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BRIEF COMMUNICATION

Oxygen evolution rate of rice cultivars

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Abstract

Under natural conditions we found a significant variation in oxygen evolution rate (OER) in flag leaves of different rice genotypes during the grain filling stage. Cv. Roxinho showed the highest OER [42 μmol(O_2) m^{-2} s^{-1}], followed by BRS Taim, BRS Pelota, BRS Bojuru, IR58025B, BRS 6 Chui, and BR-IRGA 409, with 37.0, 34.0, 33.0, 31.8, 29.0, 28.0, and 27.6 μmol(O_2) m^{-2} s^{-1}, respectively. The lack of fertility in the male-sterile rice line IR58025A prolonged the photosynthetic capacity by at least 15 d when compared to the normal fertility found in the IR58025B line. No difference was observed in OER among first (flag) and second leaves in both IR58025A and IR58025B rice lines.

Additional key words: *Oryza sativa*; photosynthesis.

Rice (*Oryza sativa* L.) is the most important crop in the world. It is used as staple food by more than half of the world population (He *et al*. 2006). Hybrid rice yield is 15–20 % higher than that of the best inbred cultivars (Virmani 1996) and it has played an important role in increasing rice production in many countries. The cytoplasmic male sterile (CMS) system, which involves three-line system (CMS, maintainer, and restorer), is the most widely used for producing F_1 hybrid seeds (Phan *et al*. 2004). This system simplifies the production of hybrids since only a pair of pure fertile and sterile lines is required. Furthermore, the nuclear genes responsible for sterility are relatively easy transferred and thus this technology is a viable option to further increase of rice yield (He *et al*. 2006).

Photosynthesis is the most important factor of crop yield (Jiang *et al*. 2002). In rice, panicle photosynthesis considerably contributes to biomass production (Kato *et al*. 2004). In contrast, some researchers reported that panicle removal did not affect the photosynthetic activity of wheat, barley, and rice leaves, but retarded the decrease of the photosynthesis in rice flag leaves during plant senescence (Koide and Ishihara 1992, Nakano *et al*. 1995). In the present study, we hypothesized that the photosynthetic capacity in rice sterile plants differs from that of normal fertile plants and the lack of grain filling (GF) in sterile plants is similar to panicle removal. Using mutant lines developed from two CMS maintainer lines we compared photosynthetic characteristics of rice sterile plants and their maintainer line (Zhou *et al*. 2006).

Canopy photosynthesis has been greatly improved in order to increase grain yield. The introduction of genes from wild rice species raises the yield of rice cultivars (Masumoto *et al*. 2004). Crop physiologists have demonstrated an association between breeding progress for yield and leaf activity traits, in particular increased carbon assimilation rate and ribulose 1,5-bisphosphate carboxylase/oxygenase (RuBPCO) and RuBPCO activase contents (Sasaki and Ishii 1992, Masumoto *et al*. 2004, Zhang and Kokubun 2004). However, they did not report OER differences among cultivars. Therefore we determined OER of rice cultivars during the GF stage. Furthermore, in order to characterize the effects of lacking fertility on photosynthetic capacity, we compared the OER of rice male sterile line (IR58025A) and its near-isogenic normal fertile line (IR58025B) using first (flag) and second leaves and compared also the dates of flowering (FL) and GF.

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Abbreviations: CMS – cytoplasmic male sterile; FL – flowering; GF – grain filling; OER – oxygen evolution rate.
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The experiment was conducted in 2004 and 2005 in the experimental field at Embrapa Clima Temperado (31º49'S, 52º27'W) during the rice growing season from October to March at Pelotas, Rio Grande do Sul State, Brazil. The genotypes screened were BRS Bojuru, BRS 7 Taim, BRS Pelota, BR-IRGA 409, BRS Atalanta, BRS 6 Chui, and Roxinho. In these genotypes, the analysis was made on flag leaf during the GF stage (considered when 95 % of spikelets had turned from green to yellow). Simultaneously, a male sterile line IR58025A and a normal fertile line IR58025B were analyzed in order to evaluate the effects of lacking of fertility on photosynthetic capacity. In IR58025B plants, two analyses were made: during FL (determined when 90 % of hills had at least one stem that had started anthesis) and GF stages. In IR58025A plants (without pollination), the analysis was made during the FL stage and after 15 d, when 95 % of spikelets had turned from green to yellow. In these genotypes, OER was measured on the first (flag) and second leaves.

The maximum OER was determined using a gas-phase oxygen electrode (*Hansatech*, King's Lynn, UK). This method is suitable for measuring a number of samples because of its short measurement time. A piece of about 3 cm^2 was cut from the centre of the leaf blade. Photosynthesis was measured under air temperature of 30 ºC and irradiance of 2 000 μmol(photon) m^{-2} s^{-1}. CO_2 was supplied as molar solution of sodium bicarbonate. The photosynthetic rate was calculated when the evolution oxygen curve reached the stability. This experiment was conducted in agreement with randomized block design and data were expressed as the mean with standard deviation and compared by analyses of variance (ANOVA) followed by the Tukey's test ($p \leq 0.05$).

There was significant variation in OER between different rice genotypes during GF stage. The OER of the Roxinho (1975 approximately) cultivar was 42 μmol(O_2) m^{-2} s^{-1}, followed by the BRS 7 Taim, BRS Pelota, and BRS Bojuru cultivars with 37, 34, and 33 μmol(O_2) m^{-2} s^{-1}, respectively (Fig. 1). The cultivars BRS 6 Chui and BR-IRGA 409 were characterized by the lowest values of OER (Fig. 1). The rice cultivar released in 1980 (BR-IRGA 409) showed the OER values similar to BRS 6 Chui (1991) and BRS Atalanta (1999), but lower than BRS 7 Taim (1991), BRS Pelota (2000), and BRS Bojuru (1997). Data between parentheses indicate the year that cultivars had been released.

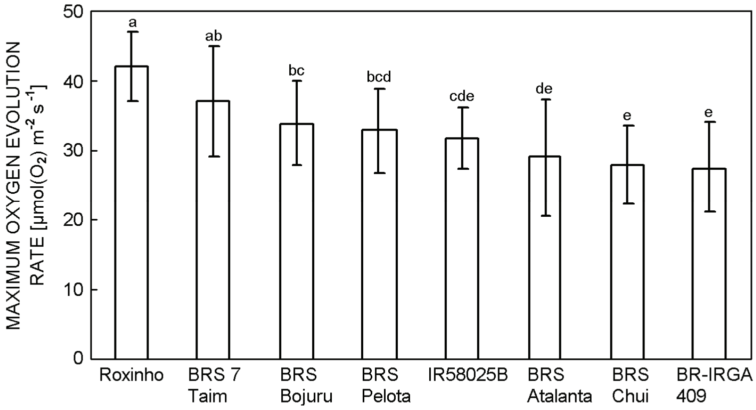

Fig. 1. Maximum oxygen evolution rate in rice cultivars during the grain filling stage. Averages with different letters indicate significant difference according to Tukey's test ($p \leq 0.05$). Vertical bars represent standard deviations (n = 5).

Table 1. Maximum oxygen evolution rate [μmol(O_2) m^{-2} s^{-1}] in flag leaf (L1) and 2nd leaf (L2) during the flowering (FL_1) and grain filling (GF) in male sterile (IR58025A) and normal fertility (IR58025B) lines of rice. In IR58025A there was no fertilization and, therefore, FL_1 and FL_2 relate to flowering and GF stages measured in IR58025B, respectively. *Capital letters* indicate significant differences between L1 and L2; *small letters* indicate difference between flowering (FL) and GF stages according to Tukey's test ($p \leq 0.05$) (n = 5).

Leaf	IR58025A		IR58025B	
	FL_1	FL_2	FL_1	GF
L1	39.61±7.16 Ab	37.70±1.78 Ab	41.70±11.15 Ba	32.88±4.53 Ac
L2	43.69±10.26 Ab	39.04±2.60 Ab	50.84±2.60 Ab	29.71±4.53 Ac

The OER of both flag leaf (L1) and 2nd leaf (L2) did not show significant differences during the FL and GF stages, except for the normal fertile IR58025B line. During FL, the 2nd leaf of IR58025B maintained a higher OER (Table 1). The results also show significant differences in OER between male-sterile and fertile lines in both developmental stages (Table 1). During the flowering stage (FL_1), OER was significantly higher in the normal fertile line than in the male-sterile line for both flag and second leaves. In contrast, in the latest stage (corresponding to GF), a significant reduction in OER values in IR58025B was also observed (Table 1) which can reflect directly the reduction of leaf metabolic activity. These results are supported in the literature. Rice plants from sterile lines showed higher photosynthetic rates than their respective fertile lines during the GF stage (Kato *et al*. 2004, Zhou *et al*. 2006).

The results suggest that the absence of fertilization in sterile lines prolonged the photosynthetic capacity in rice plants by at least 15 d. This can be supported by absence of significant differences in the photosynthetic rate in IR58025A sterile line during FL_2 period (15 d after flowering in IR58025A sterile line). On the other hand, the normal GF process in fertile lines induces the diversion of nutrients from leaves or apex to the developing grains. According to Biwas and Choudhuri (1980), the pronounced increase of leaf senescence in fertile lines results in photosynthetic capacity reduction.

Differences in photosynthetic rate between rice lines and cultivars have been reported in the literature. However, the studies generally report differences in carbon assimilation rate and RuBPCO content (Sasaki and Ishii 1992, Murchie *et al*. 2002). Zhang and Kokubun (2004) reported that the net photosynthetic rate was lower in tropical japonica cultivars, grown in the field at the International Rice Research Institute farm in the Philippines. However, all of them showed lower values of photosynthetic rate than indica cultivars on the same conditions. In addition, among the 32 cultivars released from 1882 to 1976 in Japan, a significant positive correlation between flag leaf net photosynthesis two weeks after heading and the year of cultivar release was found (Sasaki and Ishii 1992). Other studies have shown that rice cultivars released after 1950s had higher photosynthetic rate per leaf area unit (Masumoto *et al*. 2004, Zhang and Kokubun 2004). This finding indicates that the improvements of leaf photosynthesis have occurred with the advance of breeding high-yielding cultivars. Our results are consistent with this fact; breeding rice cultivars to improve yield causes significant differences in OER. Measurements on leaves bellow the flag leaf were also carried out concurrently with flag leaf measurements and showed similar patterns (Murchie *et al*. 2002). In conclusion, the rice genotypes evaluated in this study showed significant differences in OER at the GF stage. Furthermore, there were differences in OER among rice male sterile (IR58025A) and normal near-isogenic (IR58025B) plants at flowering and GF stages. Little variation was observed in OER when flag and second leaves were compared.

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