Studies on Matter Production of F_1 Hybrid in Rice

I. Heterosis in the single leaf photosynthetic rate*

Seiichi MURAYAMA, Kiyomatsu MIYAZATO and Akihiro NOSE

(College of Agriculture, University of the Ryukyus,

Nishihara, Okinawa 903—01)

Received May 17, 1985

It is known that some of the F_1 hybrids of rice show marked heterosis in grain yield and some characters related to yield components. Based on the finding that some F_1 hybrids of rice exceed certain commercial varieties in yield, MURAYAMA^{7,8)} pointed out as early as 1974 the feasibility that the F_1 hybrid of rice could be practically utilized. Currently, the F_1 hybrid of rice is cultivated on commercial basis in large area in China. It is of great interest to study the mechanism of the heterosis. Many works on the heterosis have so far been carried out from the standpoint of genetics, but it seems that very little study has been done from the standpoint of physiology.

The present study was carried out in order to investigate the degree of heterosis in some characters relating to dry matter production, such as photosynthetic rate of the leaf, nitrogen content of the leaf, SLA (specific leaf area) and leaf area.

Materials and Methods

Parental varieties used in the present experiments were Araki, Norin No.22, Suzunari, Zenith, Mitsuryuto, Akebono and Mihonishiki. In the previous papers^{7,8)}, six varieties other than Mitsuryuto, showed high combining ability in grain yield. However, Mitsuryuto showed relatively high photosynthetic ability in our preliminary experiment. For this reason, the seven varieties were used as parents in the present study. Among seven varieties, Zenith was from the United States of America and the other six varieties were from Japan. The F_1 hybrids of the following seven combinations were tested, i. e., Araki×Norin No.22, Suzunari×Zenith, Zenith×Mitsuryuto,

Akebono×Zenith, Zenith×Akebono, Mihonishiki×Zenith and Zenith×Mihonishiki. Seeds of F_1 hybrids and parental varieties were sown in nursery boxes (60×35×8cm) on July 30, 1980. Then they were transplanted in the Wagner pots of 1/5,000 a on August 13. Ten plants for each of the F_1 hybrids and parental varieties were planted at one plant per pot, and they were grown in a glasshouse of the College of Agriculture, University of the Ryukyus, Okinawa.

During the experiment period, the following amounts (g/m²) of N, P₂O₅ and K₂O fertilizers were applied : On July 30, 1980, at the seeding time 5.25, 4.20 and 4.73 : On August 13 at transplanting time 5.25, 4.20 and 4.73 : On August 28, 3.00, 2.40 and 2.70 : and on October 2, 2.25, 1.80 and 2.30. The total amount of fertilizer applied was one and a half times as much as that usually applied to the 2nd crop in Okinawa. The characteristics examined in the present experiments were photosynthetic rate of the single leaf, leaf nitrogen content, SLA, leaf area and ear weight per plant. Photosynthetic rate of the flag leaves on the main culms under the light intensities of 0, 10, 20, 40 and 60 klx was also measured for 7—10 days after heading. In most of the F_1 hybrids and parental varieties, three plants were used for the measurement of photosynthetic rate, nitrogen content and SLA, but in some of them only two plants were used.

The CO₂ concentration at the inlet and the outlet of a vinyl assimilation chamber in an open system was measured with a differential-type infrared CO₂ gas analyzer. The leaf temperature was kept at 27—28°C. Air was flown through the chamber at the rates of 10±0.5 liters per minute and 4.5±0.5 liters per minute in light and dark, respectively. Nitrogen content and SLA were measured

* The outline of this paper was presented at the 174th meeting of the Crop Science Society of Japan, October, 1982.

with the leaves whose photosynthetic rate was measured. The measurement of nitrogen content was done by using the semi-micro Kjeldahl method.

Results

Some of the results obtained in the present experiments are shown in Table 1. Heterosis in the photosynthetic rate was highest in the F₁ hybrids of Suzunari×Zenith, which exceeded the mid-parent and higher-parent values by 57% and 51%, respectively. The F₁ hybrid of Araki×Norin No.22 showed the highest photosynthetic rate of 37.7 mgCO₂/dm²/h. The F₁ exceeded the mid-parent by 18%, and it showed the same value as that of the higher-parent. Six F₁ hybrids in seven exceeded the mid-parent and four of them exceeded the higher-parent. Only one F₁ hybrid showed a value smaller than the higher-parent. The average heterosis in seven F₁ hybrids to the mid-parent and the higher-parent was 17% and 10%, respectively.

For the nitrogen content of the leaf, six out of the seven F₁ hybrids exceeded the mid-parent, and five of them exceeded the higher-parent. The heterosis was highest in the F₁ hybrid of Suzunari×Zenith, which exceeded the mid-parent and the higher-parent value by 20% and 11%, respectively. The average heterosis in nitrogen content to mid-parent and higher-parent was 9% and 4%, respectively.

All F₁ hybrids showed values smaller than the mid-parent in SLA, and five of them except for two showed values smaller than the lower parent. Five F₁ hybrids exceeded the mid-parent in leaf area, although only two of the five exceeded the higher-parent.

As for the ear weight, five F₁ hybrids exceeded the mid-parent and the higher-parent. The F₁ hybrid of Zenith×Akebono showed the highest heterosis, which exceeded the mid-parent and higher-parent by 123% and 62%, respectively. The average heterosis in seven F₁ hybrids to the mid-parent and the higher-parent was 49% and 14%, respectively.

The significant relationships in photosynthetic rate of these materials are given in Table 2. The F₁ hybrids of Araki×Norin No.22 which showed the highest value was equal to Araki, the highest-parent. The F₁ hybrid of

Suzunari×Zenith significantly exceeded the higher-parent. The three F₁ hybrids, i. e., Zenith×Akebono, Zenith×Mitsuryuto and Mihonishiki×Zenith exceeded their own higher-parent, but the difference was not significant.

Relationships between light intensity and photosynthetic rate are shown in Fig. 1. The F₁ hybrid of Araki×Norin No.22 remarkably exceeded Norin No.22, which is the lower-parent, and it showed the same value as that of the higher-parent. The F₁ hybrids of Suzunari×Zenith and Zenith×Akebono showed higher heterosis under higher light intensities, but those of Zenith×Mitsuryuto, Mihonishiki×Zenith, Zenith×Mihonishiki and Akebono×Zenith did not.

Fig. 2 shows relationships among photosynthetic rate, nitrogen content and SLA. Correlation coefficient between photosynthetic rate and nitrogen content showed a positive value and correlation in parental varieties was significant. Correlation coefficient between photosynthetic rate and SLA showed a significant negative value. On the other hand, the correlation coefficient between nitrogen content and SLA showed a negative value, and that in parental variety was significant.

Discussion

Studies on the heterosis of leaf photosynthesis have been done by some workers. IZHAR and WALLACE³⁾ reported that the net CO₂ exchange of F₁ hybrid in dry bean was significantly lower than that of the mid-parent. OJIMA et al.¹⁰⁾ reported that leaf photosynthesis of F₁ hybrid in soybean was close to that of the lower-parent. HAYASHI et al.¹⁾ and KABAKI et al.⁴⁾ also obtained the same results in rice and the latter reported that the lower heterosis for photosynthetic rate was due to the decrease of nitrogen content per unit leaf area caused by high heterosis in leaf area. On the other hand, HEICHEL and MUSGRAVE²⁾, MURESAN et al.⁹⁾, MONMA and TSUNODA⁶⁾ indicated that the F₁ hybrids of maize showed a significantly higher photosynthetic rate than their inbreds. LIN and YUAN⁵⁾, and LUO ZE MIN* also report-

* LUO ZE MIN 1982. Physiological studies on rice heterosis. Hunan Academy of Agricultural Science, Zhangsha, Hunan, China (Personal communication).

Table 1. Heterosis in photosynthetic rate, nitrogen content, specific leaf area (SLA), leaf area and ear weight.

F ₁ combinations	Photosynthetic rate at 60 klx			Nitrogen contents		
	(mg CO ₂ /dm ² /h)	% to MP	% to HP	(mg/dm ²)	% to MP	% to HP
Araki × Norin No. 22	37.7	118	100	10.8	92	85
Suzunari × Zenith	31.0	157	151	11.7	120	111
Zenith × Mitsuryuto	25.9	113	103	11.0	102	88
Akebono × Zenith	23.1	105	99	10.3	114	114
Zenith × Akebono	26.5	120	113	10.6	117	117
Mihonishiki × Zenith	21.7	106	105	10.0	112	111
Zenith × Mihonishiki	20.5	100	100	9.5	107	105
Mean	26.6	117	110	10.5	109	104

SLA			Leaf area			Ear weight		
(cm ² /g)	% to MP	% to LP*	(cm ² /pl.)	% to MP	% to HP	(g/pl.)	% to MP	% to HP
209	99	109	636	86	78	7.8	136	112
222	87	88	944	108	94	7.2	157	125
238	98	103	927	110	99	3.8	94	81
222	86	87	921	104	96	10.5	192	140
236	92	93	682	80	71	12.2	223	162
247	97	97	890	113	109	5.4	99	72
234	91	92	980	124	120	7.7	141	103
230	93	95	854	104	95	7.8	149	114

Notes. MP, HP and LP show mid-parent, higher-parent and lower-parent, respectively.

*SLA of F₁ hybrids were compared with lower SLA parents, because the leaves are thicker in the lower SLA plant than those of higher SLA.

ed that F₁ hybrids of rice showed high heterosis in photosynthetic rate.

In the present study, some F₁ hybrids showed high heterosis in leaf photosynthetic rate. The magnitude of heterosis was 17% excess of the mid-parent in the mean of seven combinations. One of them significantly exceeded the higher-parent. This is a favorable result for dry matter production of F₁ hybrid.

Heterosis in photosynthetic rate gradually increased with the increase in light intensity. This fact suggests that F₁ hybrid shows high heterosis in leaf photosynthesis under the field condition of high solar radiation.

In the present study the authors obtained a significant positive correlation between leaf photosynthesis and nitrogen content. On the other hand, relationship between leaf photosynthesis and SLA was significant with a negative correlation. These facts are favorable

for the selection of parental varieties whose F₁ hybrids show high heterosis in photosynthetic rate. These facts are also favorable for the improvement of leaf photosynthesis of rice varieties, because the measurement of nitrogen content and SLA is more convenient than the measurement of leaf photosynthetic rate. Therefore, it is convenient to use the value of nitrogen content and SLA instead of photosynthetic rate as a means to select F₁ hybrids showing high heterosis in photosynthetic rate, and also as a means to improve leaf photosynthesis of rice varieties. Heterosis in leaf area was not high in the present experiments. On the other hand, SLA of F₁ hybrids became smaller than that of the parental varieties, i. e., the leaves of F₁ hybrids became thicker than those of the parents. From the results and the negative correlation between photosynthetic rate and SLA as shown in Fig.

2, it is considered that one of the factors which brought high heterosis in leaf photosynthesis after the heading was that the leaves of F₁

Table 2. Photosynthetic rate of F₁ hybrids as compared with those of their parents.

Parental varieties and F ₁ combinations	Photosynthetic rate at 60 klx (mg CO ₂ /dm ² /h)	Significance*
Araki	37.8	a
Araki × Norin No. 22	37.7	ab
Suzunari × Zenith	31.0	abc
Zenith × Akebono	26.5	cd
Zenith × Mitsuryuto	25.9	cd
Norin No. 22	25.9	cd
Mitsuryuto	25.2	cd
Akebono	23.4	cd
Akebono × Zenith	23.1	d
Mihonishiki × Zenith	21.7	d
Zenith	20.6	d
Zenith × Mihonishiki	20.5	d
Mihonishiki	20.3	d
Suzunari	18.9	d

Notes. * by Duncan's multiple range test.

Two mean values not belonging to the same subgroup (same letter) significantly differ at 5% level.

hybrids became thicker than those of the parental varieties. It is considered that the heterosis in photosynthetic rate is different between the plants growing individually and those growing in a population. Consequently, it is also necessary to carry out the experiment of photosynthetic rate in F₁ hybrid in rice under community conditions.

Summary

It is known that some F₁ hybrids of rice show evident heterosis in grain yield. It seems, however, the heterosis of some characters in dry matter production has not been much studied so far. The present study was carried out in order to investigate the degree of heterosis in several characters relating to dry matter production, such as photosynthesis of the leaf, nitrogen content of the leaf, SLA and leaf area. The results obtained are as follows:

1. In some F₁ hybrids remarkable heterosis was found in the photosynthetic rate of the single leaf, i. e., the most excellent F₁ hybrid exceeded the mid-parent and higher-parent by 57% and 51% in its rate, respectively, which were both significant (Table 1, Table 2).

Fig. 1. Relationships between light intensity and photosynthetic rate.

Fig. 2. Relationships among photosynthetic rate, nitrogen content and specific leaf area (SLA).

** Significant at 1% level, * at 5% level. Figures by the circles show as follows: F_1 hybrids ●: 1, Araki × Norin No.22; 2, Suzunari × Zenith; 3, Zenith × Mitsuryuto; 4, Akebono × Zenith; 5, Zenith × Akebono; 6, Mihonishiki × Zenith; 7, Zenith × Mihonishiki; Parental varieties ○: 1, Araki; 2, Norin No.22; 3, Suzunari; 4, Zenith; 5, Mitsuryuto; 6, Akebono; 7, Mihonishiki.

2. The magnitude of heterosis in the photosynthetic rate was higher at a high, than at a low, light intensity (Fig. 1).

3. Heterosis in the leaf nitrogen content was as high as that in photosynthetic rate (Table 1).

4. Positive correlation was found between photosynthetic rate and nitrogen content, and the correlation in the parental varieties was significant (Fig. 2).

5. Correlation coefficient between the photosynthetic rate of the single leaf and SLA showed significant negative value (Fig. 2).

6. Negative correlation was found between nitrogen content and SLA, and the correlation in the parental varieties was significant (Fig. 2).

Acknowledgements

The authors wish to express their sincere gratitude to Professor Yoshio MURATA, Tokyo University of Agriculture, Professor Michio SHIROMA, Faculty of Agriculture, University of the Ryukyus and Lecturer Milton MAKOKHA, Jomo Kenyatta College of Agriculture for their kind reading of the manuscript.

References

1. HAYASHI, K., T. YAMAMOTO and M. NAKAGHARA 1977. Genetic control for leaf photosynthesis in rice, *Oryza Sativa* L. Japan. J. Breed. **27**: 49—56.

2. HEICHEL, G. H. and R. B. MUSGRAVE 1969. Varietal differences in net photosynthesis of *Zea mays* L. Crop Sci. **9**: 483—486.
3. IZHAR, S. and D. H. WALLACE 1967. Studies of the physiological basis for yield differences. III. Genetic variation in photosynthetic efficiency of *Phaseolus vulgaris* L. Crop Sci. **7**: 457—460.
4. KABAKI, N., S. AKITA, I. TANAKA and A. AMAMIYA 1976. Photosynthesis and photorepiration of cultivated rice and F_1 hybrid. Japan. J. Crop Sci. **45** (Extra Issue 2): 177—178*.
5. LIN, S.-C. and L.-P. YUAN 1980. Hybrid rice breeding in China. Innovative approaches to rice breeding. International Rice Research Institute, Los Banos, Philippines. 35—51.
6. MONMA, E. and S. TSUNODA 1979. Photosynthetic heterosis in Maize. Japan. J. Breed. **29**: 159—165.
7. MURAYAMA, S., T. OMURA and K. MIYAZATO 1974. Basic studies on utilization of hybrid vigor in rice IV. Heterosis under different cultural conditions. Japan. J. Breed. **24**: 287—290.
8. ——— 1976. Basic studies on utilization of hybrid vigor in rice. Sci. Bull. Coll. Agr. Univ. Ryukyus **23**: 1—71.**
9. MURESAN, T., N. HURDUC, M. TERBEA, O. COSMIN and I. NASTASIA 1975. The interdependence of the degree of heterosis, photosynthetic yield and some physiological indices in maize. II. The dynamics of photosynthetic potential. Plant Breed. Abstr.

45 : 213.

Japan. 38 : 693—699.**

10. OJIMA, M., R. KAWASHIMA and K. MIKOSHIBA
1969. Studies on the seed production of soy-
bean. VII. The ability of photosynthesis in F_1
and F_2 generation. Proc. Crop. Sci. Soc.

* In Japanese, the title was translated by the
present authors.

** In Japanese with English summary.

〔和 文 摘 要〕

イネの一代雑種の物質生産に関する研究

I. 個葉の光合成速度におけるヘテロシス

村山盛一・宮里清松・野瀬昭博

(琉球大学農学部)

イネの一代雑種が収量で顕著なヘテロシスを示すことはすでに明らかにされているが、作物の物質生産の立場からヘテロシスについて研究した例は少ない。

本研究では、物質生産要素におけるヘテロシスについて検討するために、個葉の光合成速度、窒素含量、比葉面積 (SLA)、株当り葉面積および1株穂重の測定を実施した。結果は次の通りである。

1. 個葉の光合成速度において顕著なヘテロシスを示す組合せがみられ、最も優れた F_1 は中間親、高い方の親をそれぞれ 57%, 51% も凌駕し、いずれも統計的に有意であった (第1表, 第2表)。
2. 光合成速度におけるヘテロシスは弱光域よりも強光域において高かった (第1図)。
3. 葉身の窒素含量でもかなりのヘテロシスがみられた (第1表)。
4. 光合成速度と窒素含量の間には正の相関がみられ、親品種では有意であった (第2図)。
5. 光合成速度と SLA の間では一代雑種、親品種とも負の有意な相関を示した (第2図)。
6. 窒素含量と SLA の間でも親品種では負の有意な相関を示した (第2図)。