Photosynthesis, Growth, and Yield of BC_2F_4 Lines derived from *Oryza sativa* and Wild Rice Species, *O. rufipogon*

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Abstract

The study was carried out to collect some information for using wild rice species to raise grain yield. We examined photosynthetic rates and properties of dry matter production in 4 lines of BC_2F_4 generated by backcrossing *O. rufipogon* (W630) with *O. sativa* cv. Nipponbare. These 4 lines were progenies of BC_2F_1 plants whose maximum photosynthetic rates measured by an O_2 electrode were higher than Nipponbare. The photosynthetic rates under saturated light and ambient air conditions in BC_2F_4 lines were average 7% higher than Nipponbare. The maximum value was increased 32%. These results suggested that the maximum photosynthetic rate was reflected to some extent by the photosynthetic rates of the progenies under natural conditions. Results of growth analysis indicated that relative growth rate (RGR) was limited by net assimilation rate (NAR). RGR and NAR in one of the four BC_2F_4 lines were higher than those of Nipponbare. The grain yields per plant of BC_2F_4 lines were average 16% higher and its maximum was 54% higher than that of Nipponbare. Sink sizes of BC_2F_4 lines were not significantly different from Nipponbare. The increase in grain yield is thought to be due to high percentage of filled spikelets.

Media summary

Photosynthetic rates and characteristics of dry matter production in BC_2F_4 lines derived from *O. rufipogon* and *O. sativa* were examined.

Key Words

Japonica rice, Productivity.

Introduction

Increases in grain yield of recent high-yielding rice cultivars are mainly attributed to high spikelet number per unit area, that is to say sink size (Jiang et al., 1988, Song et al., 1990, Xu et al., 1997). However, the yield of rice is also dependent on and limited by photosynthetically produced carbohydrate. And it is proposed that the improvement of photosynthetic efficiency is one of the ways to raise the grain yield in cereals (Army and Greer, 1976). Recently some scientists investigated whether wild rice species can be available for improvement of quantitative traits by molecular biotechnology. It was reported that *Oryza rufipogon*, the closest wild relatives of *Oryza sativa*, had some alleles associated with an increase in grain yield (Xiao et al. 1996). In our previous study (Masumoto et al., 2004), the maximum photosynthetic rates of single leaves of BC_2F_1 plants generated by backcrossing *O. rufipogon* with *O. sativa* were measured using an oxygen electrode at the vegetative stage. It was found that the photosynthetic rates of many BC_2F_1 plants were higher than Nipponbare. It is necessary to study whether the maximum photosynthetic rate reflects on photosynthesis under natural conditions. Characteristics of dry matter production are also needed to get some information for breeding. In this study, we selected BC_2F_1 plants with high photosynthetic rates and then examined their self-pollinated progenies, BC_2F_4 lines to determine their photosynthetic rates, growth rates during the vegetative stage, and yield.

Materials and methods

We generated BC_2F_1 populations that theoretically had 12.5% wild rice genes by crossing *O. rufipogon* (W630) from Myanmar with *O. sativa* cv. Nipponbare. The maximum photosynthetic rates in single leaves were measured by an O_2 electrode under saturated light intensity, 5% CO_2 concentration and 25℃. The BC_2F_1plants with higher photosynthetic rates than Nipponbare were selected, and 4 lines of their self-pollinated progenies, BC2F4 were used in this experiment.

For the growth analysis, seeds of Nipponbare and each BC_2F_4 line were sown in nursery boxes. At the 4 to 5 leaf stage, they were transplanted to 1/10000a pots containing paddy soils, 0.3g of N, P and K, with one plant per pot. Four and six weeks after transplanting, 10 plants per each line were harvested. They were divided into leaves, stems and roots, then dried at 80℃for 72 hours to determine dry weights.

For measuring the photosynthetic rates and yields, seeds of Nipponbare and each BC2F4 line were sown in nursery boxes. At the 4 to 5 leaf stage, they were transplanted to 1/5000a pots containing paddy soils, 1.0g of N, P and K, with one plant per pot. At about 12.3 leaf age, CO_2 gas exchange rates (CER) in the 11th leaf of the main culms were measured with an infrared gas analyzer (LI-7000, LI-COR, Lincoln). The conditions were 1800 µmol quanta/m^2/s, 360µL/L CO_2, 21% O_2 and about 28℃leaf temperature. Before heading, 0.15g N per pot was supplied. About 10 plants of Nipponbare and each BC_2F_4 line were harvested 40 days after heading.

Results and discussions

The averages of photosynthetic rate in BC_2F_4 lines under saturated light and ambient air conditions were the same or about 10% increased compared with Nipponbare (Table 1). The maximum value was 32% higher than Nipponbare. This result suggested that the maximum photosynthetic rate was reflected to some extent on the photosynthesis of the progenies under natural conditions.

Table 1. Comparison of CO_2 exchange rate (CER) relative growth rate (RGR) net assimilation rate (NAR) specific leaf area (SLA), leaf weight ratio (LWR) and leaf area per plant

Variety	CER (mmol/m^2/s)	RGR (g/g/day)		NAR (g/m^2/day)		SLA (cm^2/g)		LWR		Leaf area per plant (cm^2)	
Nipponbare	25.6 (100)	0.103 (100)	?	12.9 (100)	?	242.5 (100)	?	0.363	?	566.6 (100)	?
M9-5-14	28.1 (110)	0.128 (124)	**	14.5 (112)		268.1 (111)	**	0.347	**	743.2 (131)	**
M9-5-20	27.4 (107)	0.088 (86)	**	10.6 (82)	*	253.0 (104)	*	0.344	**	787.5 (139)	**
P4-6-10	28.7 (112)	0.099 (97)		10.8 (83)	*	267.0 (110)	**	0.364		772.4 (136)	**
P4-6-18	25.7 (101)	0.075 (73)	**	7.8 (61)	**	282.1 (116)	**	0.349	*	891.1 (157)	**

*,** indicate significant differences compared with Nipponbare at 5% and 1% levels, respectively.

The results of the growth analysis are shown in Table 1. Only the M9-5-14 line had high RGR and NAR compared with Nipponbare (24% and 12% increased, respectively). There was a positive correlation between RGR and NAR (r=0.932, P＜0.01). This result suggested that growth efficiency of BC_2F_4 lines was limited by physiological aspects including photosynthesis and respiration. In morphological aspects, specific leaf area (SLA) and leaf area per plant of BC_2F_4 were significantly higher than Nipponbare. Stem numbers per plant of these lines were not different from that of Nipponbare (data not shown). These results indicated that BC_2F_4 lines had thin and large leaves. However, light-intercepting characteristics might not be worse and could have large effects on dry matter production because this growth analysis was done on young plants at the vegetative stage. Leaf area index is considered to increase curvilinearly with respiratory rate (Cock and Yoshida, 1973). Because CERs at the same stage were the same or higher than Nipponbare, the respiratory rates might be high and lead to decreased NAR of 3 lines of BC_2F_4 except for M9-5-14.

The yield and yield components are shown in Table 2. Heading times of BC_2F_4 lines were about the same as Nipponbare. The averages of grain yield per plant in BC_2F_4 lines were 8－22% higher than Nipponbare. The maximum yield was increased 54%. Low spikelet number per panicle and high percentage of filled spikelets were common characteristics of BC_2F_4 lines. Sink sizes calculated by multiplying spikelets number per plant by weight of a filled spikelet were not significantly different between BC_2F_4 lines and Nipponbare. This result suggested that the increases in grain yield of BC_2F_4 lines were due to high percentage of filled spikelets. The photosynthates produced during the filling stage explain 70－80% of carbohydrate accumulated in the panicle (Cock and Yoshida, 1972). According to Saitoh et al. (1990), higher yield of Musashikogane than Nipponbare was attributed to high percentage of filled spikelets. They assumed that NAR and crop growth rate (CGR) of Musashikogane were higher than Nipponbare because its light–intercepting characteristics were better. Further analysis must be made to examine whether the photosynthetic capacities and light–intercepting characteristics of these backcross lines during the filling stage are superior to Nipponbare.

Table 2 Comparison of grain yield and yield components

Variety	Grain yield per plant (g)	Panicle no. per plant		Spikelet no. per panicle	Spikelet no. per plant		Filled spikelets (%)		1000-kernel weight (g)		Sink size (g)
Nipponbare	31.7	17.6	?	88.5	1559	?	79.2	?	26.1	?	40.6
	(100)	(100)		(100)	(100)		(100)		(100)		(100)
M9-5-14	37.7	23.7	**	78.7	1855	**	91.1	**	22.3	**	41.4
	(119)	(135)		(89)	(119)		(115)		(86)		(102)
M9-5-20	34.4	23.3	**	79.6	1820	*	88.4	**	21.3	**	38.9
	(108)	(132)		(90)	(117)		(112)		(82)		(96)
P4-6-10	38.7	18.7		85.2	1569		90.0	**	27.4		43.0
	(122)	(106)		(96)	(101)		(114)		(105)		(106)

P4-6-18	36.8	20.7		73.1	1481		89.5	**	27.7	*	41.0
?	(116)	(118)	?	(83)	(95)	?	(113)	?	(106)	?	(101)

*,** indicate significant differences compared with Nipponbare at 5% and 1% levels, respectively.

Conclusion

The photosynthetic rates of BC_2F_4 lines under saturated light and ambient air conditions were the same or higher than that of Nipponbare at vegetative stage. This result suggested that the maximum photosynthetic rate was reflected to some extent by the photosynthesis of the progenies under natural conditions. Not all the BC_2F_4 lines were superior to Nipponbare in growth efficiency. The growth efficiency may be limited by physiological aspects including photosynthesis and respiration. The grain yields per plant of BC_2F_4 lines were higher than Nipponbare. It was thought that this increase was due to high percentage of filled spikelets. These results supported the use of *O. rufipogon* to improve the grain yield of *O. sativa*.

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