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Heterosis and Restoring Ability of Some Cytoplasmic Male Sterile and Suggested Restorer Rice Lines

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THE PRESENT investigation was conducted at the Experimental Farm of Faculty of Agriculture, Kafrelsheikh University, Egypt during 2011 and 2012 seasons. Four cytoplasmic male sterile (CMS) lines having different cytoplasmic source, namely G46A, D297A, Yimi15A and V20A beside ten male parents and their forty F_1 hybrids as well as the iso genic maintainers of the CMS lines were the materials of this study. Sakha 105, Sakha 106 and Sakha 101 rice cultivars were identified as good maintainers for the CMS lines G46A and D297A. Contrary, Giza 182, Giza 178, Giza 181and Wita 12 were identified as good restorers for the two previous CMS lines and V20A. Most of the combinations showed either partial restorers or partial maintainers. The CMS lines G46A and D297A were easy to restore and the opposite was true for the CMS line Yimi 15A as it has japonica type which is difficult to restore. D297A x Giza 182, V20A x Giza 178 and G46A x Giza 178 were the best combinations for grain yield (high heterobeltiosis values). D297A x Giza 178 and D297A x Gz.1368 were promising hybrids for recombination breeding for grain yield, V20A x IET1444 for number of panicles/ plant, while Yimi15A x Sakha 106 and Yimi15A x Sakha 105 were promising hybrids for recombination breeding for early heading.

Keywords: Cytoplasmic male sterility, Rice, Heterosis, Potence ratio, Restoring ability .

Rice (*Oryza sativa* L.) is life for major population of the world. It provides over 3 billion persons of the world population by about 50-80% of their calorie intake (Amirjani, 2011). The current level of rice production will not meet future demand either in national or international level. Egypt has to increase the average national rice yield by about 25-30% to meet the demand of increasing population. Yield of traditional rice cultivar is now considered to have reached the plateau. So, achieving further yield improvement is now unsatisfactory.

Exploitation of heterosis through hybrid rice technology is an important strategy to increase grain yield beyond the present ceiling. Identification of effective maintainers and restorers are of great importance in any hybrid rice breeding program based on cytoplasmic male sterility (Bijral *et al.*, 1991). It is important to diversify the cytoplasmic base of the CMS lines used by hybrid rice breeders to protect CMS-based hybrid rice against genetic vulnerability which can associated with a single cytoplasm source (Casal *et al.,* 2001).

From 239 tested rice genotypes, 12 restorers and 16 maintainers were identified and most of genotypes were found partial restorers and partial maintainers (Akhter *et al.,* 2008). There is considerable variation in frequency of maintainers and restorers for different CMS lines and with lines from different sources, the average frequency of maintainers were 5% over the tested crosses (Eusebio *et al.,* 2002).

The CMS lines differed from each other in their restoration, the CMS line IR58025A was easy to restore compared with Pusa 5A and Pusa 3A based on spikelet fertility (Zaman *et al.,* 1995).

High yield of the hybrid rice was attained by the summation of the increase in each of yield components (Virmani, 1996). Desirable heterotic effects were detected for each of heading date (Li *et al.,* 2002 and Jarwar *et al.,* 2012); plant height (Jarwar *et al.,* 2012); panicle length (Muhammad *et al.,* 2007); No. of spikelets/ panicle (El-Keredy *et al.,* 2007). Presence of heterosis for yield and yield components were reported by Roy & Mandel (2001). Significant heterosis was observed for most of the studied traits (Hong *et al.,* 2002). Favorable significant heterosis were observed for number of filled grains/ panicle, number of effective tillers/ plant, 1000-grain weight and grain yield (Alam *et al.,* 2004). The objectives of this study were:

-To evaluate 10 suggested restorers and 4 elite cytoplasmic male sterile lines with different cytoplasmic source beside forty F_1 hybrid rice combinations for their status in hybrid rice breeding program.

-To study the maintenance and restoring ability of the pollen parents over different cytoplasmic sources.

- An attempt to select super hybrids for commercial exploitation and identify the best combination of the important characters for recombination breeding program.

Materials and Methods

Four cytoplasmic genetic male sterile rice (CMS) lines having diverse cytoplasmic source namely, G46A (Gambica cytoplasmic source), D297A (Dissi), Yimi15A (Dian type) and V20A (Wild abortive cytoplasmic source) were involved in this study. These CMS lines were crossed through Line x tester mating design (Kempthorne, 1957) in 2011 summer season with ten suggested restorers viz Sakha 106, Giza 182, Giza 178, Giza 181, Sakha 101, Wita 4, Wita 12, Gz.1368-5-4, IET 1444 and Sakha 105 rice cultivars. The CMS lines beside Wita 4 and Wita 12 were kindly provided by Prof. El-Keredy, Agron. Dept., Fac. of Agric., Kafrelsheikh University, Egypt.

Parentage, cytoplasmic source, origin and plant type of the parental of this investigation were as mentioned by El-Degwy (2013).

The ten pollen parents and their forty F_1 hybrids beside the four iso genic maintainers of the CMS lines were grown at the Experimental Farm of Faculty of Agriculture, Kafrelsheikh University, Egypt during 2012 summer season.

The experiment was laid out in a Randomized Complete Blocks Design with three replications. Each replication contained 54 experimental units. The 54 genotypes were sown in plastic trays on the fourth of May 2012. Thirty days old seedlings were transplanted with a single seedling per hill. Each experimental unit consisted of five rows of 3 m length with spacing of 20 cm between rows and 20 cm between plants. The type of the soil was clay, and the scientific name according to FAO is Typic Torrifluvent (Soil Survey Staff, 2010).

The observations were recorded for; days to 50% heading (when 50% of the plants in the plot reached to heading) as well as, plant height (cm), panicle length (cm), No. of primary branches/ panicle, No of spikelets/ panicle, fertility percentage, No. of filled grains/ panicle, No. of panicles/ plant, 1000-grain weight (g) and grain yield (kg/m^2) when the plants of each variety reached to the ripping stage. The data were recorded for the iso genic maintainers of the CMS lines instead of the CMS lines.

Analysis of variance of a Randomized Complete Blocks Design was conducted. Heterobeltiosis and potence ratio was calculated according to Mather & Jinks (1971). Maintainers and restorers were identified according to the scale of Manuel & Rangaswamy (1993) as follows: Restorers (Spikelet fertility in F_1 more than 80%), Partial restorers (spikelet fertility 20–80%), Partial maintainers (spikelet fertility 5–20%) and Maintainers (spikelet fertility less than 5%).

Results and Discussions

The average of genotypes as parents and hybrids after 4 x 10 factorial mating design for all the studied characters are presented in Table 1.

Growth characters

Rice genotypes differed from each other in their performance. Sakha 105 rice cultivar was the earliest parent as it reached to 50% heading after 93 days from sowing. Furthermore, the hybrid rice combination derived from such parent and the CMS line Yimi 15A was the earliest genotype and headed after 90 days from sowing. Most of the rice hybrids were later than their parents except rice combinations derived from the CMS line Yimi 15A with each of Sakha 106, Wita 12, Gz.1368, IET 1444 and Sakha 105. Vice versa, G46A X Wita 4 was the latest genotype and reached to 50% heading after 136 days from sowing.

The CMS line V20 A recorded the lower value for plant height (79.3 cm). Also, the hybrid plants derived from it with Giza 178 and IET1444 recorded significantly lower plant height than the other genotypes; 82.2 and 83.4 cm, respectively. Among the parental lines, the CMS line Yimi 15A and the pollen parent Wita 4 recorded the highest plant height; 95.1 and 119.5 cm, respectively. Also the hybrid rice derived from them recorded the tallest genotypes (121.2 cm).

TABLE 1. Means of parents and F_1 hybrids after 4 x 10 factorial crosses in rice for all the studied characters.

Genotypes	Growth characters					Grain yield and yield related characters				
	Days to 50% heading	Plant height (cm)	Panicle length (cm)	No. of primary branches/ panicle	No. of spikelets/ panicle	Fertility (%)	No. filled grains/ panicle	No of panicles/ plant	1000-grain weight (g)	Grain yield (kg/m^2)
Lines										
1- G46A	96	92.1	24.3	10.6	176.6	95.7	169.0	14.2	24.3	0.76
2- D297A	101	84.8	21.0	11.4	129.4	97.4	124.6	14.0	25.6	0.60
3- Yimi15A	104	95.1	20.7	10.8	170.6	93.0	158.6	17.8	26.3	0.84
4- V20A	101	79.3	23.0	9.7	150.0	94.4	141.6	12.6	25.7	0.70
S. Restorers**										
Sakha 106	94	91	22.4	12.8	130.4	94.6	123.5	15.6	28.2	0.68
Giza 182	101.1	87.3	24.6	9.4	120.6	92.9	112.0	19.4	26.2	0.70
Giza 178	100	94.4	22.7	10.2	180.8	98.2	177.6	17.8	20.1	0.82
Giza 181	107	92.6	22.3	9.8	133.0	91.0	121.0	14.0	25.7	0.71
Sakha 101	106	83.0	22.8	12.6	152.4	97.3	148.4	15.8	27.3	0.75
Wita 4	97	111.1	29.3	12.2	244.0	92.1	225.0	22.8	22.4	0.88
Wita 12	117	119.5	28.5	13.2	207.0	94.7	196.0	16.6	23.6	0.93
Gz.1368	103	104.0	21.7	9.6	123.4	98.3	121.4	20.8	24.4	0.69
IET 1444	100	98.2	22.9	9.0	140.2	97.1	136.2	17.0	24.2	0.68
Sakha 105	93	85.0	20.5	10.7	113.0	96.9	109.5	14.6	28.7	0.65
Crosses										
P1 x Sakha 106	116	120.3	26.7	13.2	250.4	1.4	3.4	18.4	30.7	0.02
P1 x Giza 182	102	101.5	24.5	11.4	173.4	92.5	160.4	15.4	27.8	0.89
P1 x Giza 178	102	89.0	22.5	11.0	165.6	93.0	154.0	19.8	25.1	0.95
P1 x Giza 181	129	93.4	28.1	13.0	250.2	88.3	221.0	13.6	24.4	0.91
P1 x Sakha 101	126	102.1	26.5	14.0	268.5	0.20	0.50	14.4	28.5	0.01
P1 x Wita 4	136	97.0	25.1	13.8	240.6	30.7	73.8	16.2	17.9	0.36
P1 x Wita 12	129	111.6	28.8	13.8	239.6	80.1	192.0	15.6	21.9	0.87
P1 x Gz.1368	127	90.2	24.3	12.6	191.6	67.0	128.4	13.2	23.1	0.60
P1 x IET 1444	106	101.8	25.1	12.8	220.2	9.9	21.8	16.0	24.3	0.11
P1 x Sakha 105	115	110.7	27.5	13.0	246.0	0.80	2.0	12.2	30.9	0.01

P1 = G46A ** suggested restorers

TABLE 1. Cont.

Genotypes	Growth characters					Grain yield and yield related characters				
	Days to 50% heading	Plant height (cm)	Panicle length (cm)	No. of primary branches / panicle	No. of spikelets/ panicle	Fertility (%)	No. filled grains/ panicle	No of panicles/ plant	1000-grain weight (g)	Grain yield (kg/m^2)
P2 x Sakha 106	108.0	94.0	23.0	13.0	183.4	4.3	7.9	16.2	27.0	0.03
P2 x Giza 182	105.0	90.4	22.8	10.6	145.9	93.4	136.0	19.6	27.5	1.04
P2 x Giza 178	106.0	93.2	22.2	10.8	155.5	90.2	140.0	16.2	24.8	0.84
P2 x Giza 181	127.0	86.4	25.6	11.6	190.1	89.7	171.2	12.6	24.9	0.77
P2 x Sakha 101	121.0	96.2	25.5	13.6	244.5	0.49	1.20	15.6	28.5	0.01
P2 x Wita 4	114.0	98.6	24.1	12.6	171.6	68.6	115.8	15.8	26.5	0.93
P2 x Wita 12	127.0	101.4	26.2	12.6	199.5	80.8	160.6	14.4	22.0	0.64
P2 x Gz.1368	121.0	88.6	23.7	12.0	168.6	77.3	130.0	16.6	21.8	0.70
P2 x IET 1444	106.0	88.4	22.5	10.6	167.2	7.7	12.8	15.4	24.4	0.11
P2 x Sakha 105	117.0	86.1	25.2	12.8	194.8	1.4	1.80	18.0	23.6	0.02
P3 x Sakha 106	93.0	107.0	19.5	12.5	173.0	11.6	20.0	13.4	28.5	0.10
P3 x Giza 182	102.0	111.0	22.6	10.6	165.0	39.0	64.4	17.0	27.2	0.42
P3 x Giza 178	102.0	110.2	22.7	10.8	181.4	39.0	70.8	17.4	26.9	0.50
P3 x Giza 181	105.0	107.0	23.7	10.4	162.6	35.1	57.0	14.2	27.6	0.34
P3 x Sakha 101	106.0	89.3	20.7	11.4	159.4	6.8	10.8	14.8	26.0	0.05
P3 x Wita 4	106.0	116.0	24.2	10.0	189.4	12.0	22.8	15.6	25.7	0.16
P3 x Wita 12	98.0	121.2	23.9	11.0	147.4	73.8	108.8	15.6	26.3	0.72
P3 x Gz.1368	101.0	88.8	21.9	10.4	150.6	32.1	48.4	18.0	26.4	0.50
P3 x IET 1444	99.0	115.0	23.1	11.4	181.4	55.8	101.2	17.8	26.6	0.70
P3 x Sakha 105	90.0	80.4	20.8	9.8	133.4	17.8	23.8	15.4	27.1	0.08
P4 x Sakha 106	112.0	93.6	27.5	13.6	229.2	0.52	1.2	11.6	28.7	0.01
P4 x Giza 182	108.0	84.3	22.9	10.4	154.8	85.3	132.0	12.4	27.0	0.51
P4 x Giza 178	105.0	82.2	22.2	9.8	143.6	95.4	137.0	19.6	23.8	0.98
P4 x Giza 181	134.0	85.2	26.2	12.0	170.0	76.6	130.2	16.2	20.9	0.41
P4 x Sakha 101	128.0	86.2	24.7	11.6	186.0	3.9	7.20	22.8	27.3	0.05
P4 x Wita 4	118.0	102.0	27.0	12.0	177.8	49.5	88.0	18.4	26.8	0.43
P4 x Wita 12	109.0	86.0	27.8	10.6	153.6	94.0	145.6	14.5	26.3	0.74
P4 x Gz.1368	122.0	84.0	24.2	11.4	145.8	77.0	112.2	18.0	19.8	0.73
P4 x IET 1444	105.0	83.4	22.4	10.0	135.2	17.5	23.6	16.6	23.7	0.18
P4 x Sakha 105	100.0	90.2	24.2	11.0	183.8	7.2	13.2	14.4	23.3	0.10
L.S.D 0.05	5.2	3.7	1.1	0.4	31.3	3.8	4.5	0.93	0.52	0.12
0.01	7.4	5.3	1.5	0.5	44.6	5.4	6.5	1.3	0.74	0.16

P2 = D297A P3 = Yimi15A P4 = V20A

Concerning panicle length, results in Table 1 Showed that G46A x Wita 12 rice hybrid beside their parents had the longest panicle compared with the other genotypes.

Wita 12 and D297A rice parents gave more number of primary branches/ panicle compared with the other parents. The F_1 hybrid plants derived from the CMS line G46A with each of Sakha 101, Wita 4, Wita 12, Sakha 105 and IET1444 exhibited higher mean values of this trait compared with the other hybrids.

Rice genotypes were significantly differed in their No. of spikelets/ panicle. Among the CMS lines, G46A recorded the highest mean value (176.6). Also, the hybrid rice plants derived from this line with Sakha 101 recorded the highest No. of spikelets/ panicle (268.5) compared with the other genotypes. These results were in accordance with those reported by El-Keredy *et al*. (2007).

Yield and yield related characters

As shown in Table 1, V20A x Giza 178 was the most desirable hybrid for high fertility percentage (95.4%) followed by V20A x Wita 12 (94%), D297A X Giza 182 (93.4%) and G46A X Giza 178 (93%). Large variation among rice genotypes was detected for No. of filled grains/ panicle. G46A x Giza 181 recorded the highest mean value of this trait (221) compared with the other hybrids followed by G46A X Wita 12 (192).

The CMS line Yimi 15A exceeded the other CMS lines in No. of panicles/ plant (17.8). Also, Wita 4 recorded the most favorable mean value of this trait among the suggested restorers (22.8) followed by Gz.1368 (20.80). V20A x Sakha 101 rice hybrid was the best combination for No. of panicles/ plant. Compared with other suggested restorers, Sakha 105 rice cultivar recorded the most desirable 1000-grain weight (28.7 g) followed by Sakha 106 rice cultivar (28.2 g). Also, the F_1 hybrid rice combination between such parents and G46A recorded the most favorable value for 1000-grain weight.

D297A x Giza 182 recorded the best mean value for grain yield (1.04 kg/ m^2) followed by V20A x Giza 178 (0.98 kg/ m^2), G46A x Giza 178 (0.95 kg/ m^2) and D297A x Wita 4 (0.93 kg/ m^2). The highest performance values of F_1 hybrids concerning grain yield may be attributed to increasing No. of filled grains/ panicle, No. of panicles/ plant and 1000-grain weight.

Maintenance and restoring ability

Maintainers and restorers were identified according to the scale of Manuel & Rangaswamy (1993) as presented in Table 2. It is clear that Giza 182, Giza 178 and Wita 12 rice parents were identified as restorers for the CMS lines G46A, D297A and V20A. Contrary, Sakha 106 and Sakha 101 rice cultivars were identified as maintainers for the same aforementioned CMS lines (spikelet fertility more than 80%).

TABLE 2. Classification of the parents regarding to restoring ability.

Pollen parents	Spikelet fertility of hybrids with particular CMS line			
	G46A	**D297A**	**Yimi15A**	**V20A**
Sakha 106	M	M	PM	M
Giza 182	R	R	PR	R
Giza 178	R	R	PR	R
Giza 181	R	R	PR	PR
Sakha 101	M	M	PM	M
Wita 4	PR	PR	PM	PR
Wita 12	R	R	PR	R
Gz.1368	PR	PR	PR	PR
IET 1444	PM	PM	PR	PM
Sakha 105	M	M	PM	PM

M - Maintainer PM - Partial maintainer R - Restorer PR – Partial restorer.

Giza 181was identified as restorer for the CMS line G46A and D297A and partial restorer for Yimi 15A and V20A. While, Sakha 105 rice cultivar was identified as maintainer for G46A and D297A. However, the other combinations were identified either partial maintainers or partial restorers which have less of interest in hybrid rice breeding program.

Results also showed that four testers restored the CMS lines G46A and D297A. Also, three testers restored V20A while, none of the tested parents restored the CMS line Yimi 15A, indicating that G46A and D297A were easy to restore while, Yimi 15A was hardly to restore. The difficultly of restoring ability of Yimi 15A may be due to this CMS line belongs to japonica type and most of restorer lines frequency were belongs to indica type, suggesting high sterility percentage in F_1 hybrids. These results were, in general, agree with those reported by Murayama & Sarker (2002) who found that F_1 hybrids from crosses between japonica and indica rice show variable degrees of sterility.

Previous studies showed that among 239 rice genotypes tested for their status in hybrid rice gene pool, 12 restorers and 16 maintainers were identified. Most of genotypes were found to be partial restorers and partial maintainers. (Akhter *et al*., 2008).

There are considerable variations in frequency of maintainers for different CMS lines. The average frequency was 5% over the tested crosses. Considerable variability in frequency of restorers over different CMS lines and with lines from different sources (Eusebio *et al.,* 2002).

Heterosis

Growth characters

The deviation of the F_1 generation means from the better parent (heterobeltiosis) and potence ratio for the studied growth characters are presented in Table 3. Most of F_1 hybrids exceeded its respective better parent for No. of days to 50% heading. Only one hybrid namely; Yimi 15A x Wita 12 recorded significant negative heterobeltiosis (-5.8%). While, the other crosses were not significant or had positive values which had less of interest from plant breeder point of view. The beneficial effects for heading date were due to over dominance where, the potence ratio (as measure of dominance) was more than unity. These results were in general accordance with those of Hammoud *et al.* (2008).

TABLE 3. Heterobeltiosis (H) and potence ratio (P.) for the studied growth characters in F_1 generation after 4 x 10 factorial crosses in rice.

Hybrids	Days to 50% heading		Plant height		Panicle length		No. of primary branches/ panicle		No. of spikelets/ panicle	
	H	P	H	P	H	P	H	P	H	P
P1 x Sakha 106	23.4**	-21.0	32.2**	-52.18	9.9**	3.47	3.1*	1.36	41.8**	4.19
P1 x Giza 182	6.3*	-1.3	16.3**	-4.92	-0.4	0.0	7.5*	2.33	-18.1	0.88
P1 x Giza 178	6.3*	-2.0	-3.4	3.74	-7.4**	-1.25	3.8*	3.0	-8.4	-6.23
P1 x Giza 181	34.4**	-5.0	1.4	-4.0	15.6**	4.8	22.6**	7.0	41.7**	4.37
P1 x Sakha 101	31.3**	-5.0	23.0**	-6.44	9.1**	3.87	11.1**	2.4	52.04**	8.60
P1 x Wita 4	41.7**	-79.0	5.3*	0.48	-14.3**	-0.68	13.1**	3.0	-1.39	0.90
P1 x Wita 12	34.4**	-2.14	21.2**	-0.42	1.1	1.14	4.5*	2.9	15.75*	3.15
P1 x Gz.1368	32.3**	-7.9	-2.1	1.33	0.0	1.0	18.9**	5.0	8.49	1.56
P1 x IET 1444	10.4**	-2.0	10.5**	-2.16	3.3	2.14	20.8**	3.75	24.7*	3.40
P1 x Sakha 105	23.7**	-13.3	30.2**	-6.23	13.2**	2.68	21.4**	46.0	39.3**	3.18
P2 x Sakha 106	14.9**	-3.0	10.8**	-1.96	2.7	1.86	1.6	1.43	40.6**	107.0
P2 x Giza 182	4.0	-78.0	6.6**	-3.44	-7.3**	0.0	-7.0**	0.20	12.8	4.78
P2 x Giza 178	6.0*	-11.0	9.9**	-0.75	-2.2	0.35	-5.3*	0.0	-14.0	0.02
P2 x Giza 181	25.7**	-7.6	1.9	0.59	14.8**	6.0	1.8	1.25	42.9**	196.3
P2 x Sakha 101	19.8**	-7.0	15.9**	-13.66	11.8**	4.0	7.9**	2.67	60.4**	9.0
P2 x Wita 4	17.5**	-7.5	16.3**	-0.05	-17.7**	-0.27	3.3*	2.0	-29.7**	-0.26
P2 x Wita 12	25.7**	-2.25	19.6**	0.05	-8.1**	1.31	-4.5**	0.33	-3.6	0.81
P2 x Gz.1368	19.8**	-19.0	4.5*	0.60	8.4**	6.57	5.3**	1.67	30.3*	14.07
P2 x IET 1444	6.0*	-11.0	4.2	0.46	-1.7	0.53	-7.0**	0.33	19.3	6.0
P2 x Sakha 105	25.8**	-5.0	1.5	-12.0	20.0**	17.6	12.2**	4.86	50.5**	8.98

P1 =G46A P2 = D297A

* and ** : significant at the 0.05 and 0.01 level of probability, respectively.

TABLE 3. Cont.

Hybrids	Days to 50 % heading		Plant height		Panicle length		No. of primary branches/ panicle		No. of spikelets/ panicle	
	H	P	H	P	H	P	H	P	H	P
P3 x Sakha 106	-1.1	1.2	17.6**	-6.78	-12.9**	-2.47	-2.3	0.7	1.4	1.13
P3 x Giza 182	0.90	0.4	27.1**	-5.1	-8.1**	-0.05	-1.9	0.71	-3.3	0.78
P3 x Giza 178	2.0	0.0	16.7**	-44.0	0.0	1.0	0.0	1.0	0.33	1.12
P3 x Giza 181	1.0	0.33	15.6**	-10.48	6.30*	2.75	-3.7*	0.20	-4.7	0.57
P3 x Sakha 101	1.9	-1.0	7.6**	-0.03	-9.2**	-1.05	-9.5**	-0.55	-6.6	-0.23
P3 x Wita 4	9.3**	-1.57	22.0**	-1.6	-17.4**	-0.19	-18.0**	-2.14	-22.4**	-0.49
P3 x Wita 12	-5.8*	1.92	27.4**	-1.14	-16.1**	-0.18	-16.7**	-0.83	-28.8**	-2.27
P3 x Gz.1368	-1.9	5.0	-6.6**	2.43	0.90	1.40	-3.7*	0.67	-11.7	0.15
P3 x IET 1444	-1.0	1.5	20.9**	-22.88	0.90	1.18	5.6**	1.67	6.3	1.71
P3 x Sakha 105	-3.20	1.55	-5.4*	3.88	0.50	2.00	-9.3**	-20.0	-21.8*	-0.29
P4 x Sakha 106	19.1**	-4.0	18.0**	-1.44	19.6**	16.0	6.3**	1.48	52.8**	9.08
P4 x Giza 182	6.9*	-138.0	6.3*	-0.25	-6.9**	-1.13	7.2**	5.33	3.2	1.33
P4 x Giza 178	5.0	-9.0	3.7	0.62	-3.50	4.67	-3.9*	-0.80	-20.57*	-1.42
P4 x Giza 181	32.7**	-10.0	7.4**	0.12	13.9**	10.0	22.4**	44.0	13.3	3.32
P4 x Sakha 101	26.7**	-9.8	8.7**	-5.26	7.4**	18.0	-7.9**	0.28	22.0*	29.0
P4 x Wita 4	21.6**	-9.5	28.6**	-0.43	-7.8**	0.25	-1.6	0.80	-27.1**	-0.41
P4 x Wita 12	7.9**	0.0	8.4**	0.67	-2.5	0.73	-19.7**	-0.51	-25.8**	-0.87
P4 x Gz.1368	20.8**	-20.0	5.9*	0.62	5.2*	2.77	17.5**	34.0	-2.8	0.63
P4 x IET 1444	5.00	-9.0	5.2*	0.57	-2.6	-12.0	3.1	1.71	-9.9	-2.02
P4 x Sakha 105	7.5*	-0.75	13.7**	-2.81	5.2*	1.92	2.8	1.60	22.5*	2.83
L.S.D 0.05	5.2		3.7		1.05		0.4		31.3	
0.01	7.4		5.3		1.5		0.52		44.6	

P3 = Yimi15A P4 = V20A

* and ** : significant at the 0.05 and 0.01 level of probability, respectively.

Among 40 F_1 hybrids, only two hybrids; Yimi 15A x Gz.1368 and Yimi 15A x Sakha 105 recorded significantly negative heterobeltiosis for plant height (-6.6 and -5.4%, respectively), indicating that these hybrids were shorter than their parents. The beneficial heterotic effects for plant height were due to over dominance where potence ratio was more than unity. Tallness may be dominated over dwarfness (El-Hity, 1993**.** Heterobeltiosis for plant height ranged from 3.25 to 32.21% (Saleem *et al*., 2008). These results were also in accordance with those reported by Jarwar *et al*. (2012) who found negative heterosis for days to 50% flowering and plant height.

Fourteen out of forty hybrids exhibited significant positive heterobeltiosis estimates for panicle length. Such estimates ranged from 5.2 for V20A x Sakha 105 rice hybrid to 19.6% for V20A x Sakha 106 rice hybrid. The beneficial heterotic effects for panicle length were due to over dominance. These results were in accordance with those reported by El-Keredy *et al*. (2007). Desirable heterotic effects were observed for panicle length (Rahimi *et al.,* 2010).

The desirable heterotic effects for No. of primary branches/ panicle were observed for 18 out of 40 tested F1 hybrids. G46A x Giza 181 recorded the most favorable value (22.6%) followed by V20A x Giza 181 (22.4%) and G46A x Sakha 105 (21.4%). Significant deviation of the F1 generation means from the better parent for No. of spikelets/ panicle were detected for 14 out of 40 hybrids. Such estimates ranged from 15.75 to 60.40 for the crosses G46A x Wita 12 and D297A x Sakha 101, respectively. On the other hand, the remaining crosses were not significant or had negative values which are not of interest from the plant breeder point of view.

Yield and yield related characters

Data illustrated in Table 4 revealed that none of the hybrids showed significant positive heterobeltiosis for fertility percentage as all hybrids showed significant or insignificant negative heterobeltiosis estimates. Previous results showed that only 6 out of 239 combinations had more than 80% spikelet fertility (Akhter *et al*., 2008).

Regarding to No. of filled grains panicle/ panicle, results revealed that only four crosses namely; G46A x Giza 181, D297A x Giza 182, D297A x Giza 181 showed significant heterobeltiosis with positive values. Such estimates were 30.8, 9.1, 37.4 and 4.3% for the aforementioned hybrids, respectively. These results were in accordance with those reported by Murayama & Sarker (2002) who reported that a few F_1 hybrids showed positive heterotic effects for No. of filled grains/ panicle and spikelet fertility, but the average heterosis for these traits were negative.

Desirable heterotic effects for No. of panicles/ plant were detected for 6 hybrids. The maximum increase (44.3%) was observed in the hybrid V20A x Sakha 101 followed by D297A x Sakha 105 (23.3%) and G46A x Giza 178 (17.9%). These results were, in general, harmony with those of Vennila *et al.* (2011).

TABLE 4. Heterobeltiosis (H) and potence ratio (P.) for grain yield and yield related characters in F_1 generation after 4 x 10 factorial crosses in rice.

Hybrids	Fertility (%)		No. filled grains/ panicle		No of panicles/ plant		1000-grain weight		Grain yield	
	H	P	H	P	H	P	H	P	H	P
P1 x Sakha 106	-98.5**	-170.5	-98.0**	-6.28	17.9**	5.14	8.87**	2.3	-97.4**	-17.5
P1 x Giza 182	-3.3	-1.29	-5.1**	0.70	-20.6**	-0.50	6.11**	2.6	17.1*	5.3
P1 x Giza 178	-5.29*	-3.20	-132.9**	-4.49	11.0**	2.1	3.29**	1.4	15.6	5.3
P1 x Giza 181	-77.3**	-2.17	30.8**	3.17	-4.2	-5.0	-5.1**	-0.85	19.7*	6.8
P1 x Sakha 101	-99.8**	-113.4	-99.7**	-15.4	-8.8**	-0.8	4.4**	1.8	-98.7**	-150.0
P1 x Wita 4	-67.9**	-35.8	-67.2**	-4.4	-28.9**	-0.53	-26.3**	-5.8	-59.1**	-7.7
P1 x Wita 12	-16.3**	-30.2	-2.0	0.70	-6.0	0.33	-9.88**	-6.0	-6.5	0.24
P1 x Gz.1368	-31.8**	-23.1	-24.0**	-0.71	-36.5**	-1.3	-5.33**	-26.0	-21.1**	-3.7
P1 x IET 1444	-89.8**	-123.6	-87.1**	-8.0	-5.90	0.3	0.0	1.0	-85.5**	-15.3
P1 x Sakha 105	-99.2**	-212.0	-98.8**	-4.6	-16.4**	-11.0	7.67**	2.0	-98.7**	-12.7
P2 x Sakha 106	-95.6**	-65.5	-93.7**	-211.3	3.80	1.8	-4.26**	0.1	-11.8	-15.3
P2 x Giza 182	-4.1*	-0.80	9.1**	2.80	1.0	1.1	4.96**	5.3	48.5**	7.8
P2 x Giza 178	-8.2**	-19.0	-21.2**	-0.42	-8.9**	0.2	-3.13**	0.7	2.4	1.1
P2 x Giza 181	-7.9**	-1.41	37.4**	26.9	-11.3**	-14.0	-3.11**	-15.0	8.5	2.0
P2 x Sakha 101	-99.5**	-960.9	-99.2**	-11.4	-1.3	5.1	4.4**	2.4	-98.7**	-8.9
P2 x Wita 4	-29.6**	-9.90	-48.5**	-1.20	-30.7**	-0.59	3.5**	1.6	5.7	1.0
P2 x Wita 12	-17.0**	-11.33	-18.1**	0.01	-13.3**	0-.69	-14.1**	-2.6	-31.2**	-0.8
P2 x Gz.1368	-21.4**	-45.80	4.3*	4.40	-20.2**	-0.47	-14.8**	-5.3	1.4	1.1
P2 x IET 1444	-92.1**	-597.33	-6.0**	-20.30	-9.4**	-0.07	-4.7**	-0.7	-83.8**	-13.3
P2 x Sakha 105	-98.6**	-239.0	-98.6**	-15.30	23.3**	12.3	-17.7**	-2.3	-96.9**	-24.4

P1 = G46A P2 = D297A

* and ** : significant at the 0.05 and 0.01 level of probability, respectively.

TABLE 4. Cont.

Hybrids	Fertility (%)		No. filled grains/ panicle		No of panicles/ plant		1000- grain weight		Grain yield	
	H	P	H	P	H	P	H	P	H	P
P3 x Sakha 106	-87.7**	-102.8	-87.4**	-6.9	-24.7**	-3.0	1.1	1.3	-88.1**	-8.25
P3 x Giza 182	-58.1**	-108.0	-59.4**	-3.0	-12.4**	-3.2	3.2**	19.0	-50.0**	-5.0
P3 x Giza 178	-60.3**	-21.8	-60.1**	-10.2	-2.2	-	2.3**	1.2	-40.5**	-33.0
P3 x Giza 181	-62.3**	-56.9	-64.1**	-4.4	-20.2**	-0.9	4.9**	5.3	-59.5**	-6.8
P3 x Sakha 101	-93.0**	-41.1	-93.2**	-27.9	-16.9**	-2.0	-4.8**	-1.6	-94.0**	-16.7
P3 x Wita 4	-87.1**	-179.1	-89.9**	-5.1	-31.6**	-1.9	-2.3**	0.7	-81.8**	-35.0
P3 x Wita 12	-22.1**	-23.6	-44.5**	-3.7	-12.4**	-2.7	0.0	1.0	-22.6**	-3.8
P3 x Gz.1368	-67.3**	-24.0	-69.5**	-4.9	-13.5**	-0.9	0.4	1.1	-40.5**	-3.6
P3 x IET 1444	-42.5**	-19.2	-36.2**	-4.1	0.0	1.0	1.1	1.3	-16.7*	-0.8
P3 x Sakha 105	-81.6**	-46.7	-85.0**	-4.5	-13.5**	-0.5	-5.6	-0.3	-90.5**	-7.1
P4 x Sakha 106	-99.5**	-940.0	-99.2**	-14.5	-25.6**	-1.7	1.8	1.4	-98.6**	-68.0
P4 x Giza 182	-9.6**	-11.2	-6.8**	-0.4	-36.1**	-1.1	3.1**	4.2	-27.1**	-
P4 x Giza 178	-2.9	-0.47	-22.9**	-1.3	10.1**	1.7	-7.4**	0.3	19.5*	12.7
P4 x Giza 181	-18.9**	-9.47	-8.1**	-0.1	15.7**	4.1	-18.7**	-	-42.3**	-60.0
P4 x Sakha 101	-96.0**	-63.0	-95.1**	-40.5	44.3**	5.4	0.0	1.0	-93.3**	-27.2
P4 x Wita 4	-47.6	-38.1	-60.9**	-2.3	-19.3**	0.1	4.3**	1.7	-51.1**	-4.0
P4 x Wita 12	-0.7	-4.0	-25.7**	-0.9	-12.7**	-0.1	2.3*	1.6	-20.4**	-0.7
P4 x Gz.1368	-21.7**	-9.9	-20.8**	-1.9	-13.5**	0.3	-23.0**	-8.1	4.3	6.0
P4 x IET 1444	-81.9**	-58.0	-83.3**	-42.7	-2.4	0.8	-7.8**	-1.7	-74.3**	-51.0
P4 x Sakha 105	-92.5**	-80.3	-90.7**	-7.0	-1.4	0.8	-18.8**	-2.6	-85.7	-23.2
L.S.D 0.05	3.8		4.5		0.93		0.52		0.12	
0.01	5.4		6.5		1.3		0.74		0.16	

P3= Yimi15A P4 = V20A

* and ** : significant at the 0.05 and 0.01 level of probability, respectively.

Fourteen out of forty rice hybrids showed significant or highly significant positive heterotic effects as deviation from the better parent for 1000-grain weight. Such estimates varied from 2.28 to 8.87% for the hybrids Yimi 15A x Giza 178 and G46A x Sakha 106, respectively.

Results in Table 4 showed that only 5 out of 40 F_1 rice hybrids exhibited significant desirable heterotic effects for grain yield, indicating that most of hybrid combinations either drived from pollen parents having weak restoring ability or from CMS line was hardly to restore or from both. The hybrid rice D297A x Giza 182 recorded the most desirable value (48.5%) followed by G46A x Giza 181 (19.7%), V20A x Giza 178 (19.5%), G46A x Giza 182 (17.1%) and G46A x Giza 178 (15.6%). The beneficial heterotic effects for grain yield and yield related characters were due to over dominance where potence ratio was more than unity. Heterosis for grain yield appeared to be due to heterosis for some yield related characters such as No. of filled grains/ panicle, No. of panicles/ plant and 1000-grain weight.

These results were, in general, agreement with those of Rahimi *et al*. (2010) who found favorable heterotic effects for number of panicles/ plant, number of filled grains/ panicle, 1000-grain weight and grain yield.

Based on the aforementioned results it is clear that three rice hybrids; D297A x Giza182, V20A x Giza 178 and G46A x Giza 178 could be used directly to increase grain yield. Also, Sakha 101, Sakha105 and Sakha 106 were identified as maintainers for many CMS lines with different cytoplasmic sources G46A (Gambica), D297A (Dissi type), and V20A (Wild abortive type) so, they could be used in maintainer and CMS breeding programs. Giza 181, Giza 182, Giza 178, and Wita 12 played the role of restorers of many cytoplasmic sources; (Gambica, Dissi and Wild type). Considerable variability in frequency of restorers and maintainers over different CMS lines and with lines from different cytoplasmic sources. The promising hybrids for recombination breeding for each trait are presented in Table 5 according to the method of Nadarajan (1986).

Conclusion

Most of the combinations showed either partial restorers or partial maintainers. Only 5 out of 40 F_1 rice hybrids exhibited heterotic effects for grain yield. Sakha 105, Sakha 106 and Sakha 101 rice cultivars were identified as good maintainers for the CMS lines G46A and D297A. Contrary, Giza 182, Giza 178, Giza 181 and Wita 12 were identified as good restorers for the two previous CMS lines and V20A. The hybrids D297A x Giza 182, V20A x Giza 178 and G46A x Giza 178 were the best combinations for grain yield (high heterobeltiosis values). D297A x Giza 178 and D297A x Gz.1368 were promising hybrids for recombination breeding for grain yield , V20A x IET1444 for number of panicles/ plant, while Yimi15A x Sakha 106 and Yimi15A x Sakha 105 were promising hybrids for recombination breeding for early heading.

TABLE 5. Promising hybrids for recombination breeding for each trait.

Characters	Promising hybrids for recombination breeding
Days to 50% heading	Yimi15A x Sakha 106
	Yimi15A x Sakha 105
Plant height	D297A x Giza 181
	D297A x Sakha 105
	V20A x Giza 178
	V20A x Giza 181
	V20A x Sakha 101
Panicle length	G46A x Giza 181
	G46A x Wita 12
	V20A x Giza 181
	V20A x Wita 12
No. of primary branches/ panicle	G46A x Sakha 101
	D297A x Wita 4
No. of spikelets/ panicle	G46A x Sakha 106
	G46A x Wita4
Fertility	G46A x Gz.1368-5-4
	V20A x Giza 182
	V20A x Giza 181
No. filled grains/ panicle	D297A x Wita12
No of panicles/ plant	V20A x IET1444
1000-grain weight	-------
Grain yield	D297A x Giza 178
	D297A x Gz.1368-5-4

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قوة الهجين و القدرة على اعادة الخصوبة لبعض السلالات العقيمة ذكريا فى الأرز

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اجريت هذه الدراسة بالمزرعة التجريبية بكلية الزراعة- جامعة كفر الشيخ- خلال عامى ٢٠١١ و ٢٠١٢ ، و يهدف هذا البحث إلى دراسة قوة الهجين و القدرة على اعادة الخصوبة فى الارز الهجين. و اشتملت هذه الدراسة على اربعة سلالات من الأرز بها صفة العقم الذكرى السيتوبلازمى الوراثى و هي G46A و D297A و Yimi 15A و V20A. بالإضافة للسلالات المحافظة عليها (Iso-genic maintainers)، و عشرة اصناف من الأرز استخدمت كملقحات. فى عام ٢٠١١ اجريت الهجينات بين هذه السلالات العقيمة و العشرة ملقحات من خلال نظام التزاوج العاملى (Line x Tester) لانتاج بذور اربعون هجين جيل اول. و فى عام ٢٠١٢ تم تقييم هذه الهجن بالاضافة للاباء. وكانت اهم النتائج المتحصل عليها ما يلى:-

أظهرت النتائج ان الاصناف Sakha 105 و Sakha 106 و Sakha 101 لعبت دور السلالة المحافظة الجيدة للسلالتين G46A و D297A . حيث بلغت نسبة الخصوبة فى الجيل الاول لهذه التوليفات اقل من ٥٪ ، فى حين اظهرت النتائج ان الأصناف Wita 12, Giza178, Giza 181, Giza 182 لعبت دور الاب المعيد الجيد للخصوبة لكل السلالات العقيمة ما عدا السلالة Yimi 15Aحيث زادت نسبة الخصوبة فى السنيبلات فى الجيل الأول عن ٨٠٪ .

اوضحت النتائج ان معظم التوليفات أو الهجن فى هذه الدراسة لعبت فيها الأباء اما دور السلالة المحافظة جزئيا على السلالة العقيمة او الأب المعيد جزئيا للخصوبة . كما اوضحت النتائج ان السلالات G46A و D297A من السلالات التى من السهل اعادة الخصوبة فى هجنها. و على العكس كانت السلالة Yimi 15A من السلالات التى يصعب اعادة الخصوبة للهجن الناتجة منها ، و هذا ربما يرجع إلى كونها تنتمى للطراز اليابانى التى يصعب اعادة الخصوبة اليه.

اظهرت النتائج أن الهجن D297A x Giza 182 و V20A x Giza 178 و الهجين G46A x Giza 178 كانت من افضل التوليفات لصفة محصول الحبوب و هذه الهجن يمكن استغلالها مباشرة لدى المزارع و ذلك لتفوقها، و من ناحية اخرى هناك العديد من الهجن التى يمكن استغلالها فى التربية بالانتخاب حتى اجيال متقدمة لتحسين السلالات الأبوية و ذلك لاعادة استخدامها مرة اخرى كاباء محسنة فى برنامج انتاج الهجن بعد ادخال صفات مرغوبة اليها. حيث يمكن استغلال الهجين D297A x Giza 178 و الهجين D297A x 1368-5-4 فى برنامج التربية بالانتخاب لتحسين صفة محصول الحبوب، و الهجين V20A x IET1444 لتحسين صفة عدد السنابل لكل نبات، و الهجين Yimi15A x Sakha 106 للتبكير فى النضج.