leaves, especially the flag leaf (Li *et al.*, 1998). The yield advantages of hybrid rice with 10–30% higher than inbred rice under well–irrigated condition have been well documented (Virmani *et al.*, 1982, Pham *et al.*, 2004). In our previous report, F_1 hybrid involving a thermo–sensitive genic male sterile (TGMS) line showed better photosynthesis than the parental lines under high temperature condition (Pham *et al.*, 2005). Therefore, photosynthetic characters and responses to water stresses of the flag leaf are important for yield production of hybrid rice. The objectives of this study were to (i) compare physiological characters including CO_2 exchange rate, stomatal conductance and leaf water potential between hybrid and the parent inbred variety (upland rice) under drought stress and after re–watering (the recovery following re–water), and (ii) examine dry matter accumulation to spikelets and components of grain yield.

MATERIALS AND METHODS

Plant materials

A TGMS line '103S' which released in Vietnam as the female parent, upland rice 'IR17525' as the male parent, and their F_1 hybrid rice '103S/IR17525' were used.

Plant culture

The experiment was conducted in the net house at the Faculty of Agronomy, Hanoi University of Agriculture. Seeds of F_1 hybrid rice and parental cultivars were incubated and sown in the seedling bed (60×35×8 cm) at two different times for synchronizing heading time, 25th June, 2011 for the parents and 4th June, 2011 for the F_1

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hybrid. A 3 to 4–leaf–seedling plant was then transplanted singly into a 5L–Wagner pot containing 5 kg of dry foaming soil. Total 120 pots, 40 pots for each cultivar, were laid out in a randomized complete block design with two treatments (control and drought stress), five replications and 4 plants for each replication (Gomez and Gomez, 1984). Total fertilizer was applied with N, P_2O_5 and K_2O at the dose of 0.48, 0.36 and 0.36 g per pot, respectively. Basal dressing with N, P_2O_5 and K_2O was at the dose of 0.16, 0.36 and 0.12 g per pot, respectively. Top dressing was applied 10 days after transplanting (DAT) with N and K_2O at the dose of 0.24 and 0.18 g per pot, respectively. Final dressing at the panicle initiation stage (20–18 days before heading) was applied with remained amount of N and K_2O.

Drought treatment

Drought treatment was applied at booting stage; 5 to 3 days before flowering. Water was withdrawn from 20 pots of each cultivar (start of drought stage) then tension meters were installed into the pots to measure soil water potential. Soil was sampled at 3 places in each pot to measure soil moisture content at drought stage to confirm the uniformity of drought level of each pot. When the soil water potential was –60 kPa in each pot, photosynthetic characteristics were collected (end of drought stage) then water was re–applied (start of recovery stage). Photosynthetic parameters and dry matter accumulation were measured 5 days interval until completely ripening.

Measurements

Photosynthetic characters were measured at the flowering stage (drought stage) and the ripening stage (recovery stage). Five plants of the F_1 hybrid and the parents were randomly selected for measurement in each plot. Two top–fully expanded flag leaves of a plant were selected to measure photosynthetic rate in terms of CO_2 exchange rate (*CER*) and stomatal conductance (*Gs*) using a photosynthetic portable equipment (LI6400, Licor Inc., USA) at temperature of 30°C, light intensity of 1500 μmol m^{-2} s^{-1}, CO_2 concentration of 370 μmol mol^{-1} and relative humidity of 60%. The plant measured for photosynthesis was also recorded leaf water potential. Leaf water potential was measured by using portable plant stress measurement (PMS 610, USA). These five plants were sampled, separated into different parts such as leaf, stem and panicles, and then dried at 80°C for 48 h to obtain constant weight of the dry matter accumulation. Panicle growth rate was calculated as the increase in weight of total panicles per hill per day. At the harvesting stage, five plants of IR17525 and F_1 hybrid in each plot were recorded for panicle exertion and individual yield and yield components. Panicle exertion was measured from the top node of the panicle to the flag leaf collar.

Statistical analysis

Data analysis was conducted by SAS program ver. 8.2, (2006). Mean values were compared by LSD values ($p<0.05$) based on ANOVA. The *t*–test procedure was used to examine the difference between F_1 hybrid and the male parent under both drought and control conditions. At the harvesting time, the male parent (IR17525) was considered as the best parent for comparison because the female parent (103S) was completely sterile.

RESULTS

Under drought treatment, panicle exertion from the flag leaf collar was much longer in the male parent (–8.2 cm) than that in F_1 hybrid (–3.6 cm) (Fig. 1). Thus, the panicle exertion was greatly improved in F_1 hybrid. At the drought stage, the *CER* in F_1 hybrid (19.8 μmol m^{-2} s^{-1}) was lower than that in 103S– female parent (23.2 μmol m^{-2} s^{-1}) and higher than that in IR17525–male parent (17.3 μmol m^{-2} s^{-1}) under control condition, whereas the value in F_1 hybrid is same as that in the male parent (1.1 μmol m^{-2} s^{-1}) under drought condition (Fig. 2). At the recovery stage, the *CER* significantly increased in F_1 hybrid under drought treatment (21.3 μmol m^{-2} s^{-1}) compared to the control (19.6 μmol m^{-2} s^{-1}), while both parents were not able to fully recover. The *Gs* in F_1 hybrid and both parents significantly decreased under drought treatment (Fig. 3). However, at the recovery stage, *Gs* value in F_1 hybrid was fully recovered whereas it was not in both parents. There were no significant differences in leaf water potential between F_1 hybrid and its parents under control condition at both drought and recovery

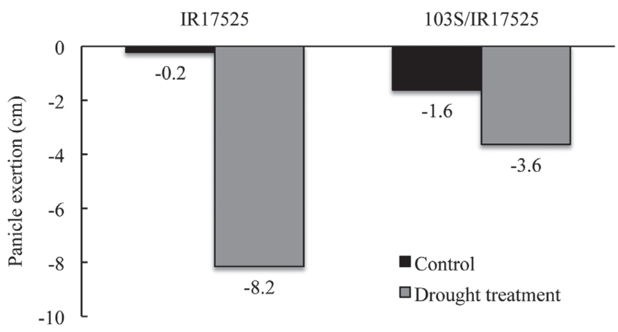

Fig. 1. Panicle exertion of F_1 hybrid (103S/IR17525) and its male parent (IR17525) in the drought treatment and the control.

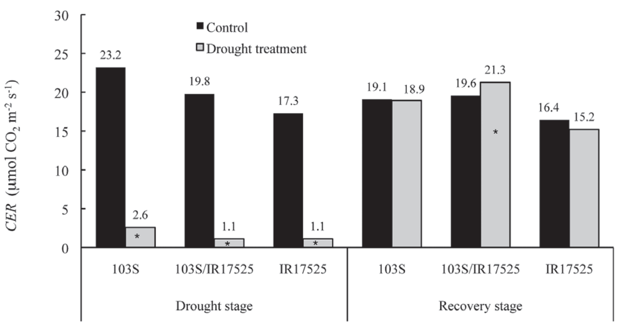

Fig. 2. CO_2 exchange rate (*CER*) of F_1 hybrid (103S/IR17525) and its parents in the drought treatment and the control at the drought and recovery stage. * $p<0.05$.

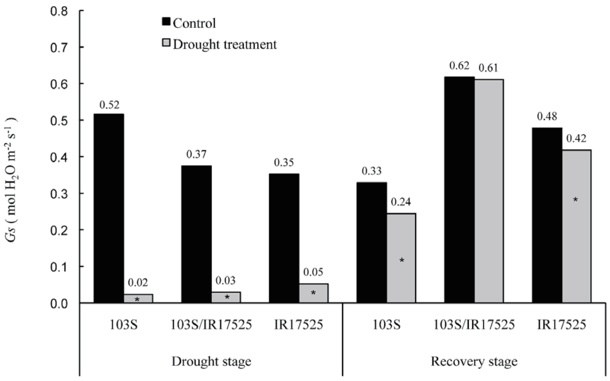

Fig. 3. Stomatal conductance (*Gs*) of F_1 hybrid (103S/IR17525) and its parents in the drought treatment and the control at the drought and recovery stage. * $p<0.05$.

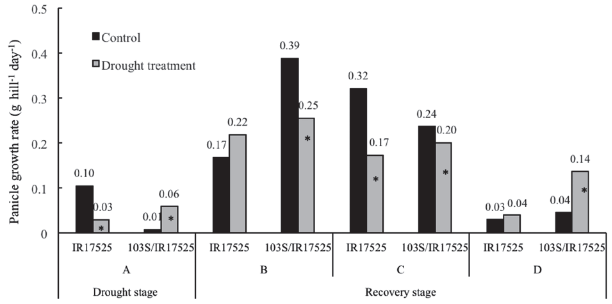

Fig. 5. Panicle growth rate (PGR) of F_1 hybrid (103S/IR17525) and its male parent (IR17525) in the drought treatment and the control at the drought and recovery stage. A, During 5 days from water withdrawn to re–watering; B, During 5 days from re–watering to 5 days; C, During 5 days from 5 days after re–watering; D, from 10 days re–watering to harvesting (28–36 days after heading). * $p<0.05$.

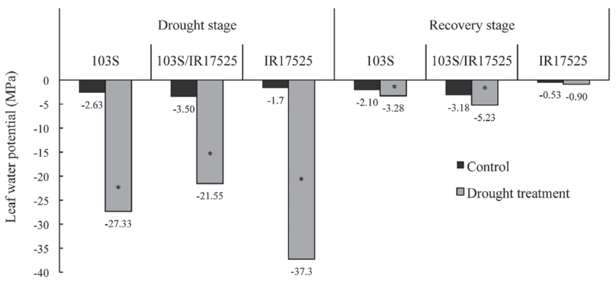

Fig. 4. Leaf water potential of F_1 hybrid (103S/IR17525) and its parents in the drought treatment and the control at the drought and recovery stage. * $p<0.05$.

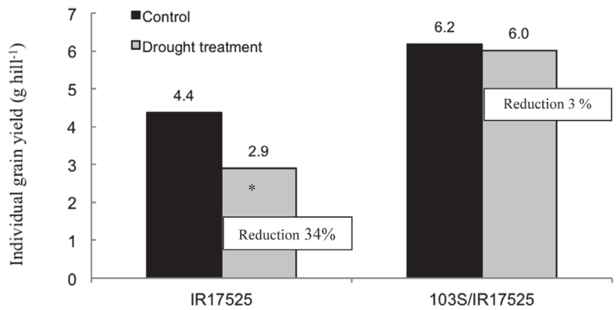

Fig. 6. Individual yield of F_1 hybrid (103S/IR17525) and its male parent (IR17525) in the drought treatment and the control. * $p<0.05$.

stages (Fig. 4). However, under drought treatment, leaf water potential was maintained much higher in F_1 hybrid (–21.55 bar) than that of the female parent (–27.33 bar) and male parent (–37.3 bar). In contrast, the leaf water potential was the lowest in the F_1 hybrid under recovery stage (–5.22 bar).

At the drought stage, the panicle growth rate (PGR) of F_1 hybrid was much higher in the drought treatment (0.06 g hill^{-1} day^{-1}) than that in the control (0.01 g hill^{-1} day^{-1}) (Fig. 5A). However, the PGR of the male parent IR17525 was lower in the drought treatment (0.03 g hill^{-1} day^{-1}) than that in the control (0.10 g hill^{-1} day^{-1}). Especially, from 10 days after re–watering to ripening, the PGR value was much higher in F_1 hybrid (0.14 g hill^{-1} day^{-1}) than that in the male parent (0.04 g hill^{-1} day^{-1}) (Fig. 5D). The duration from heading to completely ripening of F_1 hybrid after re–water was 31 days, which was shorter than that of the control plants (36 days), whereas that of IR71525 in the drought treatment (30 days) was longer than that of the control plants (28 days) (Table 1). This result may be indicated that the faster photosynthetic product translocation could be a factor to shorten ripening time required for F_1 hybrid rice. There were no significant differences in number of panicle per hill and number of spikelet per panicle in F_1 hybrid under both drought and control conditions. The similarity was also observed in IR71525. The percentage of filled grain in F_1 hybrid under drought treatment (74.3%) was not significantly different from that under the control (74.4%). However, the grain filling in IR17525 was influenced dramatically by drought; filled grain was 62.4% in the drought treatment compared to 91.1% in the control. Under the control condition, the individual grain yield of F_1 hybrid (6.2 g hill^{-1}) was slightly higher than that of the male parent (4.4 g hill^{-1}) (Fig. 6). The grain yield slightly decreased in F_1 hybrid (3%) under drought treatment compared to the control, whereas it obviously reduced in the male parent (34%).

DISCUSSION

In this study, as the affects of drought, the *CER* significantly decreased in both F_1 hybrid and the parents (Fig. 2). This might be related to osmotic adjustment which facilitated de–hydration avoidance by promoting root growth and increasing extraction of soil water, and therefore maintain partial stomatal opening and leaf growth during water stress (Wright *et al.*, 1983; Pham *et al.*, 2005). The LWP was always maintained much higher in F_1 hybrid than that of the parents under drought

Table 1. Ripening duration, yield component and grain yield in F_1 hybrid (103S/IR17525) and its male parent (IR17525) in the drought treatment and the control

Water treatment	Cultivar	Days from heading to harvesting	No of panicle hill^{-1}	No of spikelet panicle^{-1}	Percentage of filled grain (%)	1000–grain weight (g)
Control	IR17525	28	1.7	128.6	91.1	29.8
	103S/IR17525	36	2.0	178.3	74.4	29.5
Drought	IR17525	30	1.7	135.1	62.4	28.3
	103S/IR17525	31	2.0	163.1	74.3	28.7
LSD $p<0.05$ Variety			0.03	24.2	5.8	–
LSD $p<0.05$ Drought			0.03	24.2	5.8	–
LSD $p<0.05$ Variety x Drought			0.43	28.4	8.2	–

stress (Fig. 4), which might be due to the osmotic adjustment. Furthermore, the high osmotic adjustment can improve panicle exertion and spikelet fertility in F_1 hybrid rice as it was also reported in sorghum (Wright and Smith, 1983; Santamaria *et al.*, 1990) and wheat (Morgan, 1984). The significant decreases in panicle exertion and percentage of filled grain in the male parent (Fig. 1 and Table 1) could be contributed by LWP under drought treatment, which was also observed in rice (O`Toole and Namuco, 1983; Ekanyake *et al.*, 1989). Ekanyake *et al.* (1990) showed that the number of filled grain decreased from 90 to 5% when flag leaf water potential felt from –1 bar to –3 bar respectively, mainly due to a decrease in pollen viability.

The ability of osmotic adjustment to maintain leaf water status and productivity during critical stages such as flowering may be particularly beneficial to grain yield. Increased osmotic adjustment has been shown to improve green leaf retention in rice (Henderson *et al.*, 1993) and sorghum (Tangpremsri *et al.*, 1995). Continued photosynthesis and therefore increased assimilates supplied during grain filling and increased translocation of pre–anthesis assimilates to the grain are benefits of both osmotic adjustment and green leaf retention. This is in agreement with the current results as the better photosynthesis in F_1 hybrid than the parent at recovery was revealed (Fig. 2. and Fig. 3) with the contribution of better recovery of stomatal conductance. Rice yield is contributed of dry accumulation at heading time and after heading (Yang *et al.*, 2002). Garrity and O`Toole, (1994) reported that percentage of spikelet fertility was highly correlated with grain yield in the event of water stress at the reproductive stage. The higher photosynthesis at the recovery stage (Fig. 2) may lead to higher matter translocation from culms and leaves to panicle in F_1 hybrid rice that was exposed to drought stress at the heading stage. Higher dry matter produced by the flag leaf photosynthesis has to go somewhere to keep this process continuing because of the limitation of the sink in terms of space for photosynthesis matter accumulation. Duration of grain filling is under genetic control (Metz *et al.*, 1985, Smith and Nelson, 1987) and is sensitive to environmental stress, suggesting that the length of the grain–filling period is an important determinant of yield in all grain crops (Brevedan and Egli, 2003). Therefore, the better panicle exertion together with the better photosynthesis and photosynthetic product translocation into the panicle at the recovery stage resulted in the grain yield increase in F_1 hybrid.

ACKNOWLEDGEMENTS

This study was financed by Vietnam National Foundation for Science and Technology Development (NAFOSTED) No.106.11.25.09. The using equipments were supported by JICA–JST–DCGV project.

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