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The photosynthetic efficiency of some elite rice hybrids and restorers

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Abstract

At the vegetative growth stage (40 d), the mean photosynthetic rate (P_N) and canopy photosynthesis ($P_N \times$ LAI) in F_1 hybrids and their parents were similar, whereas the maintenance respiration rate (R_M) was considerably higher and P_N/R_M lower in the F_1 hybrids than in the parents. Yet at the flowering stage, the hybrids showed higher P_N and $P_N \times$ LAI values, while R_M and P_N/R_M were similar in both. A specific F_1 hybrid like IR 62829A×Vajram showed high readings in P_N, P_N/R_M, and $P_N \times$ LAI at the flowering stage, while IR 62829A×Swarna followed by IR 62829A×Vajram had high values 40 d after planting. The parents Swarna and Vajram, although moderate in P_N, had the highest $P_N \times$ LAI at the flowering stage due to a greater LAI.

Additional key words: cultivars; growth stages; heterosis; leaf area index; maintenance respiration; net photosynthetic rate; *Oryza sativa*.

Introduction

Based on the spectacular success achieved by China in commercial cultivation of F_1 rice hybrids with the yield potential of about 15-25 % over the best inbred cultivars, the International Rice Research Institute, Phillippines along with several southeastern Asian countries including India is developing a hybrid rice technology for tropical climate. The main emphasis is laid on investigating photosynthesis and respiration of the hybrid rice in tropical climate with the available cytoplasmic male sterile (CMS) lines, and purified restorers (male parents). Photosynthesis is a vital physiological factor for the biomass production and yield.

The leaf area index (LAI), photosynthetic rate per unit leaf area, and photosynthetically active radiation (PAR) within the canopy are basic components of the photosynthetic productivity. The intercultivar difference in the photosynthetic productivity mostly depends on P_N and LAI (Murty and Dey 1991). Therefore the identification of parental lines and hybrid combinations with a high P_N is essential

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for achieving potential yields. Heterosis in P_N over the restorers should be identified for possible use in heterotic breeding for this character (cf. Krebs *et al.* 1996).

Materials and methods

Six F_1 hybrids bred from CMS line IR 62829A and pollen parents (restorers) WGL 3935, WGL 3962, Swarna, Vajram, IR 36, and Tellahamsa were assessed for the photosynthetic potential and productivity in field conditions in a plot of 3 m^2 size with an entirely randomised block design, where the crop was fertilised with 3 g m^{-2} each of P_2O_5 and K_2O as basal, and 6 g N in three equal splits at planting, and 20 and 40 d later. The P_N was measured at vegetative (40 d) and flowering stages by an infra-red gas analyser, a portable system (*LI-6000*), under a saturated irradiance (above 1000 μmol m^{-2} s^{-1}). The P_N of a single intact leaf was measured at different stages of plant development between 09:30 and 11:30 h. The middle portion of a fully expanded 2nd leaf from the top was used for study at the preflowering stage, and a flag leaf at the flowering one.

R_M value of the living rice leaf tissue was measured by a differential respirometer (*Gilson*, U.S.A). The R_M of organs that are not growing or transporting substances can be determined directly from the CO_2 evolution rate. Mature leaves after 6 to 12 h darkness were used, as recommended by Penning de Vries (1975). The leaves were cut in the evening and kept for 12 h in the dark, and a weighed quantity without midrib was cut into 1-2 mm bits and suspended in 1.8 cm^3 of 0.2 M phosphate buffer at a pH of 7.0 in a Warburg flask. 20 % KOH (0.2 cm^3) was poured into the centre well, and a strip of filter paper was added to the alkali to increase the surface area for a rapid CO_2 absorption. After greasing the upper rim, the flask was attached to a manometer immersed in a water bath maintaining a constant temperature (30-33 °C) under steady shaking. The rapid consumption of oxygen by tissue in the chamber was indicated by the fall of the manometer fluid (Umbreit *et al.* 1972). The canopy photosynthesis was calculated as the product of $P_N \times$ LAI. The ratio P_N/R_M, an essential trait for crop productivity (Matsubayashi *et al.* 1963), was also calculated.

Results and discussion

F_1 hybrids *vs.* restorers: At 40 d, the mean P_N and $P_N \times$ LAI were more or less the same in F_1 hybrids and parents while R_M was considerably higher in the hybrids than in the parents (restorers) that led to a lower P_N/R_M ratio in the hybrids (Table 1). Yet at the flowering stage the F_1 hybrids showed a higher P_N and $P_N \times$ LAI while R_M and P_N/R_M were similar to the parents (Table 1). At 40 d, the Swarna F_1 hybrid showed the highest values in P_N, P_N/R_M, and $P_N \times$ LAI followed by Vajram F_1 hybrids, whereas at flowering the Vajram hybrids were most efficient in these traits. Among the parents, both Swarna and Vajram were at par. Their efficiency in the P_N was not high, but both showed a higher $P_N \times$ LAI at the flowering stage due to a greater LAI. The elite hybrid IR 62829A×Vajram exhibited a higher R_M at the flowering stage.

However, the P_N/R_M and canopy photosynthesis were still high indicating favourable balance in the P_N/R_M for efficient photosynthetic productivity of this hybrid.

Table 1. The net photosynthetic (P_N) and respiration (R_M) rates [μg(CO$_2$) m^{-2} s^{-1}], and canopy photosynthesis, P_N×LAI [mg(CO$_2$) m^{-2} s^{-1}] of hybrids and restorers at vegetative (40 d) and flowering stages.

Hybrids/restorers	40 d				flowering			
	P_N	R_M	P_N/R_M	P_N×LAI	P_N	R_M	P_N/R_M	P_N×LAI
Hybrids								
IR 62829×WGL3935	914	89	10.3	1.36	1213	64	19.0	3.14
IR 62829×WGL3962	853	58	14.6	1.17	889	61	14.5	2.53
IR 62829×Swarna	1208	92	13.2	2.00	1167	69	16.8	3.94
IR 62829×Vajram	1122	86	13.0	2.06	1564	72	21.7	6.44
IR 62829×IR 36	1064	61	17.4	1.56	1192	61	19.5	3.86
IR 62829×Tellahamsa	1122	56	20.5	1.92	1322	56	23.8	3.22
Restorers								
WGL3935	1092	61	18.0	1.83	1119	61	18.3	2.78
WGL3962	953	58	16.1	1.58	1047	58	17.9	3.03
Swarna	1161	61	18.9	1.50	1031	75	13.7	4.00
Vajram	1181	56	20.9	1.81	1044	64	16.3	3.56
IR 36	1106	36	29.9	1.86	1147	61	18.8	2.83
Tellahamsa	886	36	24.3	1.06	1564	58	26.8	2.83
Standard								
Swarnaprbha	1114	64	17.5	1.97	1522	64	23.8	5.36
Mean	1961	64	18.1	1.67	1217	64	19.3	3.64
CD at 5 %	139	6	-	0.17	27	11	-	0.14
Heterosis % over restorers								
IR 62829×WGL3935	-16	-46	-43	-25	8	5	4	13
IR 62829×WGL3962	-10	-1	-9	-26	-15	5	-19	-17
IR 62829×Swarna	3	49	-30	33	13	-7	23	-1
IR 62829×Vajram	5	52	-38	14	50	13	33	81
IR 62829×IR 36	-4	65	-42	-16	4	0	4	36
IR 62829×Tellahamsa	26	50	-16	81	-15	-5	-11	14
Mean	1	28	-30	10	7	2	6	21

A considerable variation in P_N, R_M, P_N/R_M, and P_N × LAI values at vegetative and flowering stages in both hybrids and pollen parents was recorded at 40 d and at the flowering stage (Table 2). Extent of the variation was more or less similar in both F$_1$ hybrids and parents at 40 d, while at flowering a large variation among hybrids was apparent in P_N and P_N × LAI. The variation in R_M between the two groups was negligible. The P_N/R_M variation was higher with the parents than hybrids.

The crop respiration makes approximately 40 % of gross photosynthesis (Yoshida 1981). The estimated R_M in midday under a clear sky ranges from 10 to 30 % of P_N. At the grain filling stage, 50-60 % of total respiration is done by the grain, therefore a high P_N is vital for efficient grain filling. Dwarf improved varieties in general show low photorespiratory and total respiratory activities while tall varieties, though efficient in P_N, respire a greater amount of freshly fixed CO_2 and have a high photorespiration (Janardhan and Murty 1978, Palit *et al.* 1979). P_N and respiration (photorespiration) are positively associated which is suggested by the difficulty in manipulating photorespiration and independence of P_N on breeding (Janardhan and Murty 1978, Gao *et al.* 1987). The yield is contributed by the balance of P_N and R_M (P_N/R_M) which are positively associated (Osada 1967, Yoshida 1981, Swain *et al.* 1987, Dey *et al.* 1989) and thus indicate the importance of selection for high P_N and low R_M genotypes. Evidently, a higher P_N and lower R_M at the flowering stage, and 40 d in the present hybrids may be considered as a contribution of cultivars with a low R_M to improving crop growth rate (CGR).

Table 2. Variation in net photosynthetic rate (P_N) and respiration (R_M) rates [$\mu g(CO_2)\ m^{-2}\ s^{-1}$] and canopy photosynthesis, $P_N \times$LAI [$mg(CO_2)\ m^{-2}\ s^{-1}$] in hybrids and restorers at 40 d and flowering. Figures in parentheses indicate the extent of variation.

	P_N	R_M	P_N/R_M	$P_N \times$LAI
40 d				
Hybrids	1208 - 853 (1.4)	92 - 31 (1.7)	20.5 - 10.3 (2.0)	2.05 - 1.17 (1.8)
Restorers	1181 - 886 (1.3)	61 - 36 (1.7)	29.9 - 16.1 (1.9)	1.86 - 1.06 (1.8)
Combined incl. standard	1298 - 853 (1.4)	92 - 36 (2.5)	29.9 - 10.3 (2.9)	2.06 - 1.06 (1.9)
Flowering				
Hybrids	1564 - 889 (1.8)	72 - 56 (1.3)	23.8 - 14.5 (1.6)	6.44 - 2.53 (2.5)
Restorers	1564 - 892 (1.5)	75 - 58 (1.3)	26.8 - 13.7 (2.0)	4.00 - 2.78 (1.4)
Combined incl. standard	1564 - 889 (1.6)	75 - 56 (1.4)	26.8 - 13.7 (2.0)	6.44 - 2.53 (2.5)

Heterosis (H%): H% for P_N/R_M was negative in all the F_1 hybrids at 40 d, while at flowering it was positive in the F_1 hybrids of Swarna and Vajram. P_N × LAI showed positive heterosis in 50 % of the cultivars. The hybrid IR 62829A×Vajram was highly heterotic in all the above traits at both the stages (barring P_N/R_M at 40 d).

Standard heterosis (SH%): SH% over Swarnaprabha was observed only in the Swarna F_1 hybrid at 40 d (8 %) and in the Vajram F_1 hybrid at flowering (3 %): the extent of heterosis was marginal. SH% was evident in R_M in three hybrids at 40 d while at flowering stage it was negligible. A high SH% for P_N × LAI (20 %) was recorded in the Vajram F_1 hybrid at flowering. Murayama *et al.* (1987) reported heterosis in P_N in certain cross combinations, viz. Suzunari/Zenith. Yang and Sun (1991) observed a higher H% in P_N at higher levels of N_2 due to heterosis in the leaf chlorophyll content, photosynthetic phosphorylation activity, and ATP content. However, H% was not apparent for P_N and ribulose-1,5-bisphosphate carboxylase activity at low concentrations of N_2. Obviously, heterosis among the hybrids is influenced by N_2 supply. Murty and Dey (1991) reported a considerable H% over restorer in P_N and R_M in two hybrids, IR 54752A×IR 54 and V20A×IR 36, in the latter both in the vegetative and flowering stages.

Growth stages: P_N, P_N × LAI, and P_N/R_M values increased from 40 d to flowering stage in the F_1 hybrids, whereas in parents also R_M increased with age which led to a lower P_N/R_M at flowering. The IR 62829A×Vajram maintained high P_N and P_N × LAI at both stages. In rice F_1 hybrids photosynthetic activity showed a high H% at the early vegetative stage, while at the late vegetative stage no such heterosis was apparent (Lin and Yuan 1980, Sunohara *et al.* 1985). Yamauchi and Yoshida (1985) observed little heterosis, and Murayama *et al.* (1984, 1986) reported a higher positive heterosis in P_N. Murayama *et al.* (1984) and Lin and Yuan (1980) reported a negative heterosis in the respiration rate. However, little difference between the parents and F_1 hybrids in the net assimilation rate (NAR) was observed by Blanco *et al.* (1986). Little H% in P_N activity with similar materials crossed using CMS lines (Yamauchi and Yoshida 1985) strongly suggests that H% in P_N and respiration rate is not necessarily related to the vigorous growth of F_1 hybrids at the vegetative stage.

Table 3. Interrelations among the P_N, R_M, and P_N × LAI in hybrids and restorers. For abbreviations see Table 1.

Correlation	R_M	P_N × LAI	P_N (flowering)
P_N (40 d)	0.213	0.833^{**}	0.057
P_N (flowering)	0.560^{*}	0.585^{*}	-

Correlations: Statistically significant positive correlations were observed between P_N and P_N × LAI at 40 d and at flowering stage while P_N at 40 d and flowering did not indicate any significant relationship (Table 3). Obviously, cultivars efficient in P_N at a specific stage may not be that efficient at the other stages (Janardhan and Murty 1978). In the present investigation, the P_N was positively associated with R_M at flowering only, indicating the problem of selection of genotypes with a high P_N and a low R_M for enhanced P_N/R_M ratio and bioproductivity (Janardhan and Murty 1978, Palit *et al.* 1979).

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