



Gene action and combining ability analysis for flower yield and its component traits in interspecific hybrids of marigold (*Tagetes* spp)

NAMITA¹, KANWAR P SINGH², C BHARADWAJ³, T R SHARMA⁴, HUMIRA SONAH⁵, D V S RAJU⁶ and RUPESH K DESHMUKH⁷

Indian Agricultural Research Institute, New Delhi 110 012

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ABSTRACT

A line × tester set of 14 parents involving three male sterile lines of *Tagetes erecta* (African marigold) and 11 inbred lines of *Tagetes patula* (French marigold) and their 33 hybrids were analyzed to understand the nature and magnitude of gene action and to identify the best combiner and cross combinations for flower yield and its component traits. The general combining ability (GCA) and specific combining ability (SCA) components showed the predominance of additive gene action in governing number of flowers/plant and duration of flowering and non additive gene action for days to first flowering, plant height, plant spread, flower weight, flower diameter, stalk length, harvest index and flower yield/plant. Estimates of GCA effects showed that the female parent MS-8 and pollen parents Fr. Sel.1, Fr. Sel.2 and Fr. Sel.10 were the best general combiners. Thus, these parents should involve in interspecific hybridization programme for making flower yield breakthrough in marigold by producing triploids which are having longer flowering duration. The crosses MS 8 × Fr. Sel.1, MS 8 × Fr. Sel. 2 and MS 7 × Fr. Sel. 1 recorded significant desirable SCA effects for maximum number of traits, viz. days to first flowering, plant height, plant spread, number of flowers/plant, flower weight, flower diameter, duration of flowering and flower yield/plant except stalk length and harvest index.

Key words: Combining ability, Flower yield, Gene action, Interspecific, Line × tester, Male sterile line, Marigold

The 'golden revolution' has accelerated a production boom in horticulture where floriculture assumes the position of vibrant commercial venture and traditional loose flowers are an integral part of floriculture. Among loose flowers, marigold (*Tagetes* spp) is one of the most important commercial flowers grown world over and are highly valued for their spectacular flowers, brilliant colours, delightful appearance and is endowed with large spectrum of commercial potentialities in medicinal and industrial sector. *Tagetes erecta* and *T. patula* are more commonly grown for loose flower production and used in landscape architecture due to their variable height and colour of flowers. Presently, most of the varieties being grown in marigold are open-pollinated, which are less vigorous, uneven in height with

low yield and are vulnerable to cross pollination. This situation leads to the degeneration of open pollinated varieties. Thus, efforts are needed to strengthen the genetic flower yield potential of marigold varieties. Being flower yield, a complex trait and a product of a number of component traits, it is great task to enhance the flower yield of new varieties and hybrids. These traits are polygenically inherited and required thorough understanding of the gene action involved in their inheritance. Various studies in vegetable crops have indicated that selection based on additive and dominance genetic variance for growth and flowering traits at early stages can be effective (Pounders *et al.* 2007). Despite extensive application of line × tester mating design in vegetable and field crop genetics, few such studies have been conducted on ornamental crops. Besides elucidating the nature and magnitude of gene action involved in the inheritance of these characters, combining ability analysis also provides useful information for selecting high order parents for effective breeding strategy. line × tester analysis is one of the approaches to know the nature and magnitude of gene action and also to assess the nicking ability of the parents. Therefore, keeping in view the importance of combining ability of the parents for various plant characters

¹Scientist (e mail: namitabanyal@gmail.com), ²Principal Scientist (e mail: kanwar_iari@yahoo.co.in), ⁶Senior Scientist (e mail: rajivalx@gmail.com), Division of Floriculture and Landscaping, ³Principal Scientist (e mail: chbharadwaj@yahoo.co.in), Division of Genetics

⁴Principal Scientist (e mail: trsharma@nrpcb.org), ⁵Senior Research Fellow (e mail: biohuma@gmail.com), ⁷Post Doctorate Fellow (e mail: rupeshmukh@rediffmail.com), National Research Centre for Plant Biotechnology, New Delhi 110 012

in marigold, a line × tester set of 14 parents involving three male sterile lines of African marigold (*T. erecta*) and 11 inbred lines of French marigold (*T. patula*) was studied for gene action and combining ability estimates.

MATERIALS AND METHODS

The materials utilized for the present study, consisted three male sterile lines (MS) of African marigold, namely, MS 5, MS 7 and MS 8 and a set of 11 diverse pollinators (inbred lines) of French marigold numbered as Fr. Sel.1, Fr.Sel.2, Fr.Sel. 3, Fr.Sel. 4, Fr.Sel. 5, Fr.Sel. 6, Fr.Sel. 7, Fr.Sel. 8, Fr.Sel. 9, Fr.Sel. 10 and var. Cherry Red were used as testers (pollen parents) for crossing with MS lines. This genetic material utilized as parents in the line × tester cross was selected from the germplasm purified and maintained at Research Farm of Division of Floriculture and Landscaping, Indian Agricultural Research Institute, New Delhi. The salient features of the parental materials are given in Table 1. The field trials were conducted during rainy season 2006–07 to 2007–08 for the production of F₁ hybrid seeds and their evaluation, respectively at Research Farm of Division located at 77°12'E longitude 28°40'N latitude and at an altitude of 228.16 m above the mean sea level. Seeds of all the parental materials (MS lines and pollinators) were sown in the nursery beds in July 2006 to raise seedlings. Transplanting of these seedlings was done after one month of sowing of the seeds in the nursery. Crop was maintained with following standard cultural practices. For producing F₁ hybrid seeds, male sterile lines were crossed with all 11 testers in 33 cross combinations when their flowers were fully opened. The hybrid seeds, thus obtained along with

parental lines were grown in nursery beds in July 2007. After one month of sowing the seedlings were transplanted in main field in randomized block design with three replications to evaluate interspecific F₁ hybrids and their parental lines. Ten plants were selected for taking observations after discarding the border plants at both the ends. Data were recorded on various growth and yield-related traits, viz days to first flowering, plant height (cm), plant spread (cm), flower diameter (cm), flower weight (g), duration of flowering (days), number of flowers/plant, flower yield/plant (g), stalk length (cm) and harvest index. The line × tester given by Kempthorne (1957) was adopted for gene action and combining ability studies. The variances among the parents and hybrids were partitioned further into source attributable to general and specific combining ability components (GCA and SCA).

RESULTS AND DISCUSSION

Analysis of variance for combining ability

The analysis of variance of combining ability exhibited significant differences among marigold genotypes and their F₁ hybrids for flower yield and its component traits at genotypic level (Table 2). The parent vs hybrids component was significant for most of the traits indicating the manifestation of heterotic response. Analysis for combining ability revealed that variances due to lines (female parents) was significant for all the growth and flowering traits except flower weight and flower diameter, whereas variances due to testers (pollen parents) was significant for all the traits, i.e. days to first flowering, plant height, plant spread, number of flowers/plant, flower weight, flower diameter, stalk length,

Table 1 Salient features of parental lines

Parent	Plant height	Maturity (flowering)	Flower type	Flower form	Flower diameter	Flower colour
<i>Females</i>						
MS 5	Tall	Late	Apetalous	*	Small	Yellow
MS 7	Medium	Late	Apetalous	*	Small	Light orange
MS 8	Tall	Late	Apetalous	*	Medium	Orange
<i>Males</i>						
Fr. Sel.1	Medium	Late	Carnation	Double	Medium	Maroon
Fr. Sel.2	Medium	Late	Carnation	Double	Medium	Yellow
Fr. Sel.3	Dwarf	Mid season	Carnation	Single	Small	Orange
Fr. Sel.4	Dwarf	Mid season	Carnation	Single	Small	Golden yellow
Fr. Sel.5	Dwarf	Mid season	Carnation	Single	Small	Yellow petal with maroon margin
Fr. Sel.6	Dwarf	Mid season	Carnation	Single	Small	Maroon petal with yellow margin
Fr. Sel.7	Dwarf	Mid season	Carnation	Single	Small	Dark maroon petal with Yellow margin
Fr. Sel.8	Dwarf	Mid season	Carnation	Single	Small	Golden yellow
Fr. Sel.9	Dwarf	Early	Carnation	Single	Small	Golden yellow
Fr. Sel.10	Medium	Late	Carnation	Double	Small	Golden yellow
Cherry Red	Dwarf	Early	Carnation	Single	Small	Dark red

* Only stigmas were present in the form of brush called as 'Femina'

Plant height (dwarf, 0–50 cm; medium: 51–65 cm; tall, >65 cm); Maturity (early flowering, 0–60 days; mid season flowering, 61–80 days; late flowering, >80 days); Flower diameter (small: 0–5.00 cm; medium, 6–9 cm; large, >9 cm)

Table 2 Analysis of variance for combining ability and estimates of genetic components of variance for growth and flowering traits

Source of variance	d f	Days to first flowering	Plant height (cm)	Plant spread (cm)	No. of flowers/plant	Flower weight (g)	Flower diameter (cm)	Stalk length (cm)	Duration of flowering (days)	Harvest index (%)	Flower yield/plant (g)
Replications	2	4.42	9.74	18.06	823.15	1.05	1.15	0.13	2.60	37.28	11317.09
Lines	2	970.36**	1075.39**	328.95**	1881.10**	4.37	0.0011	16.57**	110.72**	162.16**	21280.68**
Testers	10	368.83**	643.21**	1055.88**	41766.96**	11.30**	7.57**	8.43**	434.16**	203.24**	11342.75**
Lines × testers	20	322.76**	187.86**	386.45**	3053.24**	12.07**	0.68**	2.77**	47.77**	17.38**	76253.92**
Error	64	11.45	9.77	29.71	233.01	3.37	0.28	3.89	21.45	12.65	2021.41
s ² GCA		16.52	31.97	14.56	893.84	0.315	1.148	0.463	10.69	7.8724	28442.24
s ² SCA		36.02	41.73	39.83	507.97	1.22	2.52	3.61	10.20	15.02	31767.12
s ² GCA/s ² SCA		0.45	0.76	0.36	1.75	0.25	0.45	0.12	1.04	0.52	0.89

* $P=0.05$; ** $P=0.01$ d f = 64 (error)

duration of flowering, harvest index and flower yield/plant, thereby indicating their divergence and also satisfied choice of parents. The significance variances due to lines and testers is also in accordance with the reports of Gupta *et al.* (2001), Mohanty *et al.* (2003) and Sreekala and Raghava (2003), in marigold and Pounder *et al.* (2007) in crape myrtle.

Estimates of genetic components of variance

The estimate of genetic components of GCA and SCA variances and their ratios for flower yield and its components are also given in the Table 2. Since the concepts of GCA and SCA were presented by Sprague and Tatum (1942), combining ability, as an important genetic parameter, has widely been adopted in plant breeding, especially in the breeding for utilization of heterosis (Kumar *et al.* 2006). The differences of GCA are mainly due to the additive variance

in the population, and the differences of SCA are attributable to the non additive genetic variances (Falconer 1982). In this experiment, GCA as well as SCA component was highly significant for all the growth and flowering traits. However, high magnitude of GCA effects for number of flowers/plant and duration of flowering (days) were observed which indicated that additive gene action governed these traits. The predominance of additive gene action was also reported by Gupta *et al.* (2001) in marigold. These traits with high magnitude of additive gene action can be easily improved through line selection which would favour the increased expression of the traits. The characters, viz days to first flowering, plant height, plant spread, flower weight, flower diameter, stalk length, harvest index and flower yield/plant showed the higher magnitude of SCA component variance which indicated that non-additive gene action govern these

Table 3 Estimates of GCA effects on parents for growth and flowering traits in marigold

Parent	Days to first flowering	Plant height (cm)	Plant spread (cm)	No. of flowers/plant	Flower weight (g)	Flower diameter (cm)	Stalk length (cm)	Duration of flowering (days)	Harvest index (%)	Flower yield/plant (g)
MS 5	3.72**	0.20	-3.11**	5.15*	-0.07**	0.11*	0.74**	-1.26**	-0.25	-91.85**
MS 7	6.22**	5.81**	0.10	-3.52	0.30**	-0.01	0.67**	0.84**	-1.82**	34.91
MS 8	2.51**	5.60**	3.21**	8.67**	0.39**	1.00**	-0.07	0.80**	2.47**	56.94**
S.E. (g _i)	0.13	0.37	0.37	2.57	0.02	0.05	0.12	0.26	0.15	17.80
<i>Testers</i>										
Fr. Sel.1	-5.66**	8.03**	20.46**	134.74**	1.13**	1.84**	-2.27**	14.63**	9.53**	246.16**
Fr. Sel.2	-2.55**	18.71**	11.85*	56.40*	0.87*	1.72**	-0.68**	8.74**	6.83**	214.77**
Fr. Sel.3	0.32	1.68	3.46	-45.60	0.86*	-0.85	-0.02	-6.60**	-4.27*	-137.18*
Fr. Sel.4	-0.45	-1.16	-2.99	-36.82	0.12	-1.30*	0.38	-3.60	-3.13	-125.74*
Fr. Sel.5	-1.34	0.33	-10.70	-50.26*	-0.84*	-0.71	-0.49**	-2.71	-3.09	-117.01*
Fr. Sel.6	9.43**	-2.62**	-7.33	-63.60*	0.99**	-0.71	0.46**	-2.60	-3.30	-126.31*
Fr. Sel.7	-0.79	-1.77*	13.37*	-64.26*	-1.69**	-0.82	-1.03**	-1.04	-1.36	-124.75*
Fr. Sel.8	-1.24	-10.44**	-8.53	-33.15	-1.12**	0.75	-0.24	-1.60	-1.14	-120.38*
Fr. Sel.9	6.90**	-13.28**	-5.93	18.52	0.32	0.25	0.10	2.63	2.11	-57.70
Fr. Sel.10	-5.34**	-0.25	11.67*	96.63**	1.89**	1.56*	1.37**	5.40*	6.78**	145.38*
Cherry Red	-0.79	0.77	1.40	-12.60	-0.56	0.27	-0.24	-10.26**	-4.97*	53.50
S E (g _i)	0.96	0.88	5.84	22.29	0.34	0.62	0.15	2.26	2.11	62.24

* $P=0.05$; ** $P=0.01$

traits. Therefore, selection for these traits should be delayed to few generations when the effect of dominance is minimized. The governance of these traits by non-additive gene action was also reported by Gupta *et al.* (2001) and Sreekala and Raghava (2003) in marigold and Singh *et al.* (2009) in linseed.

The ratio of genetic component of variance ($\sigma^2_{GCA}/\sigma^2_{SCA}$) indicated the equal importance of additive and non-additive gene action in governing the flower yield and its component traits of marigold. Thus, for these traits population improvement programme should be taken for the development of superior lines for all growth and flowering traits studied except number of flowers/plant, duration of flowering.

General combining ability effects

Estimates of GCA effects (Table 3) revealed that the male sterile line MS7 (-6.22) was high general combiner for early flowering whereas highest positive GCA (2.51) was observed in the MS8 male sterile line for late flowering. The male sterile line MS8 was the high general combiner for all the growth and flowering traits except days to first flowering and stalk length. Among 11 pollen parents, Fr. Sel.8 (-10.44) and Fr. Sel.9 (-13.28) were the high general combiners for short plant height, whereas Fr. Sel.1 (8.03) and Fr. Sel.2 (18.71) were the best general combiners for higher plant height. Pollen parents Fr.Sel.1 (20.46, 134.74), Fr. Sel.2 (11.85, 56.40) and Fr. Sel.10 (11.67, 96.63) were observed as best general combiners for plant spread and number of flowers/plant. The parents Fr. Sel. 10 (1.89) and Fr. Sel. 1 (1.13) for flower weight, Fr. Sel.1 (1.84), Fr. Sel.2 (1.72) and Fr. Sel.10 (1.56) for flower diameter were observed the higher general combiners. The parent Fr. Sel.10 (1.37) was higher general combiner for longer stalk, whereas Fr.Sel.1 (-2.27), Fr. Sel.7 (-1.03) and Fr. Sel.2 (-0.68) were higher general combiners for shorter stalk of the marigold flowers. The testers (pollen parents) Fr. Sel.1 (14.63), was found to be the best general combiner for duration of flowering, followed by Fr. Sel.2 (8.74) and Fr. Sel.10 (5.40). Estimates of GCA effects revealed that the parents Fr. Sel.1 (9.53), Fr. Sel.2 (6.83) and Fr. Sel.10 (6.78) were high general combiner for harvest index. The pollen parents Fr. Sel.1 (246.16) and Fr. Sel.2 (214.77), followed by Fr. Sel.10 (145.38) were observed to be the high general combiner for flower yield/plant. The high GCA effect are generally ascribed to additive gene effects or additive \times additive interaction effects (Falconer 1982), thereby the good general combiners can be used for the genetic amelioration of marigold. The parents, MS8, Fr. Sel.1, Fr. Sel.2 and Fr. Sel.3, had high GCA effects for a number of desirable traits, besides possessing higher flower yield, could be used in heterosis breeding programme to recombine the favourable genes. The results showed that there is a scope for enhancing flower yield for loose flower and garland purpose by involving these parents in the

Table 4 Crosses with high *per se* performance and significant SCA effects for flower yield and its component traits in marigold

Character	Crosses with high <i>Per se</i> performance and significant SCA effects	SCA effects	<i>Per se</i> mean performance	GCA effect of parents
Days to first flowering	MS7 \times Fr. Sel.1	-21.56**	52.67	H \times H
	MS8 \times Fr. Sel.1	-14.17**	72.00	L \times H
	MS7 \times Fr. Sel.10	-12.78**	63.67	H \times H
	MS7 \times Fr. Sel.2	-11.00**	75.33	H \times M
	MS7 \times Fr. Sel.8	-10.78**	99.00	H \times M
Plant height (cm)	MS8 \times Fr. Sel.1	13.20**	88.10	L \times M
	MS7 \times Fr. Sel.1	12.57**	81.53	H \times M
	MS8 \times Fr. Sel.9	11.64**	70.70	L \times L
	MS8 \times Fr. Sel.2	9.95**	81.10	L \times H
	MS7 \times Fr. Sel.2	8.46**	67.11	H \times H
Plant spread (cm)	MS8 \times Fr. Sel.1	18.8**	91.27	H \times H
	MS7 \times Fr. Sel.10	17.35**	90.90	M \times M
	MS8 \times Fr. Sel.10	15.71**	80.53	H \times M
	MS7 \times Fr. Sel.1	10.93**	88.23	M \times H
	MS8 \times Fr. Sel.2	10.89**	85.53	H \times M
No. of flowers/plant	MS8 \times Fr. Sel.1	51.85**	309.00	H \times H
	MS7 \times Fr. Sel.10	49.60**	190.00	L \times M
	MS7 \times Fr. Sel.1	48.96**	288.00	L \times H
	MS8 \times Fr. Sel.2	47.74**	229.00	H \times L
	MS8 \times Fr. Sel.10	43.71**	232.00	H \times M
Flower weight (g)	MS5 \times Fr. Sel.2	1.72**	5.28	M \times L
	MS8 \times Fr. Sel.2	0.92**	5.50	H \times L
	MS8 \times Fr. Sel.1	0.88**	6.70	H \times M
	MS5 \times Fr. Sel.1	0.81**	5.73	M \times M
	MS7 \times Fr. Sel.1	0.80**	5.50	L \times M
Flower diameter (cm)	MS5 \times Fr. Sel.1	1.19**	7.26	M \times H
	MS8 \times Fr. Sel.1	0.74**	7.00	H \times H
	MS5 \times Fr. Sel.2	0.57**	5.78	M \times M
	MS7 \times Fr. Sel.2	0.57**	6.25	L \times M
	MS8 \times Fr. Sel.2	0.56**	6.53	H \times M
Stalk length (cm)	MS5 \times Fr. Sel.10	-1.68**	9.57	L \times L
	MS7 \times Fr. Sel.7	-1.39**	10.70	H \times M
	MS7 \times Fr. Sel.10	-1.09**	10.74	H \times L
	MS5 \times Fr. Sel.1	-1.02**	11.53	L \times H
	MS5 \times Fr. Sel.2	-0.96**	11.77	L \times H
Duration of flowering (days)	MS7 \times Fr. Sel.1	6.16**	106.67	M \times H
	MS5 \times Fr. Sel.1	6.04**	96.00	L \times H
	MS7 \times Fr. Sel.2	5.93**	90.57	M \times M
	MS5 \times Fr. Sel.10	5.40**	73.33	L \times L
	MS8 \times Fr. Sel.1	5.32**	115.28	H \times H
Harvest index (%)	MS7 \times Fr. Sel.1	4.49**	63.50	M \times H
	MS5 \times Fr. Sel.1	4.33**	62.77	L \times H
	MS5 \times Fr. Sel.10	3.89**	62.70	L \times M
	MS7 \times Fr. Sel.2	3.58**	62.00	M \times M
	MS5 \times Fr. Sel.2	3.15**	61.77	L \times M
Flower yield/plant (g)	MS8 \times Fr. Sel.1	342.80**	1675.06	H \times H
	MS7 \times Fr. Sel.1	327.33**	1364.89	M \times H
	MS8 \times Fr. Sel.2	315.47**	1005.33	H \times H
	MS5 \times Fr. Sel.2	292.47**	968.00	L \times H
	MS5 \times Fr. Sel.1	272.13**	704.53	L \times H

* $P=0.05$; ** $P=0.01$, L, M and H: Low, medium and high general combiner

breeding programme. In present study, besides obtaining maximum GCA effects in the desirable direction, the female parent MS8 and male parents Fr. Sel.1, Fr. Sel.2 and Fr. Sel.10 also recorded highest mean values for all the growth and flowering traits and also authenticate their breeding value for all the traits. This result is consistent with those of Gupta *et al.* (2001) who had observed a direct correspondence between *per se* performance and combining ability effects for all growth and flowering characters of marigold. In the results of this experiment, it was noticed that either one or two of parental lines having high GCA effects for yield and its component characters were involved in the crosses, the F₁ hybrids showed high performance for all traits which were in close conformity with the reports of Kenga *et al.* (2004) in Tropical sorghum and Lou *et al.* (2010) in *Zinnia elegans*.

Specific combining ability effects and per se performance

The top five crosses with high and significant SCA effects along with *per se* performance for each character and GCA effects of parents for each cross are presented in Table 4. The crosses exhibited significant and negative SCA effects for days to first flowering and stalk length, whereas positive and significant SCA effects were observed for plant height, plant spread, number of flowers/plant, flower weight, flower diameter, duration of flowering, harvest index and flower yield/plant, which indicated that parents involved in the crosses were good specific combiners for desirable traits. The crosses MS8 × Fr. Sel1, MS8 × Fr. Sel2 and MS7 × Fr. Sel1 recorded significant desirable SCA effects for maximum number of traits, viz days to first flowering, plant height, plant spread, number of flowers/plant, flower weight, flower diameter, duration of flowering and flower yield/plant except stalk length and harvest index. The cross MS7 × Fr. Sel1 exhibited higher SCA effects (–21.56) for days to first flowering. However, MS8 × Fr. Sel.1 showed positive and high SCA effects for number of flowers/plant. The negative and higher SCA effects for stalk length were exhibited by MS-5 × Fr. Sel.10 in desirable direction. The promising crosses, MS8 × Fr. Sel1, followed by MS7 × Fr. Sel.1 possessed desirable SCA effects for flower yield/plant. In this study, most of the crosses with high SCA effects involved the parents with high × low, high × high, high × medium, medium × medium and *vice versa* of combining abilities and few were low × low general combiners. The crosses with high *per se* performance possessed high SCA effects. Therefore, even the parents with low or medium general combining abilities can lead to high SCA effects in the crosses. High SCA effects of good × poor GCA combinations might be due to complementary non-additive interallelic interactions and hence, suitable for heterosis breeding. These

results are similar to the findings of Sreekala and Raghava (2003) in marigold and Bhardwaj *et al.* (2009) in chickpea as they reported that the best general combiner need not yield crosses having the best specific combining ability effects, but poor general combiners also yield crosses having high SCA effects.

Generally, the significant desirable SCA effects contribute much towards the improvement of cross pollinated crops like marigold where commercial exploitation of heterosis is feasible. Therefore, high SCA effects which involved not only high × high combiners but also high × low, high × medium and medium × medium combiners, can be utilized to develop F₁ hybrids which are triploid in nature using male sterile lines of *T. erecta* and pollen parents of *T. patula*.

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