AGRONOMIC PERFORMANCE OF THE F_1, F_2 AND F_3 GENERATIONS OF RICE CROSSES[1]

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The manifestation of heterosis for yield, components of yield, and several important agronomic characters in rice crosses has been reported previously (Chang *et al.*, 1971b). The average heterosis for grain yield was found to be 20.3, 19.1, and 18.3% in relation to midparent, check variety, and high parent, respectively. The results fully demonstrate that sufficient amount of hetrosis occurs in F_1 hybrid populations for grain yield of rice. However, heterosis is but one requisite for commercial production of hybrid rice. A successful utilization of hybrid vigor in F_1 hybrids also depends on the availability of techniques for economical production of hybrid seeds. Since no technique is currently available for economically producing large quantities of F_1 seeds, the use of hybrid rice is not practical under the present circumstances. Before hybrid rice being actually developed, the utilization of heterosis in F_2 and F_3 generations seems to be a promising alternative. Thus, the understanding of heterosis in the later generations of rice hybrids appears worthwhile. This experiment was designed to furnish information on the performance of several rice crosses in the F_1, F_2, and F_3 generations.

MATERIALS AND METHODS

Five, 10, and 6 cross combinations which expressed higher degree of heterosis in the previous experiment(Chang *et al.*, 1971 b)were selected from early maturing japonica, late maturing japonica, and indica rice crosses, respectively for use in this experiment. The five early maturing japonica crosses were Taichung 180 x Line 54233, Taichung 180 x Fukunishiki, Taichung 180 x Norin 22, Taichung 180 x BC 68, and Taichung 180 x Taitung 24. The 10 late maturing japonica crosses were C 236 x Tainan 1, C 236 x Tainan 4, C 236 x Tainan 5, C 236 x Line 54233, C 236 x Hsinchu 56, C 236 x Hsinchu 61, C 236 x Nankai-yu 70, Tainan 5 x Tainan 4, Tainan 5 x Taitung-yu 205, and Chianung 242 x Tainan 1. The six indica crosses were Taichung native 1 x Hsinchu-ai-chueh-chien, Hsinchu-ai-chueh-chien x IR 8, Kaohsiung shen 2 x Ti-chueh- wu-chien, C 230 x Ti-chueh-wu-chien, and C 235 x IR 9-60. F_1 hybrids of the three groups were tested in the second crops of 1970 and F_1 hybrids and F_2 populations in the first crop of 1971. In the second crop of 1971, only performance of F_1, F_2, and F_3 populations of the late maturing japonica crosses were observed. Field tests were conducted separately for each group of rice crosses. Both parents of each cross combination and a standard check variety were also included

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for comparison in each test. Rice varieties Taichung 180, Tainan 5, and Taichung native 1 were used as check varieties for early maturing japonica, late maturing japonica, and indica crosses, respectively.

The experiments were arranged in a randomized complete block design with three replications. Plot size was 0.75 x 2.0 m and consisted of three rows. The plants were grown at the spacing of 25 x 20 cm with single seedling being transplanted at each hill. Fertilization was made at the rate of 100, 50, and 50 kg per ha for N, P_2O_5, and K_2O, respectively. Data for grain yield, number of panicles per plant, plant height and days to heading were recorded and their heterosis estimated. Analysis for variance was also made for grain yield. Heterosis of the hybrids was expressed in the percentage of mid-parent (MP) high-parent (HP), and check variety (CK), repectively. The percentage decrease of F_2 and F_3 was calculated by using the formula, F_1-F_2 (or F_3)/F_1 x 100.

RESULTS AND DISCUSSION

Grain Yield of F_1 Hybrids

F_1 performance and heterosis for grain yield of 5, 6, and 10 early maturing japonica, indica, and late maturing japonica crosses are given in Table 1, 2, 3, and 4, respectively. The F_1 hybrids of early maturing japonica and indica groups were grown for 2 crops and those of late maturing japonica group for 3 crops. It was observed that differences in grain yield (expressed as grams per m^2) among crosses for each group was statistically significant with the exception of late maturing japonica group in the second crop of 1970. Yield data of this experiment should be more reliable since plot size was large enough to reflect the true performance of F_1 hybrids. Among 21 crosses evaluated, only 2 crosses in the early maturing japonica group yielded lower than the higher parent(HP), and F_1 yield was greater than the check variety (CK) in all crosses but one in the early maturing japonica group.

Table 1. Grain yields of F_1 hybrids for early maturing japonica rice crosses.

Cross	Grain yield (g/m^2)		Mean yield as % of					
			HP		MP		CK	
	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971
Taichung 180 x Line 54233	278.4^{b}*	481.2^{b}	93.3	83.9	95.8	93.0	98.5	104.3
Taichung 180 x Fukunishiki	320.2^{a}	529.4^{ab}	113.3	104.7	122.9	109.5	113.3	114.7
Taichung 180 x Norrin 22	378.8^{b}	450.4^{b}	98.7	97.6	105.4	103.3	98.7	97.6
Taichung 180 x BC 68	344.6^{a}	617.8^{a}	118.8	—	120.3	—	121.9	133.9
Taichung 180 x Taitung 24	309.8^{ab}	536.0^{ab}	107.1	95.3	108.3	104.7	109.2	116.2
Average	306.4	523.0	106.2	94.9	110.5	101.8	108.4	113.4

* Values followed by the same letter are not significantly different at 5% level.

Table 2. Grain yields of F_1 hybrids for indica rice crosses.

Cross	Grain yield (g/m^2)		Mean yield as % of					
			HP		MP		CK	
	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1970	1st crop 1971
Taichung native 1 x IR 8	542.4^{a}*	634.8^{abc}	121.7	103.5	132.3	112.1	144.9	103.5
Taichung native 1 x Hsinchu-ai-chueh-chien	414.0^{b}	684.4^{ab}	110.6	98.5	113.2	104.6	110.6	111.6
Hsinchu-ai-chueh-chien x IR 8	546.6^{a}	643.6^{abc}	122.7	92.6	136.2	106.0	146.0	104.9
Kaohsiung shen 2 x Ti-chueh-wu-chien	402.6^{b}	688.8^{a}	92.1	120.1	107.4	124.7	107.5	112.3
C 230 x Ti-chueh-wu-chien	398.0^{b}	625.2^{bc}	114.9	103.4	120.8	106.2	106.3	101.9
C 235 x IR 9-60	580.6^{a}	591.2^{c}	105.4	98.5	126.7	108.2	155.1	96.4
Average	480.8	644.6	111.2	102.3	122.7	110.0	128.4	105.1

* Values followed by the same letter are not significantly different at 5% level.

Table 3. Grain yields of F_1 hybrids for late maturing japonica crosses.

Cross	Grain yield (g/m^2)		
	2nd crop 1970	1st crop 1971	2nd crop 1971
C 236 x Tainan 1	392.6^{a}*	697.8^{ab}	601.8^{a}
C 236 x Tainan 4	402.8^{a}	678.8^{abc}	593.6^{a}
C 236 x Tainan 5	337.0^{a}	724.4^{a}	583.8^{a}
C 236 x Line 54233	368.2^{a}	655.6^{bc}	568.8^{a}
C 236 x Hsinchu 56	416.0^{a}	655.6^{bc}	591.2^{a}
C 236 x Hsinchu 61	373.4^{a}	638.0^{bc}	584.2^{a}
C 236 x Nankaiyu 70	375.4^{a}	642.2^{bc}	570.2^{a}
Tainan 5 x Tainan 4	386.2^{a}	628.8^{c}	571.2^{a}
Tainan 5 x Taitungyu 205	382.0^{a}	638.8^{bc}	565.6^{a}
Chianung 242 x Tainan 1	380.8^{a}	632.0^{c}	496.6^{b}
Average	381.6	659.0	572.8

* Values followed by the same letter are not significantly different at 5% level.

The mean F_1 yield all significantly exceeded that of parental varieties except for the early maturing japonica crosses in the first crop of 1971 (Table 5). The highest yielding crosses varied with crops but several F_1 hybrids gave consistently higher yield over the 2- or 3-crop period. For example, grain yield of Taichung 180 x BC 68 of early maturing japonica group was 21.9 and 33.9 % higher than the check variety, Taichung 180, in the second crop of 1970 and the first crop of 1971 respectively, whereas the cross C 236 x Tainan 1 of the late maturing japonica group produced 30.2, 23.6 and 27.2% more than the check variety, Tainan 5 in the second crop of 1970, first and second crops of 1971, respectively. When means over all crosses and crops are compared, the F_1 yield was 6.7, 12.9, and 19.2% above that of higher parent, mid-parent and check variety, respectively. The yield advantage of 19.2% expressed by F_1 over check variety in this experiment is comparable to the magnitude found previously (Chang *et al.*, 1971b). As F_1 hybrids of this experiment came from outstanding crosses of the previous one, the finding that majority of F_1 showed consistent, and in several cases high, heterosis for grain yield was highly encouraging. In Taiwan where the same variety is grown at different crops. F_1 hybrids with stable heterosis are more desirable when commercial production of hybrid rice becomes possible.

Table 4. Heterosis of grain yields for late maturing japonica crosses.

Cross	Mean yield as % of								
	HP			MP			CK		
	2nd crop 1970	1st crop 1971	2nd crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1971	2nd crop 1970	1st crop 1971	2nd crop 1971
C 236 x Tainan 1	113.7	110.3	105.2	117.2	113.6	112.2	130.2	123.6	127.2
C 236 x Tainan 4	113.1	103.8	103.8	114.8	108.6	105.6	133.6	120.3	125.4
C 236 x Tainan 5	97.6	121.6	102.0	104.2	124.9	111.7	111.7	128.4	123.4
C 236 x Line 54233	106.7	96.0	99.4	106.8	102.5	108.1	122.1	116.2	120.2
C 236 x Hsinchu 56	120.8	105.4	103.3	127.1	107.7	110.0	138.3	116.2	124.9
C 236 x Hsinchu 61	108.2	103.1	102.1	112.3	105.1	110.0	123.8	113.0	123.5
C 236 x Nankaiyu 70	108.8	105.8	99.7	113.1	105.8	105.7	124.5	113.8	120.5
Tainan 5 x Tainan 4	108.4	96.2	103.5	117.4	103.2	111.4	128.1	111.4	120.7
Tainan 5 x Taitungyu 203	125.7	102.9	110.9	126.2	107.6	115.1	126.7	112.8	119.5
Chianung 242 x Tainan 1	109.7	93.0	99.3	113.4	97.9	101.6	126.3	112.0	105.0
Average	111.3	103.9	102.9	115.2	107.6	109.1	126.5	116.8	121.0

Table 5. Mean grain yields of rice hybrid, F_2, F_3 and parental varieties.

Crop	Entry	Grain yield (g/m^2)		
		Early maturing japonica	Indica	Late maturing japonica
Second crop, 1970	F_1	306.4[a]*	480.8[a]	318.0[a]
	P	274.2[b]	398.8[b]	327.2[b]
First crop, 1971	F_1	523.0[a]	644.6[a]	659.0[a]
	F_2	498.0[a]	574.0[b]	649.0[a]
	P	506.8[a]	578.6[b]	625.4[b]
Second crop, 1971	F_1	—	—	572.8[a]
	F_2	—	—	626.2[b]
	F_3	—	—	519.4[c]
	P	—	—	506.4[d]

* Values followed by the same letter for different groups in each crop are not significantly different at 5% level.

Grain Yield of F_2 Generation

The F_2 yield of early maturing japonica, indica, and late maturing japonica crosses are presented in Tables 6, 7, and 8, respectively. F_2 generation of early maturing japonica and indica crosses were grown for one crop and that of late maturing japonica crosses for 2 crops. F_2 yield varied considerably among crosses of each group, but the differences all failed to attain a significant level. The F_2 produced less grain than the higher parent in all crosses with the exception of late maturing japonica crosses in the first crop of 1971 where 8 out of 10 F_2 crosses outyielded higher yielding parent. However, when comparison was made with check variety, the F_2 of all 10 late maturing and 4 out of 5 early maturing japonica crosses yielded higher than the check variety. The mean yield of F_2 in all crosses was 95.6, 101.4, and 111.9% of the higher parent, midparent, and check variety, respectively. The superiority of F_2 over the check variety in yielding ability is of particular importance since the F_2 population will need to exceed the leading commercial varieties in grain yield to warrant its use in commercial plantings.

The mean grain yield of the F_2 was lower than that of the parental varieties in early maturing japonica and indica crosses, but differences were not statistically significant(Table 5). For late maturing japonica crosses, the F_2 yielded siginificantly higher than the parental varieties in both crops of 1971. In general, yield performance of the F_2 was lower than that of the F_1, differences being statistically significant except for the early maturing

Table 6. Grain yields and percentage decrease in heterosis of F_2 generation for early maturing japonica rice crosses, first crop, 1971.

Cross	Grain yield (g/m^2)	Mean yield as % of			Percentage decrease (%)
		HP	MP	CK	
Taichung 180 x Line 54233	509.0[a]*	88.8	93.4	110.3	−5.8
Taichung 180 x Fukunishiki	487.4[a]	96.4	100.8	105.6	7.9
Taichung 180 x Norrin 22	454.6[a]	98.5	101.3	98.5	−0.9
Taichung 180 x BC 68	535.4[a]	—	—	116.0	13.5
Taichung 180 x Taitung 24	503.4[a]	89.5	93.3	109.1	6.1
Average	498.0	93.3	99.7	107.9	4.8

* Values followed by the same letter are not significantly different at 5% level.

Table 7. Grain yields and percentage derease in heterosis of F_2 generation for indica rice crosses, first crop, 1971.

Cross	Grain yield (g/m^2)	Mean yield as % of			Percentage decrease (%)
		HP	MP	CK	
Taichung native 1 x IR 8	559.6[a]*	91.2	98.8	91.2	11.9
Taichung native 1 x Hsinchu-ai-chueh-chien	613.4[a]	88.3	93.8	100.0	10.4
Hsinchu-ai-chueh-chien x IR 8	578.6[a]	83.3	95.3	94.3	10.1
Kaohsiung shen 2 x Ti-chueh-Wu-chien	577.8[a]	100.8	104.6	94.2	16.1
C 230 x Ti-chueh-wu-chien	571.2[a]	94.5	97.0	93.1	8.6
C 235 x IR 9-60	543.2[a]	90.5	99.5	88.6	8.1
Average	574.0	91.4	98.2	93.6	11.0

* Values followed by the same letter are not significantly different at 5% level.

japonica crosses. The average percentage decrease of heterosis for grain yield from F_1 to F_2 was 4.8, 11.0, and 4.8% for the early maturing japonica, indica, and late maturing japonica crosses, respectively (Tables 6, 7, and 8). Although the heterosis for grain yield in rice generally decreased from F_1 to F_2, considerable variation in the degree of decrease was noted among rice crosses, indicating that certain cross combinations could maintain a higher level of heterosis in the F_2. Since no technique is currently available for producing large quantities of F_1 seed economically, the utilization of heterosis in F_2 instead of F_1 appears promising as an interim solution. The cost of seed production may be considerably reduced as techniques for rapid increase ,increase of F_2 seed is already available (Chang *et al.*, 1971a).

Table 8. Grain yields and percentage decrease in heterosis of F_2 generation for late maturing japonica rice crosses, 1971.

Cross	Grain yield (g/m^2)		Mean yield as % of						Pecentage decrease (%)	
			HP		MP		CK			
	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop	1st crop	2nd crop
C 236 x Tainan 1	635.6[a]*	556.6[a]	100.5	97.3	103.5	103.8	112.6	117.6	8.9	7.5
C 236 x Tainan 4	674.8[a]	542.8[a]	103.2	94.9	108.0	96.6	119.6	114.7	0.6	8.6
C 236 x Tainan 5	658.2[a]	541.0[a]	110.5	94.6	113.5	103.5	116.6	114.3	9.1	7.3
C 236 x Line 54233	688.8[a]	516.6[a]	100.8	90.3	107.7	98.2	122.0	109.2	−5.1	9.2
C 236 x Hsinchu 56	637.8[a]	536.4[a]	102.5	93.7	104.7	99.8	113.0	113.4	2.7	9.3
C 236 x Hsinchu 61	659.2[a]	528.8[a]	106.6	92.4	108.6	99.6	116.8	111.8	−3.3	9.5
C 236 x Nankaiyu 70	651.2[a]	522.8[a]	107.3	91.4	108.3	96.9	115.4	110.5	−1.4	8.3
Tainan 5 x Tainan 4	600.0[a]	529.0[a]	91.8	95.9	98.5	103.2	106.3	111.8	4.6	7.4
Tainan 5 x Taitungyu 203	611.2[a]	510.0[a]	98.8	100.0	103.3	103.7	108.3	107.8	4.0	9.9
Chianung 242 x Tainan 1	630.0[a]	478.8[a]	103.3	95.8	105.3	97.9	120.5	101.2	−7.6	3.6
Average	649.0	526.2	102.5	94.6	106.1	100.3	115.1	111.2	1.5	8.1

* Values followed by the same letter are not significantly different at 5% level.

Grain Yield of F_3 Generation

The F_3 yield of 10 late maturing japonica crosses evaluated in the second crop of 1971 are shown in Table 9. It was observed that grain yield of F_3 differed significantly among crosses. The F_3 generally produced less grain than the higher parent but 9 out of 10 F_3 crosses outyielded check variety, Tainan 5. The mean grain yield of F_3 was higher than the parental varieties but lower than the F_1 and F_2 (Table 5). The differences in grain yield among generations were all statistically significant. The mean F_3 yield of the 10 crosses was 93.4, 99.0, and 109.8 % of the higher parent, mid-parent, and check variety, respectively. The average percentage of decrease in heterosis for grain yield from F_1 to F_3 was 9.3% which was nearly twice the magnitude of the decrease from F_1 to F_2. It was of interest to note that average F_3 yield was 10% higher than the check variety. The highest F_3 yield was 17.8% greater than the check variety for the C 236 x Tainan 5 cross. This amount of heterosis may be sufficient to encourage the utilization of heterosis in F_3 generation. The utilization of hybrid vigor in the F_2 or F_3 generation of particularly productive crosses in small grain crops has also been suggested by Anderson (1919) and Griffee (1921). Crosses with greater amount of heterosis are likely to be detected when more cross combinations have been sampled.

Table 9. Grain yields and percentage decrease in heterosis of F_3 generation for late maturing japonica rice crosses, second crop, 1971.

Cross	Grain yield (g/m^2)	Mean yield as% of			Percentage decrease (%)
		HP	MP	CK	
C 236 x Tainan 1	526.6^{abc}*	92.0	98.2	111.3	12.5
C 236 x Tainan 4	557.4^{a}	97.4	99.2	117.8	6.1
C 236 x Tainan 5	536.2^{ab}	93.7	102.6	113.3	8.1
C 236 x Line 54233	468.6^{c}	81.9	89.1	99.0	17.6
C 236 x Hsinchu 56	542.2^{ab}	94.8	100.9	114.6	8.3
C 236 x Hsinchu 61	528.8^{abc}	92.4	99.6	111.8	9.5
C 236 x Nankaiyu 70	515.6^{abc}	90.1	95.6	109.0	9.6
Tainan 5 x Tainan 4	535.2^{ab}	97.0	104.4	113.1	6.3
Tainan 5 x Taitungyu 205	482.2^{c}	94.6	98.1	101.9	14.7
Chianung 242 x Tain 1	501.2^{bc}	100.2	102.5	105.9	−0.9
Average	519.4	93.4	99.0	109.8	9.3

* Values followed by the same letter are not significantly different at 5% level.

Major Traits in F_1 F_2 and F_3 Generations

The average heterosis for days to heading, plant height, and panicles per hill for early maturing japonica, indica, and late maturing japonica crosses is given in Table 10. Days to heading of F_1 was generally shorter than early maturing parent, mid-parent and check variety except for the indica crosses. However, the heterosis for days to heading expressed by an earlier heading disappeared gradually with the advancement of generations. The F_1 showed heterosis for plant height in relation to taller parent, mid-parent and check variety, with the exception of early maturing japonica crosses. Heterosis for plant height in F_2 and F_3 generations was comparable to that of F_1. The F_1 showed no heterosis for panicles per hill in relation to higher parent but produced more panicles per hill than midparent and check variety. There was no heterosis for panicles per hill in F_2 and F_3 generations with the exception of late maturing japonica crosses which showed considerable heterosis in relation to check variety. Since heterosis for grain yield was only expressed based on check variety in F_2 and F_3 crosses of the late maturing crosses, it appears probable that the number of panicles per hill is an important factor contributing to heterosis for grain yield. For early maturing japonica crosses which showed no heterosis for panicles per hill, factors other than this component may be operative in the expression of heterosis for grain yield.

Table 10. Heterosis for major agronomic traits.

Mean performance as % of	Traits	Early maturing japonica		Indica		Late maturing japonica		
		F_1	F_2	F_1	F_2	F_2	F_2	F_3
HP	Days to heading	98.4	101.0	103.3	104.2	98.9	100.9	101.3
	Plnat height	97.5	100.3	100.6	100.8	100.6	100.2	98.4
	panicles per hill	99.7	87.6	99.1	93.1	96.3	91.4	89.2
MP	Days to headng	96.4	99.9	98.7	100.8	97.3	99.2	99.3
	Plant height	98.0	97.5	100.2	97.2	100.9	98.7	100.6
	panicles per hill	98.8	93.4	106.1	98.9	100.5	99.5	97.5
CK	Days to heading	97.1	100.4	102.7	105.0	95.3	95.1	94.7
	Plant height	99.7	100.5	104.3	103.2	97.8	96.1	97.3
	panicles per hill	96.4	91.3	105.1	98.2	115.5	110.2	110.0

SUMMARY

The performance of grain yield, days to heading, plant height, and number of panicles per hill was evaluated in the F_1, F_2 and F_3 generations of early maturing japonica, indica, and late maturing japonica crosses at the Chiayi Agricultural Experiment Station over the 3-crop period from the second crop of 1970 to the second crop of 1971. The mean F_1 yield of all 21 crosses was 6.7, 12.9, and 19.2% greater than the higher parent, mid-parent and check variety, respectively. The F_2 yield, relative to the higher parent, mid-parent, and check variety was 95.6, 101.4, and 111.9%, respectively. The average percentage of decrease of heterosis for grain yield from F_1 to F_2 was 6.4%. The mean F_3 yield of 10 late maturing japonica crosses was 93.4, 99.0 and 109.8% of the higher parent, mid-parent, and check variety, respectively. The average percentage of decrease of heterosis for grain yield from F_1 to F_3 was 9.3%.

F_1 generally headed earlier than parental varieties but this earliness disappeared gradually with the advancement of generations. The heterosis for plant height varied slightly with generations. The F_1 showed no heterosis for number of panicles per hill in relation to higher parent but produced more panicles per hill than mid-parent and check variety. There was no heterosis for panicles per hill in F_2 and F_3 generations.

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水稻第一、二、三代雜交後裔若干農藝性狀之雜種優勢

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摘　要

嘉義農業試驗分所自民國59年第一期作至 60年第二期作觀察水稻 F_1 F_2 與F_3組合在若干農藝性狀之表現。F_1 21 個組合平均稻谷產量對高產量親本、中間親本及對照親本所示之雜種優勢，分別爲6.7，12.9 與 19.2%。F_2 產量分別爲高產量親本、中間親本及對照品種之95.6，101.4與111.9%，雜種優勢平均遞減率爲6.4%。F_3產量分別爲高產量親本、中間親本及對照親本之93.4，99.0與109.8%，其雜種優勢之平均遞減率爲9.3%。

F_1之生育日數多較早熟親本爲短，惟其早熟性隨世代之推進而消失。株高之雜種優勢 F_1、F_2 與 F_3 各世代相若。就每株穗數而言，F_1 只對中間親本與對照品種顯示雜種優勢，而F_2 與 F_3 則無任何雜種優勢之表現。