Chapter 4

Combining Ability of Inbred Lines and Heterosis of F1 Hybrids

4.1 Introduction

The world will need at least 40% more rice than what is produced today to feed the extra billions who will rely on it within the next three decades. Because rice has remained as staple feed for half of the world population, Asia produces and consumes 90% of the world's rice (Rothschild, 1998). Increasing the yield potential of rice varieties in terms of new plant type and hybrid rice is considered an important strategy for meeting this challenge.

Heterosis or hybrid vigor in rice generally refers to the superiority of F1 hybrid over its parents in growth vigor, vitality, reproductive capacity, stress resistance, adaptability, grain yield and other characteristics.

The combining ability is used to designate the average performance of a line in hybrid combination, which is called general combining ability. In terms of specific combining ability, it is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the line involved (Griffing, 1956).

The combining ability of lines and heterosis of F1 hybrids can be used as in testing procedure in which it is desired to study and compare the performances of lines in hybrid combination. The objective of this chapter was to verify these important characters to fulfill goal of developing good hybrid rice variety.

4.2 Materials and Methods

Parental lines used for evaluating combining ability and heterosis of F1 hybrid crosses comprised of two groups of rice varieties:

1. Four cytoplasmic male sterile lines (CMS-line) or A-line included:

(1) RD21A-23	(2) IR58025A
(3) IR62829A	(4) V20A

2. Sixteen restorer lines or R-line included:

(1) RD 1	(2) RD 7
(3) RD 11	(4) RD 23
(5) Chainat 1(CNT 1)	(6) Pathumthani 1(PTT1)
(7) Supanburi 90(SPR90)	(8) Supanburi 1(SPR1)
(9) SPR85163-5-1-2-3	(10) SPR87032-3-1-1-2-1
(11) IR68926-61-2R	(12) IR63870-3-2-3-3R
(13) IR58110-144-2-2-2R	(14) IR65620-96-2-3-3-1R
(15) IR62161-1843-1-3-2R	(16) IR46R

These 16 R-lines had been evaluated and classified as promising R-lines in Chapter 3. All of these R-lines were used as male parents for further developing of good hybrid varieties.

Production of F1 hybrid seeds: Both A-lines and R-lines were planted in large ceramic pots under glass house condition. At flowering stage, each single cross between A-line and R-line was made by hands. About 500 seeds of F1's were produced which were sufficient for planting of combining ability and heterosis evaluation for two successive growing seasons under field conditions. Amount of F1 single cross was developed from crossing among 4 A-lines and 16 R-lines, equal to 64 crosses.

F1 hybrid seeds were produced in glass house of Pathumthani Rice Research Center during dry season and wet season 2003.

Field experiment

Seedling preparation: Seeds of F1 hybrids, parents and check varieties were separately germinated and sown on 0.5 x 0.5 m seed bed. In order to obtain vigorous and healthy seedlings, 5 kg/rai of urea fertilizer (46% N) was applied to the plots around 15 days after sowing. Water level was maintained about 3 cm high for weed control and avoiding of drought. Leaf diseases and insect pests were controlled as needed. Seedlings were ready to transplant after 25 days of sowing.

Experimental design and cultural practice: Seedlings of each F1 hybrid cross were transplanted along with their respective parents in a six-row plot of 5.0 m long with spacing of 20 x 20 cm within and between rows and transplanting one seedling per hill. The parents and F1's plots were laid out in the field in randomized block design with three replications. Plots were incorporated with 18-6-6 kg/rai of N-P_2O_5-K_2O fertilizer just one day before transplanting as basal application. In order to optimize crop growth and development, nitrogen fertilizer was applied twice, 15 days and 50 days after transplanting, using 15 kg/rai and 20 kg/rai of urea (46% N), respectively. Weed control during the planting period was made regularly by hands. Baylucide was applied for controlling and killing of apple snail which was one of the major problems of rice damage during the seedling stage. Leaf diseases and insect pests were controlled as needed. Water level was maintained 5-10 cm high during the growing period to avoid crops from drought. Water was drained out from plots during maturing stage in order to regulate uniform grain maturity.

Measurements: At harvesting time, observations were recorded on five competitive hills, chosen randomly in each plot and each replication, to collect data for plant height, number of panicle per hill, number of grain per panicle, number of filled grain and 1,000 grain weight. Grain yield of each plot was obtained from harvesting of four middle rows. The harvested plot size was 0.8 x 4.0 m. Panicles of each sample were dried for 2-3 days and grains were threshed with small windnowing machine. Grains were cleaned and dried again for 1-2 days in order to reduce grain moisture. Weight of grain yield of each sample was adjusted to 14.0% moisture standard basis.

Data analysis: All recorded parameters were analysed according to Virmani *et al.* (1977) as following procedures:

1. Analysis of variance:

$$\text{Correction Factor (CF)} = \frac{(\text{Grand Total})^2}{\text{Total No.of Observations}}$$

$$\text{Total S.S. (T.SS)} = \Sigma Yij^2 - CF$$

$$\text{Replication S.S. (R.SS)} = \frac{\Sigma Y.j^2}{t} - CF$$

$$\text{Treatment S.S. (TR.SS)} = \frac{\Sigma Yi^2}{r} - CF$$

$$\text{Error S.S. (Er. SS)} = \text{TSS} - \text{Tr.S.S.} - \text{R.SS}$$

Line x tester analysis:

SS due to lines = $\frac{\Sigma Yi^2..}{r \times t}$ - CF (crosses)

r = replications t = testers

SS due to tester = $\frac{\Sigma Y.j.^2}{l \times r}$ - CF (crosses)

SS due to lines x testers = SS (crosses) – SS (lines) – SS (testers)

2. Estimation of combining ability:

2.1 General combining ability (GCA) effects:

i) GCA effects of lines

$$gi = \frac{Yi..}{tr} - \frac{Y..}{ltr}$$

Where : Yi.. – Total of ith line over testers

Y.. – Grand total

l, t, r – Number of lines, testers and replications, respectively

Work out GCA effects for g_1 to g_{21}.

Check Σg_i = 0

ii) GCA effects of testers

$$gj = \frac{\Sigma Y.j.}{lr} - \frac{Y..}{ltr}$$

Where: Y.j. = Total of jth tester over lines

Y.. = Grand total

l, t, r = Number of lines, testers and replications, respectively

Work out GCA effects for g_1 to g_4.

Check Σg_i = 0

2.2 Specific combining ability (SCA) effects:

$$sij = \frac{Yij.}{r} - \frac{Yi..}{rt} - \frac{Y.j.}{rl} + \frac{Y..}{ltr}$$

Where: Yij. - Value of jth line with ith tester

Yi.. - Total of ith line over all testers

Y.j. - Total of jth tester over all lines

Y.. - Grand total

l, t, r - Number of lines, testers, and replications, respectively

Work out SCA effects for all hybrids

Check $\Sigma_i \ \Sigma_j \ S_{ij} = 0$

Testing the significance of combining ability effects:

S.E. (gca for lines) = $\left[\frac{Me}{rt}\right]^{1/2}$

S.E. (gca for tester) = $\left[\frac{Me}{rl}\right]^{1/2}$

S.E. (sca effects) = $\left[\frac{Me}{r}\right]^{1/2}$

S.E. (gi – gj) line = $\left[\frac{2Me}{rt}\right]^{1/2}$

S.E. (gi - gj) testers = $\left[\frac{2Me}{rl}\right]^{1/2}$

S.E. (Sij - Skl) = $\left[\frac{2Me}{r}\right]^{1/2}$

Me is the error mean sum of squares.

3. Estimation of heterosis:

Heterosis (H) and heterobeltiosis (Hb) of particular character were calculated as percent increase and decrease over mid-parents and better parent values following a standard procedure:

(a) Heterosis (H) = $\frac{F1-MP}{MP}\times 100$

(b) Heterobeltiosis (Hb) = $\frac{F1 - BP}{BP} \times 100$

Where: BP = Better parent value

MP = Mid parent value

Significances of H and Hb were determined by T-test procedure described by Chen *et al.* (2003).

Location and experiment period: The experiments were carried out for two successive growing seasons. Dry season was conducted during January to June 2003 and rainy season was conducted during July to December 2003. The experiments were conducted at the rice experimental field, Pathumthani Rice Research Center.

4.3 Results

4.3.1 Estimation of combining ability

Dry season

Analysis of variance: The experimental results revealed that the variety, parents, hybrid, tester line and interaction of line x tester differed significantly for each of the parameters measured. For line entry, significant difference was found for all parameters except number of grain/panicle. The interaction of parents x hybrid and check x parent x hybrid showed significant difference for grain yield, panicle/hill and filled grain, respectively (Table 4.1).

General combining ability (g.c.a.): The estimates for g.c.a. effects of A-line and R-line for measured parameters are shown in Table 4.2. It indicated that A-line and R-line parents exhibited positive g.c.a. for grain yield, which were RD21A-23, IR62829A, RD7, RD11 and IR58110-144-2-2-2R, suggesting that these tested varieties/lines would perform as good general combiners in hybrid crosses for increasing grain yield. Only one A-line, V20A showed significant negative g.c.a. effect for grain yield, implying that this A-line variety would perform as a poor general combiner and tend to give low yield in hybrid crosses.

For other agronomic characters, all A-line showed positive g.c.a. effect for plant height. R-line showing positive g.c.a. effect were RD1, RD7, RD23, SPR1, SPR90 and negative effects were RD11, SPR85163-5-1-2-3 and so on.

A-line and R-line parents showing positive g.c.a. effects for panicle/hill were IR2829A, IR68926-61-2R, IR58110-144-2-2-2R, IR62161-1843-1-3-2R and IR46R.

For number of grain per panicle, A-line and R-line parents that showed positive g.c.a. effects were RD21A-23, IR580110-2-2-2R, V20A, RD1, RD7, SPR1, SPR90 and SPR87032-3-1-1-2-1.

Both positive and negative g.c.a. effects were found for filled grain among the A-line and R-line parents. For positive effects, they included RD21A-23, RD1, RD7, RD11, CNT1, SPR1, IR58110-144-2-2-2R and for negative g.c.a. effects, they were V20A, SPR90, SPR90, SPR85163-5-1-2-3, SPR87032-3-1-1-2-1 and IR65620-96-2-3-3-1R.

For 1000-grain weight, both positive and negative g.c.a. effects were also found among the A-line and R-line parents. A-line and R-line which showed positive g.c.a. effect were RD21A-23, V20A, RD1, RD7, RD11, RD23, CNT1, IR68296-61-2R and IR58110-144-2-2-2R. Only R-line, IR63870-3-2-3-3R, showed nonsignificant g.c.a. effect. All the remaining A-line and R-line parents gave significant negative effects.

Specific combining ability (s.c.a.): Estimation of specific combining ability (s.c.a.) among the F1 hybrid crosses in dry growing season indicated that non significant difference for s.c.a. effect were not found for grain yield among the hybrid crosses (Table 4.3-4.8).

Hybrid V20A/RD2 and IR62829A/IR46R showed positive s. c. a, while hybrid V20A/CNT1 and RD21A-23/IR46R showed negative s.c.a. for plant height (Table 4.4).

Only two hybrids, RD21A-23/PTT1 and V20A/PTT1 gave positive s.c.a. effect for panicle/hill (Table 4.5). For number of grain yield per panicle, both significant positive and negative s.c.a. effects were found among hybrid crosses. Hybrids which showed positive s.c.a. effects were RD21A-23/RD11, RD21A-23/RD23, RD21A-23/PTT1 and so on. Hybrids showing negative s.c.a. effects for number of grain were IR58025A/RD27 and IR58025A/SPR90 and so on (Table 4.6). Only one hybrid cross IR58025A/PTT1 showed positive s.c.a. and one hybrid, IR62829A/PTT1 showed negative s.c.a. effects for filled grain (Table 4.7).

Most of hybrid crosses showed significant positive and negative s.c.a. effects for 1000-grain weight. Hybrids showing positive s.c.a. effects included RD21A-23/RD7, RD21A-23/IR68926-61-2R and so on. Hybrids exhibiting negative s.c.a. effects were RD21A-23/RD11, RD21A-23/RD23, RD21A-23/CNT1 and so on (Table 4.8).

Table 4.1 Analysis of variance of grain yield and yield components of F1 hybrid grown at Pathumthani Rice Research Center in dry season 2003.

Source of variation	df	Mean square: Grain yield (kg/rai)	Plant height (cm.)	Panicle/hill	No. of grain/ panicle	Filled grain (%)	1000- grain weight (gm)
Replication	2	28633**	10.9ns	49.4**	642.9*	60.5ns	0.1ns
Varieties	84	60000**	575.8**	49.4**	1934.4**	154.0**	16.9**
Parent(P)	19	43903**	560.6**	48.0**	2183.0**	53.5**	24.0**
Hybrid (H)	63	65784**	518.4**	51.0**	1884.0**	159.0**	15.1**
Parent x Hybrid	1	2001ns	2223.7**	39.0**	890.0*	1907.3**	7.3**
CK x P x H	1	59410**	2838.6**	8.0ns	1424.0**	0.0ns	5.5**
Line	15	61,929**	566.3**	44.5*	182.8ns	325.9**	14.3*
Tester	3	738,935**	5346.4**	494.3**	12700.3**	385.5**	214.5**
Line x Tester	45	22,192**	180.5**	23.3**	1163.4**	88.3**	2.1**
Error	168	5478	22.2	8.9	175.3	20.9	0.2
C.V. (%)		10.7	4.7	14.4	9.2	6.1	1.7

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.2 Estimate of GCA effects of 4 CMS-testers and 16 R-lines were for grain yield and yield components evaluated at Pathumthani Rice Research Center in dry season 2003.

Variety/line	Grain yield (kg/rai)	Plant height (cm)	Panicle/hill	No. of grain/ panicle	Filled grain (%)	1000- grain weight (gm)
Testers (A-Line)						
RD21A-23	106.8**	15.75**	-1.9ns	14.7**	4.1**	0.33**
IR58025A	1.6 ns	-3.99**	1.9ns	1.0**	-0.1ns	-0.66**
IR62829A	66.1**	-5.30**	3.5**	7.2**	-1.8ns	-2.32**
V20A	-174.4**	-6.46**	-3.5**	-22.9**	-2.1*	2.69**
S.E.(gi) testers	15.09	0.2313	0.9375	0.2178	0.2177	0.0023
R-Lines						
RD1	25.5 ns	3.14**	-2.7*	11.3**	5.3**	1.0**
RD7	103.83**	11.06**	0.5ns	17.8**	3.8**	1.4**
RD11	82.34*	-3.14**	-3.0*	-0.2ns	4.8**	2.2**
RD23	-33.08 ns	10.10**	-1.3**	-1.9*	0.6ns	0.6**
CNT1	61.84 ns	5.52**	-2.9**	1.1ns	3.8**	1.4**

Table 4.2 Continue

Variety/Line	Grain yield (kg/rai)	Plant height (cm)	Panicle/hill	No. of grain/ panicle	Filled grain (%)	1,000- grain weight (gm)
R-Lines						
SPR90	-37.66 ns	7.55**	-1.00*	14.88**	-3.34**	-0.05**
SPR1	40.84 ns	6.73**	-1.11*	7.59**	2.90**	0.60**
SPR85163-5-1-2-3	-51.59 ns	-5.03**	0.32ns	-24.31**	-10.62**	-0.42**
SPR87032-3- 59 -1	-62.24 ns	0.92ns	-0.98*	19.02**	-2.09*	-0.87**
IR68926-61-2R	47.92 ns	0.27ns	1.58**	-18.46**	2.56*	0.06**
IR63870-3-2-3-3R	33.17 ns	-6.14**	0.57ns	1.71ns	5.67ns	0.01ns
IR58110-144-2-2-2R	86.01*	-1.11ns	1.79**	1.04ns	3.56**	0.02*
IR65620-96-2-3-3-1R	-65.83 ns	-11.75**	2.90**	-4.48**	-5.39**	-1.44**
IR62161-1843-1-3-2R	-40.99 ns	-8.03**	1.38**	-15.36**	-0.25ns	-1.97**
IR46R	-25.08 ns	-7.45**	1.16**	-1.38ns	-1.57ns	-1.52**
S.E.(gj) lines	30.1800	0.9250	0.3750	0.8708	0.8708	0.0092

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.3 Estimate of SCA effect of crosses combination for grain yield (kg/rai) among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	50.41ns	-10.08ns	-81.23ns	40.91ns
RD7	-16.59ns	-88.42ns	97.43ns	7.58ns
RD11	17.58ns	2.74ns	-57.73ns	37.41ns
RD23	17.58ns	157.83ns	76.68ns	-118.17ns
CNT1	-25.59ns	1.58ns	119.1ns	-95.09ns
PTT1	67.24ns	78.08ns	-230.4ns	85.08ns
SPR90	51.91ns	-45.59ns	72.27ns	-78.59ns
SPR1	-89.59ns	68.91ns	51.43ns	-30.76ns
SPR85163--5-1-2-3	-115.84ns	23.66ns	27.85ns	64.33ns
SPR87032-3-1-1-2-1	48.49ns	-154.34ns	79.52ns	26.33ns
IR68926-61-2R	76.66ns	-74.17ns	-6.32ns	3.83ns
IR63870-3-2-3-3R	98.08ns	55.74ns	-100.9ns	-52.75ns
IR58110-144-2-2-2R	-9.08ns	-72.25ns	-23.73ns	105.08ns
IR65620-96-2-3-3-1R	14.74ns	-25.42ns	-17.23ns	27.91ns
IR62161-1843-1-3-2R	-19.42ns	10.08ns	-33.73ns	43.08ns
IR46R	-32.67ns	71.83ns	27.01ns	-66.17ns
	S.E. for SCA = 60.36			

Table 4.4 Estimate of SCA effect of crosses combination for plant height among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	7.48ns	-1.78ns	-7.30ns	1.59ns
RD7	6.05ns	-5.20ns	-1.73ns	0.88ns
RD11	11.58ns	-11.61ns	-6.24ns	6.26ns
RD23	-6.76ns	-8.90ns	0.64ns	15.02*
CNT1	1.59ns	8.95ns	10.54ns	-21.07*
PTT1	4.22ns	0.97ns	-9.14ns	3.95ns
SPR90	0.73ns	-8.53ns	5.62ns	2.18ns
SPR1	0.219ns	0.70ns	0.12ns	-1.03ns
SPR85163--5-1-2-3	-11.08ns	11.17ns	2.75ns	-2.85ns
SPR87032-3-1-1-2-1	0.52ns	-10.78ns	4.30ns	5.96ns
IR68926-61-2R	3.51ns	1.65ns	-4.11ns	-1.05ns
IR63870-3-2-3-3R	4.37ns	6.46ns	-2.03ns	-8.79ns
IR58110-144-2-2-2R	1.68ns	3.31ns	-4.38ns	-0.61ns
IR65620-96-2-3-3-1R	-2.35ns	2.95ns	-0.47ns	-0.13ns
IR62161-1843-1-3-2R	-5.74ns	7.34ns	-0.41ns	-1.19ns
IR46R	-16.02*	3.31ns	11.89*	0.87ns
S.E. for SCA effects = 3.7000				

* Significant at p<0.05

Table 4.5 Estimate of Estimate of SCA effect of crosses combination for number of panicle/ hill among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	-0.69ns	2.17ns	-2.78ns	1.30ns
RD7	1.80ns	2.00ns	-3.58ns	-0.22ns
RD11	0.70ns	-0.75ns	0.01ns	0.90ns
RD23	1.96ns	1.38ns	0.76ns	-4.10ns
CNT1	0.22ns	0.88ns	1.41ns	-2.51ns
PTT1	5.17*	-4.29ns	-6.48*	5.60*
SPR90	1.37ns	0.06ns	-0.23ns	-1.20ns
SPR1	1.20ns	0.95ns	-1.51ns	-0.64ns
SPR85163--5-1-2-3	-6.01*	0.41ns	3.34ns	2.26ns
SPR87032-3-1-1-2-1	-1.72ns	3.59ns	-1.25ns	-0.62ns
IR68926-61-2R	-0.67ns	-0.63ns	1.91ns	-0.62ns
IR63870-3-2-3-3R	-2.43ns	-1.17ns	4.04ns	-0.44ns
IR58110-144-2-2-2R	-1.31ns	-1.78ns	4.70ns	-1.60ns
IR65620-96-2-3-3-1R	0.52ns	-0.62ns	1.98ns	-1.88ns
IR62161-1843-1-3-2R	0.70ns	-0.98ns	-1.95ns	2.24ns
IR46R	0.75ns	-1.21ns	-0.39ns	2.36ns
S.E. for SCA effects = 1.500				

* Significant at p<0.05

Table 4.6 Estimate of SCA effect of crosses combination for number of grain / panicle among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	6.02ns	-1.59ns	-5.58ns	1.15ns
RD7	3.03ns	-19.20*	-4.22ns	20.39**
RD11	15.13*	-6.15ns	-26.59**	17.61*
RD23	14.78*	13.84*	22.41**	-51.03**
CNT1	5.35ns	18.01*	21.37**	-44.74**
PTT1	12.71*	18.89*	-33.04**	1.35ns
SPR90	-18.97*	-23.63**	29.44**	13.16*
SPR1	-4.14ns	-17.03*	10.00ns	11.17*
SPR85163--5-1-2-3	-24.94**	12.72*	12.53*	-0.31ns
SPR87032-3-1-1-2-1	-3.44ns	-21.83**	-10.75ns	36.03**
IR68926-61-2R	-7.18ns	0.93ns	-5.6ns	11.84*
IR63870-3-2-3-3R	-6.13ns	6.70ns	-9.90ns	9.33ns
IR58110-144-2-2-2R	2.87ns	3.93ns	-13.82*	7.01ns
IR65620-96-2-3-3-1R	3.45ns	6.89ns	1.18ns	-11.47*
IR62161-1843-1-3-2R	-2.33ns	16.50*	-7.25ns	-6.92ns
IR46R	3.79ns	-9.09ns	19.87*	-14.57*
S.E. for SCA effects = 3.182				

*, ** Significant at p<0.05 and p<0.01, respective.

Table 4.7 Estimate of SCA effect of crosses combination for %filled grain/panicle among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	0.10ns	-1.81ns	-0.75ns	2.46ns
RD7	-2.86ns	3.05ns	-0.30ns	0.11ns
RD11	2.58ns	-2.58ns	-3.57ns	3.57ns
RD23	-1.50ns	1.95ns	1.53ns	-1.98ns
CNT1	-1.67ns	-1.72ns	6.73ns	-3.34ns
PTT1	6.43ns	14.80*	-19.85*	-1.38ns
SPR90	7.59ns	-4.91ns	1.17ns	-3.85ns
SPR1	-3.88ns	3.17ns	-1.08ns	1.79ns
SPR85163--5-1-2-3	-4.02ns	5.42ns	3.47ns	-4.87ns
SPR87032-3-1-1-2-1	2.67ns	-1.55ns	2.75ns	-3.87ns
IR68926-61-2R	1.89ns	-7.21ns	1.22	4.10ns
IR63870-3-2-3-3R	-0.39ns	-1.08ns	1.95	-0.47ns
IR58110-144-2-2-2R	1.80ns	-3.13ns	-5.58	6.91ns
IR65620-96-2-3-3-1R	-3.95ns	0.75ns	3.44	-0.24ns
IR62161-1843-1-3-2R	-0.74ns	-3.09ns	5.77	-1.94ns
IR46R	-4.04ns	-2.05ns	3.10	2.99ns
S.E. for SCA effects = 3.4833				

* Significant at $p<0.05$.

Table 4.8 Estimate of SCA effect of crosses combination for 1,000 - grain weight among F1 hybrid of rice grown at Pathumthani Rice Research Center in dry season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	0.11ns	0.33**	-0.01ns	-0.40**
RD7	0.44**	0.55**	-0.50**	-0.49**
RD11	-0.39**	-0.28**	-1.19**	1.86**
RD23	-0.75**	0.69**	0.03ns	0.03ns
CNT1	-0.48**	0.73**	0.18**	-0.44**
PTT1	0.84**	-0.52**	-0.06ns	-0.26ns
SPR90	-0.49**	-0.80**	1.31**	-0.03ns
SPR1	0.00ns	0.87**	-1.13**	0.27**
SPR85163--5-1-2-3	-1.19**	-0.72**	1.88**	0.02ns
SPR87032-3-1-1-2-1	-0.37**	-0.14*	-0.32**	0.84**
IR68926-61-2R	0.62**	-1.55**	0.18**	0.76**
IR63870-3-2-3-3R	0.92**	0.21*	-0.60**	-0.53**
IR58110-144-2-2-2R	1.17**	-0.06ns	-0.03ns	-1.07**
IR65620-96-2-3-3-1R	-0.50**	0.37**	-0.24**	0.38**
IR62161-1843-1-3-2R	0.40**	0.20*	-0.48**	-0.12*
IR46R	-0.35ns	0.16*	0.98**	-0.80ns
S.E. for SCA effects = 0.3667				

*, ** Significant at p<0.05 and p<0.01, respectively.

Rainy season

Analysis of variance: The experimental results revealed that parents, hybrid, line, tester, line x tester and parent x crosses differed significantly for each of the parameters measured. Interaction of check x parent x hybrid showed significant difference for all parameters measured except number of panicle per hill and 1000-grain weight (Table 4.9).

Estimation of general combining ability (g.c.a.): The estimates for general combining ability (g.c.a.) effects of A-line and R-line parents for all measured traits are presented in Table 4.10.

It indicated that significant positive effects of g.c.a. were not found for grain yield among A-line or R-line parents exept A-line V20A which showed negative g.c.a. effect for this trait.

Both significant positive and negative g.c.a. effects were obtained from A-line and R-line parents for plant height. A-line and R-line showing positive g.c.a. effects were RD21A-23, RD7, RD11, RD23, SPR31 and IR46R. Some parents showing negative g.c.a. effects were IR62829A, V20A, PTT1 and so on.

Most of parental lines showed significant negative g.c.a. effect for panicle per hill. There were only four parents including IR58025A, PTT1, SPR85163-5-1-2-3 and SPR 87032-3-1-1-2-1 which gave positive g.c.a. for this trait.

Nonsignificant g.c.a. effects were found among A-line and R-line parents, only two parents showed positive g.c.a. effects which were RD21A-23 and RD11.

It is interesting to point out that most of parental lines, both A-line and R-line, showed high to highly positive g.c.a. effects for filled grain. These lines included

RD21A-23, IR58025A, RD7, RD11 and so on. There were few of parental lines that showed negative or nonsignificant g.c.a. effect for this filled grain trait.

For 1000-grain weight, both significant positive and negative g.c.a. effect were also found for this trait among A-line and R-line parents. Parents exhibited positive g.c.a. effect were RD21A-23, V20A, RD1, RD7, RD11 and so on.

Specific combining ability: Estimation of specific combining ability (s.c.a.) among hybrid crosses in rain growing season indicated that significant s.c.a. effects were not found for grain yield among the hybrids (Table 4.11). For plant height, positive s.c.a. effects were found in hybrid IR62829A/SPR85163-5-1-2-3 and IR62829A/SPR87032-2-1-1-2-1 while negative s.c.a. effects were found in hybrid IR58025A/SPR87032-2-1-1-2-1 and V20A/CNT1 (Table 4.12).

Both positive and negative significant s.c.a. effects were identified for number of panicle per hill. Hybrids giving positive s.c.a. effects included RD21A-23/RD7, RD21A-23/CNT1, RD21A-23/IR63870-3-2-3-3R and so on. For negative s.c.a. effects, hybrids RD21A-23/PTT1, RD21A-23/SPR85163-5-1-2-3 and so on were found for this trait (Table 4.13). It is interesting to point out that both positive and negative s.c.a. effects were not identified among the hybrids for number of grain/panicle (Table 4.14).

Both significant positive and negative s.c.a. effects were found for 1000-grain weight among the hybrids. Hybrids exhibiting positive s.c.a. effects included RD21A-23/RD23, IR58025A/RD1, IR58025A/RD11 and so on (Table 4.15).

There was only one hybrid, V20A/IR58110-144-2-2-2R, that showed positive s.c.a. effect for filled grain. All the remaining hybrids showed nonsignificant s.c.a. effects on this trait (Table 4.16).

Table 4.9 Analysis of variance of grain yield and yield components of F1 hybrid grown at Pathumthani Rice Research Center in rainy season 2003.

Source of Variation	df	Grain yield (kg/rai)	Plant height (cm)	Panicle/hill	No. of grain/ panicle	Filled grain (%)	1,000 grain weight (gm)
Replication	2	11134*	494.3**	2.7ns	1531.0**	1.0ns	.05ns
Varieties	84	43093**	700.1**	24.9**	4100.6**	236.5**	17.9**
Parent(P)	19	37211**	775**	13.5**	4816**	64.6**	22.5**
Hybrid (H)	63	45460**	640.9**	26.7**	3880**	257.3**	16.7**
Parent x Crosses	1	21340*	756.6**	156.4**	2692**	2273.3**	26.5**
CK x P x H	1	27533**	2950.4**	1.7ns	5827**	153.8**	0.0ns
Line	15	41669.9**	913.9**	40.3*	3673*	603.9**	18.2**
Tester	3	464180.5**	6214.8**	106.2**	37248**	889.8**	229.9**
Line x Tester	45	18808.6**	178.4**	16.9**	1723.8**	99.5**	1.9**
Error	168	3512.5	21.4	2.7	250	17.15	0.68
C.V. (%)		8.8	4.3	11.7	9.6	5.2	2.9

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.10 Estimate of GCA effects of 4 CMS-testers and 16 R-lines were evaluate for grain yield and yield component evaluate at Pathumthani Rice Research Center in rainy season 2003.

Variety	Grain yield (kg/rai)	Plant height (cm)	Panicle/hill	No. of grain/panicle	Filled grain (%)	1000- grain weight (gm)
Tester						
RD21A-23	64.72ns	15.84*	-2.02**	31.99**	3.97**	0.58*
IR58025A	17.55ns	-0.05	1.56**	4.38ns	0.92*	-0.62*
IR62829A	61.65ns	-5.36*	0.24ns	-0.51ns	1.23**	-2.59*
V20A	-143.92**	-10.42*	0.23ns	-35.85ns	-6.12**	2.63*
S.E.(gi) testers	3.5888	0.2229	0.2833	2.6042	0.1786	0.0066
R-lines						
RD1	-31.84ns	-1.05ns	-0.24ns	7.93ns	-2.03*	1.10**
RD7	7.35ns	18.11**	-1.84**	19.32ns	3.53**	1.48**
RD11	48.82ns	6.15**	-2.46**	33.39**	9.61**	2.00**
RD23	-18.64ns	10.68**	-1.22**	0.07ns	4.04**	0.59**
CNT1	21.94ns	-0.56ns	-1.98**	2.31ns	-0.54ns	1.00**
PTT1	-127.31ns	-9.46**	3.92**	-20.1ns	-13.85**	-0.19**

Table 4.10 Continue

Variety	Grain yield	Plant height	Panicle / hill	grain / panicle	% filled grain	1000 grain weight
R-Lines						
SPR90	-74.78ns	0.09ns	-0.01ns	14.79ns	10.31**	-0.20**
SPR1	44.32ns	9.69**	-1.15**	-5.74ns	4.47**	1.27**
SPR85163--5-1-2-3	-71.48ns	-12.21**	2.80**	-37.90**	-10.88**	-0.73**
SPR8703[illegible]-1-2-1	-25.63ns	-0.92ns	1.51**	14.25ns	-5.67**	-0.75**
IR68926-61-2R	35.52ns	-0.36ns	-0.66**	-6.26ns	2.87**	0.57**
IR63870-3-2-3-3R	21.41ns	-4.55**	-0.48**	-7.07ns	5.57**	-0.14**
IR58110-144-2-2-2R	107.39ns	-0.33ns	-0.51**	-3.18ns	8.29**	-0.33**
IR65620-96-2-3-3-1R	-3.88ns	-14.79**	2.70**	-15.67ns	-3.33**	-1.74**
IR62161-1843-1-3-2R	-3.87ns	-6.89**	0.23ns	-12.00ns	2.20*	-1.98**
IR46R	70.69ns	6.37**	-0.60**	15.88ns	6.05**	-1.95**
S.E.(gj) lines	8.3600	0.8917	0.1133	10.4167	0.7145	0.0262

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.11 Estimate of SCA effect of cross combination for grain yield (kg/rai) among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	8.88ns	-30.75ns	-35.98ns	57.86ns
RD7	-60.2ns	81.13ns	88.77ns	-109.7ns
RD11	-7.25ns	-67.32ns	-75.16ns	149.74ns
RD23	17.26ns	120.97ns	-4.9ns	-133.34ns
CNT1	-63.36ns	49.24ns	68.37ns	-54.25ns
PTT1	80.59ns	30.44ns	-195.36ns	84.33ns
SPR90	-33.24ns	44.33ns	54.1ns	-65.19ns
SPR1	21.08ns	-18.21ns	49.87ns	-52.74ns
SPR85163--5-1-2-3	-72.82ns	-63.97ns	91.95ns	44.83ns
SPR87032-3-1-1-2-1	-18.53ns	12.52ns	29.68ns	-23.67ns
IR68926-61-2R	59.66ns	-67.9ns	-35.42ns	43.66ns
IR63870-3-2-3-3R	49.12ns	50.14ns	-20.46ns	-78.69ns
IR58110-144-2-2-2R	-25.59ns	-94.14ns	-19.76ns	139.5ns
IR65620-96-2-3-3-1R	104.08ns	-69.23ns	-7.75ns	-27.09ns
IR62161-1843-1-3-2R	-62.55ns	27.58ns	35.41ns	0.43ns
IR46R	2.99ns	-4.8ns	-23.37ns	25.18ns
		S.E. for SCA effects = 13.33		

Table 4.12 Estimate of SCA effect of cross combination for plant height among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	4.51ns	3.40ns	-6.57ns	-1.34ns
RD7	-0.72ns	1.57ns	-2.73ns	1.88ns
RD11	1.80ns	4.36ns	-8.61ns	2.46ns
RD23	-6.84ns	0.50ns	-1.58ns	7.93ns
CNT1	-0.72ns	11.18ns	8.71ns	-19.17*
PTT1	8.24ns	-4.65ns	-6.00ns	2.40ns
SPR90	3.26ns	-12.86ns	5.74ns	3.86ns
SPR1	0.14ns	7.93ns	-7.04ns	-1.03ns
SPR85163--5-1-2-3	-13.79*	-3.90ns	15.57*	1.81ns
SPR87032-3-1-1-2-1	7.97ns	-14.86*	11.69*	-4.81ns
IR68926-61-2R	0.76ns	-1.07ns	-4.93ns	5.25ns
IR63870-3-2-3-3R	4.60ns	0.90ns	-5.74ns	0.24ns
IR58110-144-2-2-2R	-5.94ns	6.12ns	-6.35ns	6.17ns
IR65620-96-2-3-3-1R	2.02ns	-6.64ns	4.56ns	0.07ns
IR62161-1843-1-3-2R	-1.66ns	4.23ns	3.60ns	-6.17ns
IR46R	-3.65ns	3.81ns	-0.61ns	0.45ns
	S.E. for SCA effects = 3.5667			

* Significant at p<0.05.

Table 4.13 Estimate of of SCA effect of cross combination for number of panicle/ hill among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	-1.20ns	1.63*	-0.98ns	3.81**
RD7	3.83**	-0.97ns	-0.76ns	-2.09*
RD11	1.34ns	-2.35*	-0.86ns	0.15ns
RD23	-1.22ns	-0.16ns	1.61*	-0.22ns
CNT1	2.58*	-1.67*	0.21ns	-1.11ns
PTT1	-2.60*	1.98*	1.30ns	-0.69ns
SPR90	-0.83ns	3.08**	-1.83*	-0.43ns
SPR1	0.47ns	-1.12ns	1.37ns	-0.73ns
SPR85163--5-1-2-3	-2.48*	2.11*	-2.07*	2.44*
SPR87032-3-1-1-2-1	-1.69*	5.07**	-2.89**	-0.49ns
IR68926-61-2R	0.26ns	-1.99*	1.83*	-0.10ns
IR63870-3-2-3-3R	2.92**	-1.23ns	-0.41ns	-1.29ns
IR58110-144-2-2-2R	-0.17ns	-2.86**	2.35*	0.69ns
IR65620-96-2-3-3-1R	-1.77*	5.21**	-1.97*	-1.46*
IR62161-1843-1-3-2R	-1.18ns	-2.10*	-0.39ns	3.68**
IR46R	1.76*	-1.38ns	1.78*	-2.16*
	S.E. for SCA effects = 0.4533			

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.14 Estimate of SCA effect of cross combination for number of grain / panicle among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	1.15ns	5.56ns	-12.35ns	5.55ns
RD7	-5.96ns	-2.90ns	7.15ns	1.71ns
RD11	8.81ns	28.03ns	-31.09ns	-5.74ns
RD23	24.84ns	0.85ns	26.23ns	-51.93ns
CNT1	4.33ns	43.05ns	12.11ns	-59.50ns
PTT1	9.17ns	4.35ns	-27.77ns	14.24ns
SPR90	-0.54ns	-39.21ns	33.74ns	6.02ns
SPR1	12.37ns	-4.57ns	-4.46ns	-3.35ns
SPR85163--5-1-2-3	-37.13ns	9.82ns	12.73ns	14.55ns
SPR87032-3-1-1-2-1	5.55ns	-43.33ns	21.28ns	16.50ns
IR68926-61-2R	-10.15ns	16.40ns	-18.32ns	12.08ns
IR63870-3-2-3-3R	26.32ns	-16.90ns	-6.57ns	-2.84ns
IR58110-144-2-2-2R	-3.35ns	5.49ns	-30.52ns	28.38ns
IR65620-96-2-3-3-1R	3.91ns	-8.75ns	1.86ns	2.97ns
IR62161-1843-1-3-2R	-25.36ns	8.20ns	6.36ns	10.81ns
IR46R	-13.96ns	-6.19ns	9.59ns	10.55ns
	S.E. for SCA effects = 41.6667			

Table 4.15 Estimate of SCA effect of cross combination for 1,000 - grain weight among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	-0.03ns	0.40*	0.45*	-0.82**
RD7	0.45*	0.30ns	0.26ns	-1.00**
RD11	-0.90**	0.52*	-1.00**	1.38**
RD23	0.76**	0.49*	0.11ns	-0.36*
CNT1	-0.24ns	0.58*	-0.70**	0.36*
PTT1	1.35ns	-0.80**	-0.18ns	-0.37*
SPR90	-0.10ns	-1.10**	1.49**	-0.29ns
SPR1	0.01ns	0.34*	-0.90**	0.56*
SPR85163--5-1-2-3	-1.23**	-0.98**	2.18**	0.03ns
SPR87032-3-1-1-2-1	-0.05ns	-0.74**	0.50*	0.29ns
IR68926-61-2R	0.81**	-0.54*	-0.59*	0.31ns
IR63870-3-2-3-3R	0.43*	1.14**	-0.84**	-0.73**
IR58110-144-2-2-2R	0.27ns	-0.62**	0.00ns	0.35*
IR65620-96-2-3-3-1R	-0.15ns	0.11ns	-0.49*	0.52*
IR62161-1843-1-3-2R	0.19ns	0.57*	-0.34ns	0.41*
IR46R	-0.57*	0.33ns	0.05ns	0.18ns
	S.E. for SCA effects = 0.1050			

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.16 Estimate of SCA effect of cross combination for %filled grain/panicle among F1 hybrids of rice grown at Pathumthani Rice Research Center in rainy season 2003.

R-Lines	A-lines			
	RD21A-23	IR58025A	IR62829A	V20A
RD1	5.92ns	-1.12ns	-1.41ns	-3.38ns
RD7	-3.11ns	5.48ns	2.27ns	-4.65ns
RD11	-2.40ns	-0.69ns	-5.46ns	8.47ns
RD23	2.24ns	0.77ns	-1.87ns	0.40ns
CNT1	1.57ns	4.14ns	2.22ns	-7.94ns
PTT1	3.39ns	9.51ns	-13.19ns	0.29ns
SPR90	-4.52ns	-4.47ns	6.91ns	2.08ns
SPR1	-3.49ns	-3.80ns	-0.41ns	6.88ns
SPR85163--5-1-2-3	-4.45ns	-0.88ns	9.63ns	-4.27ns
SPR87032-3-1-1-2-1	1.11ns	-7.17ns	8.55ns	-2.49ns
IR68926-61-2R	-1.05ns	3.43ns	-2.08ns	-0.31ns
IR63870-3-2-3-3R	-3.90ns	3.82ns	-0.62ns	0.70ns
IR58110-144-2-2-2R	-0.06ns	-3.10ns	-6.03ns	9.19*
IR65620-96-2-3-3-1R	7.60ns	-9.86ns	6.08ns	-3.82ns
IR62161-1843-1-3-2R	2.14ns	5.69ns	-3.56ns	-4.27ns
IR46R	-0.99ns	-0.21ns	-1.93ns	3.12ns

S.E. for SCA effects = 2.86

4.3.2Estimation of Heterosis

Estimations of heterosis were made for heterotic (H) and heterobeltiotic (Hb) effects for all measured parameters. Estimation was conducted in both dry and rain growing season. Results of heterosis estimation in dry growing season are shown in Table 4.17-4.22.

Dry season

Grain yield: Both significant positive and negative heterotic and heterobeltiotic effects for grain yield were found among hybrid crosses. Hybrids that gave positive heterosis and were ranked on top-five of the crosses were IR62829A/RD7 (64.31%), RD21A-23/RD11 (45.64%), V20A/IR58110-144-2-2-2R (43.97%), RD21A-23/RD7 (42.24%) and V20A/RD11 (41.29%). For heterobeltiosis, hybrids ranked on top-five were IR62829A/RD7 (64.31%), RD21A-23/RD11 (46.87%), RD21A-23/RD7 (42.09%), IR62829A/RD11 (27.90%) and RD21A-23 /RD1 (26.29%) (Table 4.17).

Plant height: Both significant positive and negative heterotic and heterobeltiotic effects for plant height were found among the hybrid crosses. Both positive and negative heterotic effects were important for increasing and reducing of plant height. Hybrids showing positive heterotic effects were V20A/RD23 (23.81%) and RD21A-23/RD7 (11.12%). For heterobeltiosis, hybrid was IR58025A/IR46R (16.30%). Hybrids giving negative heterosis for this trait were V20A/CNT1 (-21.23%)

IR58025A/SPR87032-3-1-1-2-1 (-19.93%) and IR62829A/RD11 (-18.32%)

(Table 4.18).

Panicle per hill: As well, both significant positive and negative heterotic and heterobeltiotic effects for panicle/hill were found among the hybrids. Hybrids showing high heterosis were RD21A/23/PTT1 (32.71%), IR62829A/SPR85163-5-1-2-3 (29.42%) and IR58025A/ SPR87032-3-1-1-2-1 (27.65%). For heterobeltiosis, there was not hybrid showing any significant positive effects (Table 4.19).

Number of grain per panicle: Both significant positive and negative heterotic and heterobeltiotic effects for grain/panicle were obtained among the hybrids. High levels of heterosis were shown in hybrid V20A/RD7 (40.19%), V20A/ SPR87032-3-1-1-2-1 (39.73%) and V20A/ IR58110-144-2-2-2R (36.06%). Hybrids exhibiting high level of positive heterobeltiosis were IR58025A/ IR58110-144-2-2-2R (35.76%), IR58025A/IR62161-1843-1-3-2R (24.30%) and V20A/ IR58110-144-2-2-2R (16.93%) (Table 4.20).

Percent of filled grain: Both significant positive and negative heterotic and heterobeltiotic effects for filled grain were found among the hybrids. There were only two hybrids which gave low positive heterosis; RD21A-23/RD11 (12.50%) and V20A/ IR58110-144-2-2-2R (9.16%). Some of hybrid crosses showed high negative heterotic and heterobeltiotic effects for this trait (Table 4.21).

1000-grain weight: Both significant positive and negative heterotic and heterobeltiotic effects for 1000 grain weight were found among the hybrids. Positive heterosis was found in hybrids IR62829A/SPR85163-5-1-2-3 (13.13%), V20A/RD11 (9.39%) and IR62829A/RD23 (8.15%). For positive heterobeltiosis, hybrids were V20A/IR46R (13.14%) and V20A/RD11 (7.16%) (Table 4.22).

Table 4.17 Heterosis (H) and heterobeltiosis (Hb) for grain yield of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	33.05**	26.29**	4.09	2.36	13.56	1.4 0	18.83	-15.69
RD7	42.24**	42.09**	9.65**	5.88	64.31**	53.85**	37.67**	0.86
RD11	45.64**	46.87**	21.52*	16.28	35.39**	27.90**	41.29**	4.14
RD23	1.20	-1.77	23.01*	22.21*	33.04**	21.29*	-23.00**	-44.60**
CNT1	10.30	-2.78	1.93	-7.19	38.11*	15.13	-12.42	-40.64**
PTT1	-0.35	-15.62	-19.14**	-26.98	-47.27**	-56.36**	-21.93	-47.33**
SPR90	19.54	10.17	-13.29*	-17.31*	23.64	7.41	-21.96	-45.64*
SPR1	5.96	-5.46	10.24	1.64	27.15*	7.19	-2.62	-33.50*
SPR85163-5-1-2-3	-12.64**	-23.30**	-10.81	-19.13	7.41	-10.78	-4.73	-35.58**
SPR87032-3-1-1-2-1	18.56	11.83	-30.46**	-32.07	24.43*	10.45	-2.93	-31.40
IR68926-61-2R	37.28	27.72	-4.17	-7.70*	26.21**	10.61	12.38	-21.26*
IR63870-2-2-3-3R	31.21	17.00	6.88	-1.51	3.14	-13.10*	-8.18	-37.32**
IR58110-144-2-2-2R	33.03*	26.13	3.67	1.83	32.47**	18.16	43.97**	2.06
IR65620-96-2-3-3-1R	10.63	2.51	-13.90*	-17.42*	6.00	-7.45	-5.92	-34.25**
IR62161-1843-1-3-2R	15.73	12.96	0.15	-1.05	14.09**	-4.54	10.11	-20.51**
IR46R	13.69	8.76	9.60*	8.66	24.03**	11.55*	-12.53	-37.64**

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.18 Heterosis (H) and heterobeltiosis (Hb) for plant height of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	8.34*	7.69	-10.59	-17.54**	-12.39*	-23.49**	0.93	-16.77**
RD7	11.12*	7.77	-8.92	-17.88**	-1.88	-16.09*	5.23*	-14.89**
RD11	5.45	3.89	1.48	-7.17**	-18.32**	-29.20**	-1.88	-19.66**
RD23	2.89	2.54	-9.87	-16.16**	3.49	-8.86**	23.81**	2.86
CNT1	4.44	3.05	0.91	-7.57*	6.78	-7.33	-21.23**	-35.43**
PTT1	3.30	0.93	-10.79	-15.44*	-17.39**	-25.97**	0.70	-14.97*
SPR90	4.97	3.12	-13.97*	-21.52**	3.89	-10.62*	4.62	-14.54**
SPR1	-0.35	-5.76	-10.20	-20.89**	-7.24	-22.37**	-4.40	-24.20**
SPR85163-5-1-2-3	-8.44**	-14.58**	1.85	1.19	-2.51	-8.70*	-4.02	-15.59**
SPR87032-3-1-1-2-1	1.80	0.88	-19.93*	-25.11**	-1.41	-12.76*	5.07	-12.31*
IR68926-61-2R	6.69	2.94	-5.95	-9.74*	-7.81	-16.42**	0.03	-14.63**
IR63870-2-2-3-3R	4.35	-1.96	-4.85	-6.17	-9.64	-15.97*	-12.93**	-23.93**
IR58110-144-2-2-2R	8.28**	0.09	-0.86	-1.20	-4.99	-10.20*	4.29	-7.49*
IR65620-96-2-3-3-1R	-1.14	12.82*	-7.98	-12.88	-7.47	-7.94*	-2.07	-8.90*
IR62161-1843-1-3-2R	-2.51	-12.72*	-0.80	-4.52	-4.77	-6.87	-0.85	-9.22
IR46R	-1.36	-4.16	-12.60*	16.70**	-0.03	-9.96*	-7.19*	-21.26**

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.19 Heterosis (H) and heterobeltiosis (Hb) for panicle per hill of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	-20.49	-21.49	-0.37	-10.30	-19.91	130.76	-9.68	-19.26
RD7	23.97	9.77	27.09**	1.79	0.79	-22.00*	15.78	13.11
RD11	2.04	-12.74	-0.58	-23.49*	4.92	-21.79	-0.19	-7.45
RD23	5.19	2.03	6.06	-8.05	4.53	12.82	-29.18**	-34.15*
CNT1	-14.94	-15.18	-6.05	-16.55	-1.91	-16.29	-31.32**	-37.75**
PTT1	32.71*	26.97	-7.59	-14.31	-14.78	-24.23*	40.06	21.72
SPR90	5.77	0.02	3.69	-12.08	3.74	-15.28	-7.59	-11.90
SPR1	-0.29	-1.42	3.31	-8.94	-6.00	-20.36	-9.47	-17.30
SPR85163-5-1-2-3	-24.64**	-31.22*	15.10	-5.37	29.42**	2.66	22.11	20.83
SPR87032-3-1-1-2-1	-4.85	-15.75	27.65*	2.23	4.74	-18.94	3.45	1.06
IR68926-61-2R	-2.32	-7.01	2.51	-4.48	14.25*	20.4	-0.89	-14.25
IR63870-2-2-3-3R	-14.17	-16.72	-2.45	-10.74	20.89	6.12	-3.23	-14.84
IR58110-144-2-2-2R	-10.23	-18.94	-6.83	-8.28	20.13*	13.04	-11.34	-26.80**
IR65620-96-2-3-3-1R	-3.57	-17.37	-3.64	-7.78	7.35	7.14	-13.88	-32.11**
IR62161-1843-1-3-2R	0.52	-6.65	-2.35	-6.71	-4.68	-12.83	9.99	-6.89
IR46R	-6.29	-12.07	-3.19	-8.50	1.68	-7.94	10.89	-5.28

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.20 Heterosis (H) and heterobeltiosis (Hb) for number of grain per panicle of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	7.16	5.34	15.02**	-4.16	11.04	-2.82	10.92	-17.26
RD7	14.03	7.47	12.47	-2.85	22.49	11.41	40.19**	7.73
RD11	12.13	3.92	10.85	-2.76	-5.68	-12.78	24.77**	-2.88
RD23	0.78	-1.06	11.69*	-9.50	-16.54	-1.02	-46.01**	-60.64**
CNT1	4.39	-1.14	27.75**	9.88*	28.37**	16.24**	-32.13**	-48.02**
PTT1	9.42	-2.36	30.45**	18.75**	-12.89	-16.21	8.43	-12.95
SPR90	-11.41*	-15.06*	-5.89	-25.14*	28.92**	7.35	14.14*	-18.04*
SPR1	3.32	-2.96	6.59	-7.64	25.93*	14.94	23.60*	-4.76
SPR85163-5-1-2-3	-22.39	-34.44*	19.8	15.85	17.96	15.07*	-0.77	-16.18
SPR87032-3-1-1-2-1	2.59	0.93	1.48	-17.64*	8.52	-7.68	39.73**	1.99
IR68926-61-2R	-11.87	-20.33	5.12	-5.55	-0.73	-5.84	6.78	-15.21
IR63870-2-2-3-3R	3.68	-7.64	28.83**	17.49	13.61**	9.49	25.99**	1.29
IR58110-144-2-2-2R	17.19*	-2.66	37.56**	35.76**	19.50**	14.25**	36.06**	16.93*
IR65620-96-2-3-3-1R	6.74	-5.62	24.95**	14.82	18.52	15.17	1.31	-18.02
IR62161-1843-1-3-2R	-0.89	-15.56*	29.82**	24.30*	7.72	6.14	2.45	-15.86
IR46R	-5.08	-6.56	-3.90	-21.98*	15.56*	-1.64	-16.37*	-38.93**

*, ** Significant at $p<0.05$ and $p<0.01$, respectively.

Table 4.21 Heterosis (H) and heterobeltiosis (Hb) for percent filled grain of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	2.77	-3.88	-5.00	-9.80	-6.42	-11.67	1.86	-8.27
RD7	2.56	0.76	3.18	3.00	-2.70	-3.48	2.43	-3.31
RD11	12.50*	12.00	-1.50	-0.36	-4.40	-4.89	10.02	5.17
RD23	1.70	1.39	-0.89	-2.15	-3.01	-3.64	-3.25	-7.39
CNT1	0.71	-4.12	-6.10	-9.22*	2.98	-1.05	-5.60	-13.54**
PTT1	-0.64	-9.71*	-2.20	-4.55	-47.66**	-49.24**	-20.85	-26.87
SPR90	2.88	-2.45	-19.40**	-22.40**	-13.41*	-17.14**	-16.12*	-23.48**
SPR1	-4.92	-10.85	-2.83	-7.51	-9.58*	-14.45*	-1.86	-11.42*
SPR85163-5-1-2-3	-19.11**	-21.67*	-13.68**	-15.09	-17.79**	-19.64*	-25.25**	-30.42**
SPR87032-3-1-1-2-1	0.32	-3.05	-11.88**	-13.50*	-7.99*	-10.24*	-12.64**	-18.83**
IR68926-61-2R	3.18	-2.13	-14.89**	-18.02**	-5.94	-9.96*	2.08	-6.83
IR63870-2-2-3-3R	6.12	2.33	-1.68	-3.71	0.61	-2.07	2.06	-5.37*
IR58110-144-2-2-2R	6.29	2.54	-6.89**	-8.76**	-11.58**	-13.89**	9.16**	1.26
IR65620-96-2-3-3-1R	-10.94*	-12.51*	-11.67**	-11.84*	-9.79*	-10.54	-10.60*	-15.63*
IR62161-1843-1-3-2R	-2.71	-7.41	-12.33	-15.28	-2.78	-6.62	-8.53	-16.26*
IR46R	-9.05	-13.34	-13.18	-15.99	-8.28	-11.79	-4.29	-12.27*

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.22 Heterosis (H) and heterobeltiosis (Hb) for 1000-grain weight of F1 hybrids grown at Pathumthani Rice Research Center in dry season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	-1.69	-2.42	-0.70	-5.15**	4.92**	-12.08**	-0.12	-3.87*
RD7	2.86*	1.62	3.73**	0.98*	6.98**	-8.89**	2.82**	-2.88*
RD11	-1.09	-3.58*	-0.42	-6.51**	2.73	-15.15**	9.39**	7.16**
RD23	-2.47	-5.29*	3.19**	2.21	8.15**	-6.54**	3.62**	-3.73*
CNT1	-4.94**	-5.09*	-0.39	-4.03*	4.34**	-11.92**	-1.39	-5.92
PTT1	0.05	-2.03	-4.59**	-6.30**	3.88*	-10.87**	-0.41	-6.72**
SPR90	-4.08*	-6.68*	-5.06**	-6.15**	10.51**	-4.66**	0.93	-6.04**
SPR1	-1.80	-2.71	1.68*	-1.30	0.64	-14.50**	2.41*	-3.01*
SPR85163-5-1-2-3	-6.67**	-10.43**	-4.77**	-5.00**	13.19**	-1.16	1.17	-7.05**
SPR87032-3-1-1-2-1	-3.57*	-9.13*	-2.44**	-4.51**	3.94*	-7.72**	4.23**	-5.89**
IR68926-61-2R	1.28	-2.43	-6.49**	-6.63**	7.41**	-6.53**	5.01**	-3.17*
IR63870-2-2-3-3R	2.51	-1.56	0.29	0.11	4.24*	-9.04**	0.73	-7.39**
IR58110-144-2-2-2R	4.17**	-0.66	0.04	-0.87	7.63**	-5.48*	-0.49	-9.11**
IR65620-96-2-3-3-1R	-0.11	-11.56**	3.87**	-4.74**	9.73*	3.71	6.76**	-9.14**
IR62161-1843-1-3-2R	-1.05	-10.29**	-1.48	-7.39**	3.02*	-5.02**	0.63	-12.42**
IR46R	-1.51	-11.32**	0.89	-5.83**	12.84**	4.76**	0.44	13.14**

*, ** Significant at p<0.05 and p<0.01, respectively.

Rainy season

Estimation of heterosis (H) and heterobeltiosis (Hb) were also evaluated among F1 hybrid crosses in the rainy growing season. Results of estimation for all measured parameters are shown in Table 4.23-4.28.

Grain yield: Both significant positive and negative heterotic and heterobeltiotic effects for grain were obtained among the F1 hybrid crosses. Hybrids exhibiting high positive heterosis and were ranked on top-five of crosses were V20A/ V20A/IR58110-144-2-2-2R (47.74%), V20A/RD11 (43.22%), IR58025A/RD23 (30.11%), IR62829A/RD7 (28.22%) and IR62829A/CNT1 (25.86%). For heterotic effects, hybrids giving high positive effect and were ranked on top-five of crosses were IR62829A/RD7 (26.42%), IR58025A/RD23 (24.83%), IR62829A/CNT1 (22.75%) and IR58025A/IR62161-1843-1-3-2R (7.12%) (Table 4.23).

Plant height: Both significant positive and negative heterotic and heterobeltiotic effects were found for plant height among the hybrid crosses. Hybrids giving positive heterosis were IR62829A/RD7 (16.30%), RD21A-23/RD7 (17.06%) and IR58025A/RD7 (18.68%). For heterobeltiotic effect, hybrids were RD21A-23/RD7 (15.78%) and IR62829A/IR62161-1843-1-3-2R (11.49%). Hybrids showing high level of negative heterotic effects were IR58025A/SPR87032-3-1-1-2-1 (-18.33%) and IR58025A/SPR90 (-16.25%). Hybrids exhibiting high level of negative heterobeltiotic effects were IR58025A/SPR87032-3-1-1-2-1 (-28.76%) and IR58025A/SPR90 (-27.36%) (Table 4.24).

Panicle per hill: Both significant positive and negative heterotic and heterobeltiotic effects for panicle/hill were obtained among the hybrids. Hybrids exhibiting high level of positive effects were IR58025A/SPRR87032-3-1-1-2-1

(89.34%), IR58025A/IR65620-96-2-3-3-1R (71.45%) and IR58025A/SPR90 (62.75%). For heterobeltiotic effects, hybrids were IR58025A/SPR87032-3-1-1-2-1 (78.2%), V20A/RD1 (54.93%), IR58025A/PTT1 (53.49%) and IR58025A/SPR90 (50.68%) (Table 4.25).

Number of grain per panicle: As well, both significant positive and negative heterosis and heterobeltiotic effects for grain/panicle were found among the hybrids. High levels of positive heterosis were obtained from hybrids IR58025A/CNT1 (54.22%), IR58025A/RD11 (43.17%) and IR58025A/IR68926-61-2R (39.20%). For heterobeltiotic effect, hybrids were IR58029A/CNT1 (39.91%), IR58025A/IR68926-61-2R (30.99%) and RD21A-23/RD11 (18.44%) (Table 4.26).

Percent of filled grain: Significant positive and negative heterotic and heterobeltiotic effects for filled grain were obtained among the hybrids. For this trait, low positive heterosis was found in hybrid V20A/IR58110-144-2-2-2R (12.58%) and V20A/RD11 (12.15%). Significant positive heterobeltiotic effect was not found for this trait among the hybrid crosses (Table 4.27).

1000-grain weight: As well, both significant positive and negative heterotic and heterobeltiotic effects for 1000-grain weight were found among the hybrids. Low levels of positive heterotic effects were obtained from hybrids IR62829A/SPR85163-5-1-2-3 (9.48%), IR62829A/SPR90 (8.36%), V20A/RD11 (6.22%) and RD21A-23/RD23 (5.32%) (Table 4.28).

Table 4.23 Heterosis (H) and heterobeltiosis (Hb) for grain yield of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-line	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	4.56	3.12	-1.84	-9.59	-0.09	-3.89	12.19	-20.24
RD7	2.75	1.57	25.60*	18.45	28.22*	26.42**	11.08*	-35.83**
RD11	11.61	7.73	2.68	-7.30	3.81	-2.23	43.22**	0.49
RD23	12.48	9.30	30.21**	24.83*	11.44	11.79	-19.78*	-41.47**
CNT1	3.33	3.29	21.32*	13.32	25.86**	22.75**	2.26	-26.69**
PTT1	-1.07	-4.40	-9.35*	-18.07*	-40.20**	-43.60**	-4.79	-33.17**
SPR90	-12.61	-16.78	-2.18	-12.70	2.33	-5.47	-25.56**	-49.10**
SPR1	9.43	1.02	3.88	-10.90	15.64*	4.28	-4.84	-34.97**
SPR85163-5-1-2-3	-17.90**	-22.91*	-18.16**	-27.97**	7.38	-1.55	-5.74	-34.93**
SPR87032-3-1-1-2-1	-3.13	-8.40	0.96	-10.62	5.76	-2.42	-9.22*	-37.09**
IR68926-61-2R	15.40	8.01	2.34	-10.19	4.07	-4.86	13.98	-21.47
IR63870-2-2-3-3R	16.87	13.77	17.81	7.19	8.90*	3.44	-6.71	-34.22**
IR58110-144-2-2-2R	14.55	8.08	4.78	-7.38	17.72	8.45	47.74**	2.24
IR65620-96-2-3-3-1R	12.03	1.76	-12.54	-25.34*	-1.29	-12.37	-11.39	-40.01**
IR62161-1843-1-3-2R	-0.70	-0.48	14.27	7.12*	17.34*	15.02	7.75	-21.70*
IR46R	12.72	5.8	12.01	-1.46	11.19	1.91	17.64	-18.85

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.24 Heterosis (H) and heterobeltiosis (Hb) for plant height of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	4.90*	4.09	1.79	-8.73	-7.31*	-21.70**	-5.46	-21.57
RD7	17.06**	15.78**	18.68**	6.75	16.30*	-1.47	17.97**	-1.85
RD11	5.47	3.19	5.90	-7.47	-5.55	-22.10	1.92	-17.39
RD23	3.52	2.65	8.16**	-4.39	7.39	-10.46	13.78**	-6.81**
CNT1	2.03	0.14	11.01	0.53	10.95**	-6.23	-22.17**	-34.84**
PTT1	3.70	0.18	-11.15*	-18.34*	-12.43	-24.33	-7.26	-21.34**
SPR90	0.81	-2.18	-16.25**	-27.36**	1.41	-16.92	-3.61	-22.38**
SPR1	1.42	-5.50	5.87	-11.36*	-6.71	-26.01*	-4.29	-25.32**
SPR85163-5-1-2-3	-11.72**	-20.54**	-5.85	-6.97	17.0	8.13	-2.66	-11.85*
SPR87032-3-1-1-2-1	4.56	2.12	-18.33**	-28.76**	7.05	-11.83	-12.32*	-29.02**
IR68926-61-2R	7.34	1.53	3.67	-2.76	0.65	-11.36	8.14	-6.57
IR63870-2-2-3-3R	8.65	1.25	3.17	-1.77	-2.95	-13.34	-0.02	12.45**
IR58110-144-2-2-2R	1.20	-4.04	10.47	3.37	-1.12	-13.11	8.84	-6.17
IR65620-96-2-3-3-1R	0.88	-9.48	-11.18**	-11.93**	1.67	-5.73	-7.31*	-15.79**
IR62161-1843-1-3-2R	6.33	-5.95	10.55*	9.70	11.49	4.96	-3.67	-11.18*
IR46R	5.79*	3.48	10.99	0.83	7.98	-7.68	5.82*	-11.18**

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.25 Heterosis (H) and heterobeltiosis (Hb) for panicle per hill of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	-0.48	-048	19.37	11.82	4.93	-7.95	59.81*	54.93*
RD7	46.24**	30.51**	23.85	4.38	3.83	-17.34	5.42	-8.4
RD11	5.97	2.52	-2.37	-11.32	4.87	-10.57	12.03	5.18
RD23	-9.28	-9.51	23.86	15.75*	17.68**	3.01	16.52	12.68
CNT1	6.34	18.03	-5.28	-8.19	-8.05	-11.7	-8.08	-1.41
PTT1	8.74	-3.48	62.64**	53.49**	37.66**	35.84*	37.58	25.58
SPR90	6.33	5.01	62.75*	50.68*	1.29	-12.09	26.47	21.13
SPR1	-4.70	-13.77	4.63	.80	5.48	1.90	0.85	-6.09
SPR85163-5-1-2-3	-12.83	-30	35.25*	14.55	-6.22	-15.45	32.6*	9.09
SPR87032-3-1-1-2-1	10.45	9.89	89.34**	78.2**	3.21	-9.06	36.85*	33.32
IR68926-61-2R	2.58	-3.12	6.61	5.69	17.13*	8.28	15.07	12.0
IR63870-2-2-3-3R	30.6	26.88	17.47*	13.13	4.79	-5.68	10.11	9.85
IR58110-144-2-2-2R	0.47	-4.92	1.11	.03	22.29*	12.84	23.09**	20.06**
IR65620-96-2-3-3-1R	1.89	-12	71.45**	57.1**	3.33	1.46	18.04*	4.74
IR62161-1843-1-3-2R	-9.95*	-20.3*	4.51	-1.91	-0.01	-0.77	41.77*	18.74
IR46R	11.56	2.07	8.08	5.37	13.45**	8.31	-4.85	1.41

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.26 Heterosis (H) and heterobeltiosis (Hb) for no. of grain per panicle of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	12.28*	2.82	35.62**	16.87*	-2.12	-4.45	5.06	-15.10
RD7	3.25	1.55	13.15	-10.51	4.23	-7.97	-3.73	-28.0
RD11	19.04**	18.44**	43.17**	14.22	-8.03	-17.96*	2.19	-22.99*
RD23	7.67	4.66	1.94	-20.09*	2.70	-10.26	-52.39**	-64.68**
CNT1	13.57	1.58	54.22**	35.91**	12.62	12.40	-46.66**	-56.01**
PTT1	6.88	-7.34	14.09	3.81	-24.78*	-27.54*	-2.47	-17.19
SPR90	0.61	-3.81	-15.44*	-34.52**	12.64	-2.99	-7.60	-32.20**
SPR1	0.00	-1.53	-3.32	-23.47*	16.08*	-25.82*	-23.39**	-42.67**
SPR85163-5-1-2-3	-21.36	-39.9**	23.74	16.23	4.40	-12.97	-0.30	-1.83
SPR87032-3-1-1-2-1	-4.22	-14.12	-25.45**	-44.94**	-2.82	-20.88	-10.48	-37.05*
IR68926-61-2R	6.86	-10.13	39.20**	30.99*	-6.09	-12.61	11.70*	-2.19
IR63870-2-2-3-3R	6.25	4.56	-18.88	-30.27**	-18.04	-27.60*	-23.99**	-43.14**
IR58110-144-2-2-2R	6.04	-5.11	22.77*	8.15	-18.34	-18.46	17.57	-3.07
IR65620-96-2-3-3-1R	3.99	-7.76	4.35	-7.29	-4.63	-5.70	-10.92	-25.98**
IR62161-1843-1-3-2R	-6.71	-20.77	26.52**	17.73	5.77	-0.46	4.29	-9.61
IR46R	2.63	-0.82	16.15**	-4.48	9.73	1.45	6.80	-17.27*

*, ** Significant at $p<0.05$ and $p<0.01$, respectively.

Table 4.27 Heterosis (H) and heterobeltiosis (Hb) for percent filled grain of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	2.42	1.66	-12.93*	-15.46	-10.61**	-11.02**	-14.89*	-21.21*
RD7	-3.67	-6.25	-0.99	-1.95	-1.75	-3.25	-11.36	-19.43
RD11	3.88	0.76	-1.40	-2.05	-3.89	-5.66	12.15**	1.64
RD23	3.73	1.48	-6.90	-8.35	-5.41**	-6.35**	-3.88	-12.19
CNT1	-2.82	-5.29	-6.91	-7.96	-6.35*	-7.65	-20.42*	-27.57*
PTT1	-15.04*	-16.08*	-14.70**	-16.79*	-38.61**	-38.63**	-25.66*	-31.49*
SPR90	-20.99**	-22.7**	-27.26**	-28.37**	-11.85**	-12.72**	-19.76**	-26.70**
SPR1	-1.21	-2.14	-8.72	-11.21	-1.03	-1.29	6.25	-1.81
SPR85163-5-1-2-3	-16.40*	-19.79*	-19.04**	-25.02**	-3.50	-8.48*	-23.36**	-25.62*
SPR87032-3-1-1-2-1	-8.74**	-10.52**	-24.91**	-26.21**	-4.37	-5.10	-19.45**	-26.27**
IR68926-61-2R	-0.39	-1.87	-2.82	-4.95	-6.35*	-6.63	-5.49	-13.11*
IR63870-2-2-3-3R	-2.52	-5.40	-0.84	-1.53	-3.03	-4.78	-2.48	-11.59*
IR58110-144-2-2-2R	6.11*	3.89	-4.66	-6.19	-5.23	-6.09	12.58**	2.93
IR65620-96-2-3-3-1R	6.46*	3.67	-21.87**	-26.60**	-0.02	-3.78	-14.00**	-17.77**
IR62161-1843-1-3-2R	2.95	2.16	-0.31	-3.19	-8.18*	-8.59	-10.65**	-17.30**
IR46R	-0.54	-5.20*	-6.58	-7.67*	-5.81	-9.18	-0.95	-11.68**

*, ** Significant at p<0.05 and p<0.01, respectively.

Table 4.28 Heterosis (H) and heterobeltiosis (Hb) for 1000-grain weight of F1 hybrids grown at Pathumthani Rice Research Centre in rainy season 2003.

R-lines	A-lines							
	RD21A-23		IR58025A		IR62829A		V20A	
	H	Hb	H	Hb	H	Hb	H	Hb
RD1	2.51	-2.48	-0.15	-5.08*	33.3	-11.53**	-1.04	-3.66**
RD7	7.65	4.31	2.87	-0.39	6.39	-7.44*	1.49	-3.00
RD11	1.32	-4.65	2.18	-3.92	-0.26	-15.42**	7.87**	6.22*
RD23	5.71**	5.32**	4.06**	3.75**	6.45	-4.46	4.06**	-3.82**
CNT1	3.18*	-0.25	1.91**	-1.55	0.33	-12.88**	4.17**	-0.22
PTT1	7.62**	6.89	-4.68*	-5.40	0.80	-10.37*	0.37	-6.32**
SPR90	2.80	2.7	-5.26**	-5.43**	8.36*	-3.15	1.15	-6.10**
SPR1	6.10**	3.53**	3.03	0.47	1.74	-10.93**	6.70**	1.27
SPR85163-5-1-2-3	-3.10	-2.72	-6.44**	-6.65**	9.48*	-1.79	0.77	-6.80**
SPR87032-3-1-1-2-1	6.20	1.04	-1.09	-5.83**	7.89	1.09	6.11**	-5.99**
IR68926-61-2R	6.14	5.45	0.41	-0.17	3.75	-6.65*	6.59**	-1.74*
IR63870-2-2-3-3R	5.75	5.11	3.99	3.44	-0.35	-10.38**	0.51	-7.30**
IR58110-144-2-2-2R	3.31	2.80	-4.36	-4.90	1.18	-9.88*	2.52	-4.49
IR65620-96-2-3-3-1R	5.91	-2.89	2.05**	-6.36**	3.39	0.63	6.92**	-8.44**
IR62161-1843-1-3-2R	6.29	-2.64	3.06	-5.56*	3.14	0.49	2.69*	-12.15**
IR46R	1.55	-5.35*	0.43	-6.33	2.97	-1.49	3.31	-10.19**

*, ** Significant at p<0.05 and p<0.01, respectively.

4.4 Discussion

Results of estimation of general combining ability (g.c.a.) of A- line and R- line parents, specific combining ability (s.c.a.) and heterotic effects of F1 hybrid crosses are discussed as follow:

Combining ability: Results of g.c.a. effects evaluated in dry season revealed that there were some parents which showed positive effects for grain yield. These parents included both A- line and R- lines; RD21A-23, IR62829A, RD7 and RD11. The remaining parents showed either negative or nonsignificant g.c.a. effects. Parents with good g.c.a. effects since all of them had been evaluated and were classified as good A- line and R- line (Table 4.2). As pointed by Yuan and Virmani (1988), most of good A- line and R- line possessed good g.c.a. and agronomic characters. This result is similar to Kim and Rutger (1988) who reported that agronomic characters of parents in hybrid crosses were affected by g.c.a. ability, especially characters mainly contributed to grain yield. Hence, good combiner for grain yield would be RD21A-23, having positive g.c.a. effects for grain/ panicle, filled grain and 1000-grain weight while RD7 possessed good positive g.c.a. effects for grain/ panicle, filled grain and 1000-grain weight in contrast to poor combiner parents such as V20A and RD23 which had negative g.c.a. effects for grain yield and negative g.c.a. effects for their agronomic traits (Table 4.2). However, positive g.c.a. effects for grain yield were not obtained widely among parents but some parents provided highly significant positive g.c.a. effects for agronomic traits. For examples, RD1, SPR1 and SPR90 gave positive g.c.a. effects for grain/ panicle while RD1, RD7, RD11, SPR1 and IR58110-144-2-2-2R gave good g.c.a. effect for filled grain (Table 4.2).

In rainy season, it was revealed that significant g.c.a. effects were not found in all parents. This effect was probably resulted from fertility of hybrid which was affected directly from restorer ability of R- lines grown under unfavorable climate, together with improper cultural management in rainy growing season. As mentioned earlier, most agronomic traits were affected largely by g.c.a. ability, so poor g.c.a. effects for grain yield of parents also were resulted from poor combining of traits contributed for their grain yields (Table 4.10). However, positive g.c.a. effects were not obtained for grain yield among parents, but some parents had good g.c.a. effects for important agronomic traits such as RD21A-23, RD7, RD11 and RD23 which gave good g.c.a. effects for grain/ panicle while IR580110-144-2-2-2R and PTT1 gave good g.c.a. effects for panicle/ hill as shown in Table 4.10.

For s.c.a. evaluation of F1 hybrid crosses, it was surprising and interesting to point out that significant positive s.c.a. effects were not identified for grain yield in all hybrids, both in dry and rainy season in spite of the fact that some parents showed good g.c.a. effects for this trait before taking them into hybrid combinations. Unexpected poor s.c.a. effects obtained for this particular trait might probably be due to the importance of genetic control of additive genes which played more important role than non-additive gene (Vermani, 1994). Unfavorable climate condition together with improper cultural management would also give greater effects than genetic expression of non-additive gene, especially for grain yield of hybrid crosses (Kim and Rutger, 1988). However, there were some hybrids giving good s.c.a. effects for certain important agronomic traits such as hybrids V20A/ PTT1, RD21A-23/ PTT1 which gave good s.c.a. effects for panicle/ hill and hybrids V20A/ RD7, V20A/ RD11 were good for filled grain in dry season (Table 4.5 and 4.7). As well, hybrids V20A/

RD1, RD21A-23/ RD7 and RD21A-23. CTT1 were good for panicle/ hill in rainy season (Table 4.13).

Heterosis: Results of heterotic effect evaluation for hybrid crosses revealed that positive heterotic effects were pronounced for grain yield among the hybrid crosses in both growing seasons. Some hybrids which exhibited high positive heterotic effects for grain yield over their mid-parents because their parents had been evaluated for good g.c.a. effects, both for yield and good agronomic characters, which had already been discussed in combining ability section. Even though, these hybrids did not show any good positive s.c.a. effects for grain yield (Table 4.3) but under favorable growing condition of yield trial, influence of environmental effects may be greater than genetic effects, so high heterotic effects were found largely in crosses. For low and negative heterotic effect found in some crosses, it might be resulted either from combination of poor g.c.a. parents or due to small diversity of genetical bases of A- line and R- line parents. Results of this study agreed with Kunta *et al.* (1997) reporting in soybean, mungbean (Chen *et al.*, 2003) and azuki bean (Weerapun *et al.*,2006).

Estimation of combining ability and heterotic effects of parents presented in this chapter could be inclusively summarized that evaluation of both A- line and R- line for their good specific combining ability and testing for high heterotic effects of their hybrid combination are first priority needed for studying in order to develop superior F1 hybrid rice variety for cultivation in the country.