RESEARCH ARTICLE

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COMBINING ABILITY FOR YIELD AND AGRONOMIC TRAITS IN HYBRID RICE DERIVED FROM WILD ABORTIVE, GAMBIACA AND KALINGA CYTOPLASMIC MALE STERILE LINES

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SUMMARY

Four CMS lines and eight elite testers were crossed in 4 x 8 half diallel to obtain 32 hybrids. These lines were used to estimate the heterosis values, general combining ability (GCA) of parents and specific combining ability (SCA) effect for grain yield and its components. The research was conducted in November 2010 to March 2011 at Sukabumi. Thirty-two hybrids and their parental lines were planted using randomized complete block design with three replications. The characters of yield components and yield were observed. The variances due to SCA were larger than the variance due to GCA for characters plant height, panicle length, number of filled grain per panicle, number of unfilled grain per panicle, total grain per panicle, filled grain percentage per panicle and grain yield. Those characters were controlled by non-additive genes. BI485A and BI599A lines were good general combiner for number of productive tiller per plant, filled grain per panicle and filled grain percentage per panicle, while a good tester combiner were IR53942, CRS8, CRS9, SMD10 and SMD15. The yielding character was controlled by overdominant gene action, dominant x dominant or epistasis. The highest specific combining ability for grain yield was achieved by BI855A/SMD11. The best hybrid rice derived from WA male sterile lines was BI485A/IR53942 (10.21t/ha), while the best hybrids derivated from Gambiaca male sterile lines was BI855A/SMD11 (9.88 t/ha) and Kalinga derivated hybrid was BI665A/IR53942 (9.15 t/ha). These three new hybrids were showed the highest heterobeltiosis and standard heterosis.

Key words: Hybrid rice, line x tester, combining ability, heterosis

Key findings: The research identified new cytoplasmic male sterile lines with three different cytoplasmic backgrounds having high combining ability for yield with Indonesian restorers. This study showed the importance of overdominance, dominant by dominant or epistasis gene actions in controlling yield. Specific combining ability is more important in producing high yield of hybrid rice variety.

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INTRODUCTION

Rice yields have been reported to be stagnant and it is opposite to human population which increase steadily. Alternative technologies are needed to overcome barriers to increase rice productivity. Hybrid rice technology is an important approach for improving rice production. Whereas the first progeny will perform better than their parental lines. Hybrid rice known having 20% higher of yield than inbred rice. This technology is not only contributing to food security but also beneficial to the environment.

The discovery of cytoplasmic male sterile (CMS = A line) in the rice makes it possible for plant breeders to develop hybrids (F_1) which has higher potential than inbred rice. In three lines system, hybrid rice breeding conducted by crossing CMS with the restorer (R line). Compatibility among two parental lines will determine the performance and the product of hybrid heterosis. The compatibility itself is determined by the value of general combining ability (GCA) and specific combining ability (SCA) of these two lines. The information of combining ability is useful to estimate compatibility among parental lines in self-pollinated crops and relative magnitude of gene actions involved (Gosh *et al.*, 2012). Therefore, to exploit heterosis in rice, breeders need to test the combining ability between CMS and R lines. Information on combining ability is useful to determine ability of lines in producing hybrid and to study the magnitude and action direction of related genes (Saidaiah *et al.*, 2010).

Rumanti *et al.* (2013) was developed new cytoplasmic male sterile lines with three different cytoplasm background i.e. Kalinga, Gambiaca and Wild Abortive. These CMS lines have a stable of sterility and good flowering behaviour related to outcrossing ability such as larger stigma, higher stigma exertion, wider angle and longer duration of glume opening during anthesis. The characters were reported successfully increased the outcrossing ability in seed production and its resistance to bacterial leaf blight.

Evaluation of heterosis is the most important thing in the breeding of hybrid rice. There are three heterosis value commonly measured on the new hybrid combinations, namely heterobeltiosis, mid-parent and standard heterosis. Heterobeltiosis is hybrid heterosis against the best parent while mid-parent heterosis is measured hybrid on the mean of the two parents (Virmani *et al.,* 1997). Standard hybrid heterosis is not associated with genetic of the hybrid parents but it is very important in the commercialization process of hybrid rice because its value will reflect hybrid superiority against popular varieties used by farmers.

This study was carried out to: (1) determine estimates of combining ability and genetic parameters of yield and its components; and (2) to evaluate the heterosis of new hybrids rice derived from WA, Gambiaca and Kalinga CMS system.

MATERIALS AND METHODS

Experimental material

A total of 47 entries including 32 F_1s of rice produced by crossing 4 new CMS lines (i.e. BI485A, BI599A, BI855A and BI665A) with 8 diverse elite and good restorer lines as testers (i.e IR53942, CRS8, CRS9, SMD9, SMD10, SMD11, SMD12 and SMD15) were used for the study. All the parental lines were selected from the previous study (Rumanti *et al.,* 2013). CMS lines were improved for bacterial leaf blight through backcrossing, while the restorer lines were selected through testcross and selected based on their respective F_1. The line x tester mating design (Singh and Chaudary, 1979) was used. The CMS lines of BI485A and BI599A are wild abortive, while BI855A and BI665A are Gambiaca and Kalinga respectively. Among the checks, Ciherang and Inpari13 are popular inbred varieties of Indonesia, while Hipa6 Jete is hybrid rice variety released in Indonesia.

Experimental design

The resultant 32 F_1s, 12 parents and 3 check varieties was planted at field station in Sukamandi, Indonesian Center for Rice Research in a randomized complete block design with three replications. The experiment was conducted from November 2010 - March 2011 under irrigated conditions. Each plot comprised of 4 rows of 2.0 m long with the spacing of 25 x 25 cm. One-two seedlings were planted per hill with recommended cultural practices and packages was applied for growing the healthy and good crop. Other cultural practices including weeding and pest management has been done manually throughout the entire growing season as required.

Data collection

Data on grain yield and other important agronomic traits were collected on plot and individual plant basis. For data individual plant basis, the average of ten randomly sampled plants was used. The traits under observation were plant height, productive tillers per plant, days to flowering, panicle length, fertility spikelet per panicle, sterility spikelet per panicle, spikelet fertility, 1000 grain weight and grain yield per plot.

Data analysis

Data were subjected to analysis of variance following Randomized Complete Block Design (RCBD) format using Statistical Tool for Agricultural Research (STAR) from IRRI. The mean data of different traits were subjected to analysis of standard statistical and biometrical method for combining ability by Singh and Chaudary (1979). Percentage heterosis was calculated for those traits that showed statistically significant differences among genotypes as suggested by Falconer (1996). Heterobeltiosis was computed as percentage increase or decrease of the hybrid rice performances over the best parents, meanwhile standard heterosis was computed over check varieties namely Ciherang, Inpari13 and Hipa6 Jete.

RESULTS

Analysis of variance

Analysis of variance showed that there was significant difference among lines for all traits except the number of productive tiller per plant, whereas among testers, the significant mean squares were detected for plant height, fertile spikelet per panicle, sterile spikelet per panicle, the percentage of spikelet fertility and grain yield. A high mean square proportion of line x tester will accompany high proportion of line and tester value, showed the traits of fertile spikelet per panicle, sterile spikelet per panicle, panicle length, spikelet fertility and grain yield (Table 1).

Table 1. Analysis of variance for line x tester analysis.

Sources of variation	DF	Days to flowering	Plant height	Productive tiller per plant	Fertile spikelet per panicle	Sterile spikelet per panicle	Panicle lenght	Spikelet fertility	Grain yield
Replication	2	152.0^{**}	244.1^{**}	3.5^{tn}	980.1^{tn}	1266.8^{tn}	10.2^{**}	130.8^{tn}	9.7^{**}
Treatments	43	45.1^{**}	157.3^{**}	2.4^{tn}	2185.2^{**}	2586.0^{**}	8.8^{**}	666.4^{**}	8.7^{**}
Parents	11	106.5^{**}	244.9^{**}	2.5^{tn}	1093.0^{tn}	1716.0^{*}	12.7^{**}	355.9^{*}	4.7^{*}
P vs H	1	466.0^{**}	17.7^{tn}	7.5^{tn}	2105.7^{*}	7286.3^{**}	61.5^{**}	1061.3^{**}	24.2^{**}
Hybrids	31	9.8^{tn}	130.6^{**}	2.2^{tn}	2575.4^{**}	2743.0^{**}	5.7^{**}	763.9^{**}	9.6^{**}
Lines	3	56.0^{**}	492.2^{**}	4.1^{tn}	2871.7^{**}	6425.4^{**}	16.3^{**}	1710.1^{**}	10.5^{**}
Tester	7	8.2^{tn}	160.8^{*}	0.8^{tn}	3811.1^{**}	4428.9^{**}	4.6^{tn}	1314.0^{**}	11.4^{**}
Line x Tester	21	3.6^{tn}	68.9^{tn}	2.5^{tn}	2121.1^{**}	1655.0^{**}	4.5^{*}	445.3^{**}	8.8^{**}
Error	86	9.0	53.8	2.8	497.7	604.5	2.2	107.9	2.0

DF - degree of freedom, *, ** Significant at 5 and 1 percent level, respectively, tn - not significant

Table 2. Proportional contribution of lines, testers and their interactions to total variance in a set of line × tester crosses.

Contribution (%)	Days to flowering	Plant height	Productive tiller per plant	Fertile spikelet per panicle	Sterile spikelet per panicle	Panicle length	Spikelet fertility	Grain yield
Lines	55.6	36.5	17.7	10.8	22.7	27.7	21.7	10.7
Testers	19.1	27.8	7.9	33.4	36.5	18.4	38.8	26.8
Lines x Testers	25.3	35.7	74.5	55.8	40.9	54.0	39.5	62.5

Table 3. Estimates of general combining ability effects of parents (lines and testers) for grain yield and yield components.

Genotypes	Days to flowering	Plant height	Productive tiller per plant	Fertile spikelet per panicle	Sterile spikelet per panicle	Panicle length	Spikelet fertility	Grain yield
Testers								
IR53942	1.3	1.6	-0.3	10.4^{**}	-2.9^{**}	0.3	2.4^{*}	1.3
CRS8	-1.4	-6.2^{**}	0.1	14.8^{**}	-24.0^{**}	-1.4	12.0^{**}	0.3
CRS9	0.3	-3.2^{**}	-0.1	14.1^{**}	-17.4^{**}	-0.0	9.1^{**}	0.3
SMD9	-0.8	-0.0	-0.2	1.9	8.3^{**}	-0.2	-3.3^{**}	0.6
SMD10	-0.4	0.1	0.1	3.0^{**}	-11.7^{**}	0.1	5.9^{**}	0.2
SMD11	0.5	-0.9	0.2	-28.9^{**}	23.4^{**}	0.3	-13.4^{**}	-0.5
SMD12	0.2	2.8^{*}	0.4	-26.7^{**}	30.2^{**}	0.0	-17.0^{**}	-2.0
SMD15	0.4	5.8^{**}	-0.3	11.6^{**}	-6.0^{**}	0.8	4.4^{**}	-0.2
SE (gi) testers	0.9	2.1	0.5	6.4	7.1	0.4	3.0	0.4
SE (gi-gj)	1.2	3.0	0.7	9.1	10.0	0.6	4.2	0.6
Lines								
BI485	-1.3	-3.5^{**}	0.1	12.0^{**}	-20.6^{**}	-0.1	10.4^{**}	0.7
BI599	-1.3	-2.3^{*}	0.3	5.5^{**}	-1.6	-0.9	1.8	-0.8
BI855	1.3	-0.8	0.3	-4.6^{**}	2.9^{**}	-0.1	-2.3^{*}	0.3
BI665	1.4	6.6^{**}	-0.6	-12.8^{**}	19.2^{**}	1.1	-9.9^{**}	-0.2
SE (gi) lines	0.6	1.5	0.3	4.6	5.0	0.3	2.1	0.3
SE (gi-gj)	0.4	2.2	0.1	20.7	25.2	0.1	4.5	0.1

*, ** significant at $P \leq 0.05$ and 0.01 levels, respectively.

The contributions of lines, testers, interaction of line x tester the traits are presented in Table 2. The high contribution of interaction of line x tester than lines for productive tillers per plant, fertile and sterile spikelet per panicle, panicle length, spikelet fertility and grain yield, indicated high estimates of GCA variances for interaction.

General combining ability

General combining ability (GCA) effect for different characters is given in Table 3. The tester (restorer) lines, i.e. IR53942, CRS8 and CRS9 had higher significant positive GCA effect for filled grain per panicle and spikelet fertility. The three restorers had also higher significant negative GCA effect for plant height and sterile spikelet per panicle. It is possible to use parents with a high significant positive and negative effect of GCA in breeding programs. The parental lines with significant positive or negative GCA effect for certain characters were revealed that those characters could be transferred to progenies. For example, parents which have a high negative GCA effects for plant height and sterile spikelet per panicle i.e. BI485 could be used in breeding programs. While IR53942, CRS8 and CRS9 could be used for breeding program to improve spikelet fertility and filled grain per panicle. The line which is good general combiner for plant height traits are BI485A and BI599A while for the tester are restorer line CRS8 and CRS9 (Table 3). For flowering days, some CMS and restorer have relatively same low GCA ability but not statistically significant. However, based on the results of this analysis, CMS or restorer which has negative GCA for flowering days can be selected. Days to flowering is probably caused by narrow range of the number. BI485A was good general combiner for traits of fertile spikelet per panicle, sterile spikelet per panicle and spikelet fertility. The best tester for general combining ability was IR53942, CRS8, CRS9 and SMD10 (Table 3). The combination of the CMS and restorer will produce hybrids that have higher fertile spikelets per panicle and spikelet fertility, thus minimizing the amount of sterile spikelets per panicle. None of both CMS and restorer acts as the general combiner for grain yield because this character is more influenced by SCA among specific parents.

Specific combining ability

The highest SCA value for grain yield trait was showed by BI855A/SMD11 (Table 4). High SCA value was generated by the parent with low GCA which indicate that these properties are controlled by overdominant gene action, dominance x dominance or epistasis. Such combination with high SCA can be exploited for the breeding of hybrid rice with good heterosis. Some hybrids do not show high SCA and statistically significant values for measured traits. This may be due to a combination of parent genetic expression can not fix these characters. High SCA value for plant height, days to flowering, panicle length and grain yield, all derived by the parent with low GCA value.

Table 4. Estimates of specific combining ability effects of crosses for grain yield and yield components.

Genotypes	Days to flowering	Plant height	Productive tiller per plant	Fertile spikelet per panicle	Sterile spikelet per panicle	Panicle length	Spikelet fertility	Grain yield
BI485/IR53942	1.4	1.1	1.1	-16.1**	22.6**	1.1	-11.9**	1.2
BI485/CR8	-1.0	-8.8**	-1.2	-8.6**	10.2**	-1.2	-4.1**	-1.4
BI485/CR9	0.4	-2.1*	0.7	13.6**	-1.9	0.7	1.6	1.9
BI485/SMD9	-0.2	9.5**	0.2	12.7**	23.8**	0.2	-5.3**	-0.5
BI485/SMD10	-0.6	2.9**	0.3	2.2*	-6.7**	0.3	3.2**	1.1
BI485/SMD11	-0.1	-3.7**	0.3	-17.0**	-11.5**	0.3	-0.4	-2.2
BI485/SMD12	0.1	2.1*	-0.9	7.8**	-22.2**	-0.9	9.8**	-0.9
BI485/SMD15	-0.0	-1.1	-0.5	5.5**	-14.2**	-0.5	7.1**	0.4
BI599/IR53942	1.8	0.5	-0.5	-8.7**	7.5**	-0.5	-2.4*	0.9
BI599/CR8	-1.9	-2.7*	1.9	-0.5	-0.4	1.9	-0.6	-0.4
BI599/CR9	0.1	2.5*	-0.1	-5.7**	-16.9**	-0.1	6.9**	0.1
BI599/SMD9	-1.5	-5.0**	-0.7	2.0	-4.8**	-0.7	2.2*	-0.6
BI599/SMD10	-0.2	-3.2**	-0.4	16.4**	-9.8**	-0.4	4.7**	0.8
BI599/SMD11	0.9	2.1*	0.7	-46.3**	34.7**	0.7	-23.8**	-2.7
BI599/SMD12	0.2	-0.6	-0.6	34.1**	10.3**	-0.7	4.5**	0.2
BI599/SMD15	0.7	6.4**	-0.2	8.8**	-20.7**	-0.2	8.5**	1.7
BI855/IR53942	-1.9	3.7**	-0.1	-30.8**	15.4**	-0.1	-10.3**	-3.1
BI855/CR8	1.5	6.0**	-0.6	2.3*	-2.1*	-0.6	1.4	2.3
BI855/CR9	-0.2	2.4*	-0.1	15.0**	-8.7**	-0.1	5.4**	-1.3
BI855/SMD9	0.9	-4.5**	0.9	2.8**	-5.6**	0.9	2.9**	0.5
BI855/SMD10	0.5	-2.1*	-0.6	-22.0**	24.5**	-0.6	-11.1**	-1.1
BI855/SMD11	-0.4	-2.0	-0.4	43.4**	-41.6**	-0.4	23.4**	3.1
BI855/SMD12	-0.1	-0.9	-0.3	-26.5**	14.3**	-0.3	-11.8**	0.0
BI855/SMD15	-0.3	-2.7*	1.1	15.9**	3.7**	1.1	0.3	-0.4
BI665/IR53942	-1.3	-5.4**	-0.5	55.6**	-45.5**	-0.5	24.7**	1.1
BI665/CR8	1.4	5.5**	-0.1	6.9**	-7.8**	-0.1	3.3**	-0.5
BI665/CR9	-0.3	-2.8**	-0.5	-22.9**	27.4**	-0.5	-13.9**	-0.6
BI665/SMD9	0.8	0.0	-0.4	-17.4**	-13.4**	-0.4	0.2	0.5
BI665/SMD10	0.4	2.4*	0.7	3.4**	-7.9**	0.7	3.2**	-0.8
BI665/SMD11	-0.5	3.6**	-0.6	20.0**	18.3**	-0.6	0.8	1.8
BI665/SMD12	-0.2	-0.6	1.8	-15.4**	-2.3*	1.8	-2.5*	0.2
BI665/SMD15	-0.4	-2.7*	-0.3	-30.2**	31.2**	-0.3	-15.8**	-1.7

*, ** significant at $P \leq 0.05$ and 0.01 levels, respectively.

Table 5. Estimates of heterosis and standard heterosis for grain yield.

Genotypes	Grain yield (tha^{-1})	Heterosis		Standard heterosis compare to		
		Ht	MP	Ciherang	Inpari13	Hipa6 Jete
BI485/IR53942	10.2	48.9	72.7	52.2	41.2	33.8
BI485/CR8	6.6	-4.0	4.6	-1.9	-9.0	-13.7
BI485/CR9	9.9	26.2	34.7	47.4	36.758	29.6
BI485/SMD9	7.8	13.8	16.3	16.3	7.9	2.3
BI485/SMD10	9.1	31.9	41.6	34.8	25.1	18.6
BI485/SMD11	5.1	-26.3	-22.0	-24.6	-30.1	-33.7
BI485/SMD12	5.2	-23.7	-17.0	-22.0	-27.7	-31.4
BI485/SMD15	7.8	14.2	57.8	16.7	8.2	2.6
BI599/IR53942	8.4	55.0	61.6	24.9	15.9	9.9
BI599/CR8	6.0	5.2	8.3	-10.1	-16.6	-20.9
BI599/CR9	6.6	-15.8	-0.4	-1.7	-8.8	-13.6
BI599/SMD9	6.2	-5.6	3.4	-7.8	-14.4	-18.9
BI599/SMD10	7.2	21.6	27.2	7.4	-0.4	-5.6
BI599/SMD11	3.0	-51.7	-48.7	-55.9	-59.1	-61.3
BI599/SMD12	4.4	-23.0	-20.7	-34.1	-38.8	-42.0
BI599/SMD15	7.7	41.4	80.6	14.0	5.7	0.2
BI855/IR53942	5.6	-25.9	-10.9	-17.3	-23.3	-27.3
BI855/CR8	9.8	31.4	48.8	46.7	36.1	29.0
BI855/CR9	6.3	-19.2	-17.3	-5.6	-12.5	-17.0
BI855/SMD9	8.4	11.6	18.9	24.5	15.5	9.5
BI855/SMD10	6.4	-14.7	-4.8	-4.9	-11.8	-16.3
BI855/SMD11	9.9	32.0	45.3	47.3	36.6	29.5
BI855/SMD12	5.3	-28.8	-19.4	-20.5	-26.3	-30.1
BI855/SMD15	6.7	-10.8	26.6	-0.5	-7.7	-12.5
BI665/IR53942	9.2	39.3	58.6	36.3	26.5	19.9
BI665/CR8	6.6	0.1	6.8	-2.1	-9.1	-13.9
BI665/CR9	6.5	-17.4	-10.1	-3.5	-10.5	-15.1
BI665/SMD9	7.9	19.5	19.5	16.9	8.5	2.8
BI665/SMD10	6.2	-6.3	-1.5	-8.3	-14.9	-19.3
BI665/SMD11	8.1	22.5	26.9	19.9	11.2	5.4
BI665/SMD12	5.0	-24.2	-19.2	-25.8	-31.2	-34.8
BI665/SMD15	4.8	-26.6	0.2	-28.1	-33.3	-36.8

Note: Ht = heterobeltiosis, MP = mid parent heterosis.

Heterobeltiosis, mid-parent heterosis and standard heterosis of new hybrid

Heterosis value of yield character of the 32 hybrids is shown in Table 5. The hybrid derived from WA CMS showed varied heterobeltiosis value between -51.67 to 54.98%. Six hybrids have heterosis values above 20% over the best parent. Two hybrids performed the highest heterobeltiosis, with the yield up to 8.38 and 10.21 t/ha respectivelly. The hybrids were BI485/IR53942 and BI599/IR53942, they gave yield 48.9% and 55.0% better than the best parent. Heterosis against average among two parents is expressed as mid-parent heterosis. Seven hybrids showed mid-parent heterosis more than 20%. The best hybrid in the Wild Abortive group namely BI599A/SMD 15 produced yield 80.55% higher than their parents.

Table 5 shows that WA CMS type produced three hybrids and two hybrids with standard heterosis > 20% compared to Inpari13 and Hipa6 Jete. The best hybrid from CMS WA-type group was BI485A/IR53942 with heterosis value 52.2% higher than Ciherang, 41.2% higher than Inpari13 and 33.8% higher than Hipa6 Jete. Hybrids from CMS type Gambiaca produces three hybrids that > 20% superior to Ciherang and 23 standard heterosis hybrids that show > 20% compared to Hipa6 Jete and Inpari13. Hybrids with the highest standards heterosis was BI855A/SMD11 (9.88 t/ha). The hybrid has standard heterosis 47.3% higher than Ciherang, 36.6% higher than Inpari13 and 29.5% higher than Hipa6 Jete. In contrast to hybrids derived from CMS type WA and type Gambiaca, hybrid from CMS type Kalinga, namely BI665A/IR53942 is only able to achieve the standard value of heterosis less than 20% when compared to Hipa6 Jete. However, the hybrids showed standard heterosis more than 20% compared to Inpari13 and Ciherang.

DISCUSSION

To initiate an effective hybrid breeding program, information on the combining ability of inbred lines is an essential and critical factor for selection of the best parents and the best hybrid. The analysis illustrated in the experiment showed that lines and testers used in the breeding of the hybrids had high variability for observed traits. Pratap *et al.* (2013) was also found that among the tested hybrid rice population and the parents, the variance value of the line, tester and their interaction were quite high, shown variation among CMS, restorer and the hybrids diverse. CMS and restorers having good traits were expected to be able to produce hybrids with high heterosis. High interaction proportion between line x tester to the total variance than the proportion of each line or tester indicated that the variance in hybrid population was caused by high GCA (Chakraborty *et al*., 2009; Rahimi *et al*., 2010).

The proportional contribution of lines, testers and their interactions to total variances showed that tester had an important role for characters of fertile and sterile spikelet per panicle, spikelet fertility and grain yield and indicated the dominant influence of R line on the character. The line had the significant role in the breeding of hybrid rice, especially for the character of days to flowering, plant height and panicle length. This result indicated the high maternal effect on these characters. Improvement of the male sterile line for these characters is very important. Contributions of maternal and paternal interaction (line x tester) showed high value on the character of plant height, fertile and sterile spikelet per panicle, panicle length and grain yield. This result is in agreement to the result of Dar *et al.* (2014) and Hassan *et al.* (2013).

The value of interaction contributions of line x tester indicated the magnitude of SCA effect compared to GCA in a test population (Sarker *et al.,* 2002). Raju *et al.* (2014) stated that there was no direct relationship between the effects of parental GCA with SCA effects derivatives hybrid. This can only be explained in more detail from the point of view of gene action because in general GCA is more influenced by additive gene action while SCA is caused by dominant over gene action and epistasis.

Exploitation of hybrid vigor is determined by the appearance of the hybrid and the amount of heterosis. The amount of heterosis can be estimated by calculating the advantage of the hybrid compared to the average of the parents (mid-parent heterosis), best parent (heterobeltiosis) and check varieties (standard heterosis). Hybrid performance cannot be predicted simply by mid-parent and heterobeltiosis. Hybrid combinations will have commercial value if it shows high and real standard heterosis against the popular varieties by farmers. Standard heterosis is hybrid performance reflection per se (Malini *et al.*, 2006). For grain yield, heterosis value can be estimated on the best parent, average parent and two check varieties. Grain yield is economical character and heterosis value of this character is important for plant breeding (Patil *et al.*, 2011). Tiwari *et al.* (2011) state that the hybrid give yield excess 20-30% compared to the inbreed varieties will encourage farmers to adopts the hybrid.

Observation on grain yield showed that CMS with cytoplasmic wild abortive (WA) is able to produce more hybrid combinations with high heterosis, either for heterobeltiosis, mid-parent heterosis or standard heterosis, compared to CMS type Kalinga and Gambiaca. These indicated that the CMS types WA has good combining ability with the available R line. In this study, CMS type of Kalinga and Gambiaca did not produce many hybrids with high heterosis. This revealed the need to improve specific R lines for those two CMS. However, some of R lines were also appropriate for breeding of hybrid rice with CMS type Gambiaca or Kalinga, because some of the hybrids-derived have standards heterosis more than 20% with yield around 8.36-9.88 t/ha for Gambiaca-type and 8.05 – 9.15 t/ha for Kalinga-type. The results showed that the restorer lines specific for Kalinga and Gambiaca-type need to be develop in the future to produce a higher yield of hybrids. Sattari *et al.* (2008) were reported the genetic relationship of WA, Dissi and Gambiaca male sterile lines. A similar biological processes govern fertility restoration in the WA and Gambiaca system. It was governed by two independent and dominant genes with classical duplicate gene action. The similar system of them were indicated that the restorer lines of wild abortive supposed to be compatible as restorer of Gambiaca lines.

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