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Estimation of Heterosis and Combining Ability in Petunia (*Petunia hybrida* Hort.)

Hassan BAYAT[1*], Hossein NEAMATI[1], Abdolreza BAGHERI[2], Ali TEHRANIFAR[1], Marjan SAIE[1]

[1]*Ferdowsi University of Mashhad, Faculty of Agriculture, Department of Horticultural Science, Mashhad, Iran; hassanbayat55@gmail.com (*corresponding author)*

[2]*Ferdowsi University of Mashhad, Faculty of Agriculture, Department of Biotechnology and Plant Breeding, Mashhad, Iran*

Abstract

Combining ability and heterosis were estimated for ornamental and vegetative traits of four petunia (*Petunia hybrida* Hort.) inbred lines viz. L5 (P1), L8 (P2), L11 (P3) and L17 (P4) and their diallel hybrids in horticultural research farm of Ferdowsi University of Mashhad, Iran in 2011. The measured traits were plant height at first flower, number of leaf to first flower, flower diameter, flower tube length, internode length, stem diameter, plant height at flowering stage, plant spreading, number of branches per plant, leaf length and width. The results of combining ability for all studied traits revealed that both additive and non-additive gene effects contributed to the inheritance of the traits. Estimates of general combining ability effects showed that parent P3 was a good general combiner for most of the studied traits. For flower diameter, hybrid combination P1 × P2 had the highest significant positive specific combining ability effects. Reciprocal effects were significant for all traits and hybrid combination P1 × P2 had the highest significant positive reciprocal effects for flower tube length and plant height. Heterosis was found significant relative to both the mid parent and batter parent for all traits. For flower diameter, the highest positive values of heterotic effects were recorded in hybrid combination P2 × P3 both relative to the parental mean (37.3%) and relative to the better parent (33.9%). It is obvious that heterotic effects represent an important resource in hybrid breeding of petunia.

Keywords: diallel cross, GCA, gene action, reciprocal effects, SCA

Introduction

Petunia (*Petunia* spp.), which belong to the family Solanaceae, is a popular annual bedding ornamental choice, for summer home gardens and landscaping projects, in the world (Dole and Wilkins, 2004). *Petunia hybrida* includes a wide variety of flower types and flower colors, and has a long-lasting bloom. As an important ornamental plant throughout spring and summer months, petunia is commercially cultivated and marketed throughout the world. Cultivars of *Petunia hybrida* are used in flower beds, hanging baskets, window boxes and as cut flowers. In addition, cultivars with dwarf compact plant habits and double-flowers are used as potted plants. The contribution and information available on combining ability and heterosis studies in petunia plant is very little. Hence, there is a need to identify suitable parents with good combining ability for increasing the quality production and exploitation of hybrid vigor.

Nowadays, F_1 hybrid breeding is used for many flowers; breeders and breeding companies have developed many inbred lines as candidates for parents, and have chosen the best combinations of parents of new F_1 hybrids from these lines. The information on genetics of different traits is required for devising any breeding methodology for the improvement of various traits. The selection of the breed-

ing method for taking genetic problems is an equally important consideration in all genetically and breeding studies as the performance of the parents and their F_1 hybrid. Diallel crossing method is most frequently used in genetic research and breeding (Bhatt *et al.*, 2001; Kaya and Atakisi, 2004; Muraya *et al.,* 2006; Oritz and Golmirzaie, 2004; Subhan *et al.*, 2003), because it provides greatest information about gene effects, combining ability, heterosis, heritability and possible gene interactions (Hallauer, 2007). Combining ability describes the breeding value of parental lines to produce hybrids. Sprague and Tatum (1942) defined general combining ability (GCA) as the average performance of a line in hybrid combinations, and the specific combining ability (SCA) as those cases in which certain combinations do better or worse than expected, based on the average performance of the parents involved. Heterosis or hybrid vigor refers to the phenomenon by which an F_1 hybrid exhibits phenotypic characteristics superior to the mean of the two parents (mid parent heterosis) or to either of them (high-parent heterosis). Reciprocal effects (RE) in a diallel mating design are important in order to determine if plasmagenes from mitochondria and plastids contribute to trait inheritance (Glover *et al.*, 2005).

Breeding of the garden petunia started in early 19th century by the crossing of *Petunia axillaris* and *Petunia integrifolia* (Sink, 1984). The genus *Petunia* spp. comprises

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35 species mostly occurring in tropical and warm South America (Wijsman and Jong, 1985). An F_1 single-flowered multiflora hybrid first became commercially available in 1949 (Weddle, 1976) and breeders have since bred dozens of F_1 hybrids. Hussein and Misiha (1978) reported that plant height, flowering time and flower size of petunia are genetically controlled by additive-dominance polygenic systems. They also observed positive and negative heterosis for these three characters. Although numerous analyses of combining ability have been reported for important agronomic traits such as yield (El-Hadi *et al.,* 2007) and disease resistance (Mardi *et al.*, 2004) in edible crops, few studies have investigated the combining abilities and heterosis of ornamental and vegetative characteristics in floricultural crops. The objectives of this study were to evaluate combining ability of parents and hybrids and to estimate heterosis for selecting the superior hybrids that can be used in breeding program of petunia.

Materials and methods

Plant material, diallel crosses and experimental design

Four different inbred lines of *Petunia hybrida* Hort. (all belonging to multiflora types) viz. L5 (P1), L8 (P2), L11 (P3) and L17 (P4) were used as parents in a diallel cross (Tab. 1). These inbred lines had been genetically homogeneous through inbreeding of five to six generations. The plants were grown in a greenhouse at Ferdowsi University of Mashhad (36° 17' 44" N and 59° 36' 42" E), Iran on 9th April 2010. A set of 4 × 4 diallel crosses between 4 inbred lines were crossed in all possible combinations (including reciprocals) and 12 F_1 hybrids were produced. Seeds of these hybrids were sown in coco peat in plastic germination trays under greenhouse conditions on 5th March 2011. Seedlings were transplanted in the main experimental plots at the age of 45 days. The average minimum and maximum temperatures during the crop period were 21.5°C and 35.7°C respectively. The experiment was set up in a randomized complete block design (RCBD) with three replications. The plot size was 5 × 1 m and seedlings were spaced 50 cm on row. Each unit plot contained single row accommodating 10 plants where data were collected from randomly selected 5 plants.

Tab. 1. Characteristics of parental petunia inbred lines used to generate 12 F_1 hybrids in a diallel cross design

Inbred lines	Flower color	No. of inbred generations	Plant height (cm)
L5 (P1)	purple	5	36
L8 (P2)	violet	6	30
L11 (P3)	white	6	41
L17 (P4)	red	5	21

Measured traits in F_1 generation

The measured traits in F_1 generation were number of leaf to first flower, plant height at first flower, flower diam-

eter, flower tube length, internode length, stem diameter, plant height at flowering stage, plant spreading, number of branches per plant, leaf length and width.

Statistical analyses

Calculated means of all traits were used to estimate general combining ability effects of the inbred lines and specific combining ability effects of the crosses, including reciprocity effects. Analyses of combining ability were performed following Griffing's Method III and Model I of diallel analysis (Griffing, 1956) using diallel 98 software (version 2002). The GCA/SCA variance ratios with a theoretical maximum of unity were computed according to Baker (1978). This ratio was calculated to determine the relative importance of GCA and SCA effects. Mid-parent heterosis (MPH) and high-parent heterosis (HPH) were estimated using the following formula (Hallauer and Miranda, 1988):

$$\text{Mid parent heterosis (MPH)} = \frac{F_1 - \text{Mid parent}}{\text{Mid parent}} \times 100$$

$$\text{Mid parent heterosis (HPH)} = \frac{F_1 - \text{High parent}}{\text{High parent}} \times 100$$

Results and discussion

Combining ability analysis revealed that variances due to GCA and SCA were significant for all traits indicating that both additive and non-additive gene actions played significant role for the expression of these traits (Tab. 2). From the GCA/SCA ratio (<1.0) for plant height at first flower, flower diameter and flower tube length indicates that these traits were under larger influence of non-additive genetic effects (dominance and epistasis) (Tab. 2). For other traits the magnitude of GCA variances was however higher than SCA variances which revealed preponderance of additive gene action for these traits (Tab. 2), which is in accordance with the results of Ahmad *et al.* (2009) in tomato, Hemanthkumar *et al.* (2008) in gladiolus, Hussein and Misiha (1978) in petunia and Lou *et al.* (2010) in zinnia. Romanus *et al.* (2008) and also Satija and Thukral (1985) have provided evidence for the greater importance of additive gene action in hybrid breeding outcomes. Reciprocal effects mean squares were significant and highly significant for all the measured traits, showing that inheritance of these traits governs not only nuclear but also plasma-genes (Tab. 2). The total genetic variability was partitioned into general combining ability (GCA), specific combining ability (SCA) and reciprocal effects (RE) as defined according to Griffing (1956).

General combining ability effects

The estimates of GCA effects for plant height at first flower showed that parents P3 and P4 had the highest positive (2.33**) and negative (-2.28**) GCA effects,

Tab. 2. Analysis of variance for combining ability of plant height at first flower, number of leaf to first flower, flower diameter, flower tube length, internode length, stem diameter, plant height, plant spreading, number of branches per plant, leaf length and width in hybrids and their parents of petunia

Source of variation	d.f.	Plant height at first flower (cm)	Number of leaf to first flower (cm)	Flower diameter (cm)	Flower tube length (cm)	Internode length (cm)	Stem diameter (mm)	Plant height (cm)	Plant spreading (cm)	Number of branches per plant	Leaf length (cm)	Leaf width (cm)
					Mean sum of square							
GCA	3	44.71**	9.01**	0.20**	0.07**	1.40**	0.74**	303.04**	1029**	28.80**	2.63**	0.14**
SCA	2	148.92**	2.20*	6.00**	0.13**	0.18**	0.22**	12.10*	48.90*	1.70*	1.90**	0.08*
RE	6	7.79**	6.90**	0.16**	0.06*	0.28**	0.37**	14.70**	133.3**	29.50**	2.32**	0.16**
Error	22	0.12	0.55	0.03	0.02	0.03	0.02	2.20	11.10	0.49	0.04	0.02
GCA/SCA		0.31	4.02	0.03	0.53	7.70	3.40	25.00	21.00	16.70	1.40	1.75

*Significant at 5% level of probability; ** Significant at 1% level of probability

respectively (Tab. 3). Reduction of plant height at first flower could be obtained by using P1 and P4 as parents in petunia breeding programs, because they had negative GCA estimates that could be used for developing of dwarf compact F_1 hybrid. In case of flower diameter and flower tube length as the main goals of petunia breeding programs, parent P2 showed the highest positive significant GCA effects (Tab. 3). As can be seen, for internode length, stem diameter, plant height, plant spreading and number of branch per plant, parents P3 and P4 had the highest positive and negative GCA values, respectively (Tab. 3). These parents can be useful in breeding programmes for the increase and decrease of these traits. The parents P3 showed the highest significant positive GCA values for leaf length and width (Tab. 3). Thus this parent was the best general combiner to use in crosses for the improvement of leaf length and width.

Specific and reciprocal combining ability effects

Estimates of specific and reciprocal combining ability effects were presented in Tab. 4 and 5. For plant height at first flower, hybrid combination P2 × P3 had the highest significant positive SCA value (2.32 **), while P1 x P2 had the highest significant negative SCA value (Tab. 4). Reciprocity effects were outstanding in hybrid combinations P1 × P4 and P1 × P3 for plant height at first flower and number of leaf to first flower, respectively (Tab. 4). Hybrid

combinations P1 × P4 and P2 × P3 showed positive significant SCA effect for number of leaf to first flower (Tab. 4).

For flower diameter, hybrid combinations P1 × P2 and P2 × P3 had the highest significant ($p<0.01$) positive SCA effects indicating these combinations were the best specific combiner to increase the trait. For flower tube length hybrids P2 × P3 and P1 × P3 showed the highest positive (0.14**) and negative (-0.11**) significant SCA effects, respectively.

Hybrid combinations P1 × P3 (0.09**), P2 × P3 (0.27**) and P3 × P4 (0.14**) showed higher significant positive SCA values for internode length (Tab. 4). In contrast, cross combination P2 × P4 and P1 × P2 had highly significant and negative SCA effects for internode length (Tab. 4). Three combinations viz. P1 × P3, P1 × P4 and P2 × P3 were the best specific combinations to enhance stem diameter in petunia (Tab. 4).

Hybrid combinations P1 × P3 and P2 × P3 were the best specific combinations to enhance plant height and plant spreading (Tab. 5). The hybrid combination P1 × P4 was the best specific combiner for a potted flowering plant because of exhibiting the highest negative SCA effect for plant height (Tab. 5). Hybrid combination P1 x P2 had the highest significant and positive reciprocity effects for plant height and plant spreading (Tab. 5). In combining ability the maternal effects which came through cytoplas-

Tab. 3. Estimates of general combining ability (GCA) effects of the parents for plant height at first flower, number of leaf to first flower, flower diameter, flower tube length, internode length, stem diameter, plant height, plant spreading, number of branches per plant, leaf length and width in petunia

Parents	Plant height at first flower (cm)	Number of leaf to first flower (cm)	Flower diameter (cm)	Flower tube length (cm)	Internode length (cm)	Stem diameter (mm)	Plant height (cm)	Plant spreading (cm)	Number of branches per plant	Leaf length (cm)	Leaf width (cm)
P1	-0.58**	0.90**	0.04 ns	-0.05 ns	0.07**	0.02**	2.38**	0.33	0.83**	-0.32**	-0.07**
P2	0.52**	-0.30*	0.16**	0.09**	0.08**	0.03**	-0.62**	0.33	-0.99**	-0.17**	0.01**
P3	2.33**	0.46**	-0.11**	0.04 ns	0.33**	0.27**	4.71**	11.00**	1.74**	0.70**	0.15**
P4	-2.28**	-1.07**	-0.09*	-0.08**	-0.48**	-0.33**	-6.46**	-11.67**	-1.58**	-0.20**	-0.09**

*Significant at 5% level of probability; ** Significant at 1% level of probability

Tab. 4. Estimates of specific combining ability (SCA) and reciprocal (RE) effects of hybrids for plant height at first flower, number of leaf to first flower, flower diameter, flower tube length, internode length and stem diameter in petunia

Hybrids	Plant height at first flower (cm)		Number of leaf to first flower (cm)		Flower diameter (cm)		Flower tube length (cm)		Internode length (cm)		Stem diameter (cm)	
	SCA	RE	SCA	RE	SCA	RE	SCA	RE	SCA	RE	SCA	RE
P1 × P2	-1.05**	0.47**	0.14	-0.83**	0.12**	0.05	0.02	0.17**	-0.04**	0.32**	-0.10**	0.03
P1 × P3	0.25**	-0.10	0.06	2.00**	-0.15**	-0.23**	-0.11**	0.05	0.09**	-0.35**	0.07**	0.33**
P1 × P4	0.42**	1.13**	0.40**	-0.98**	0.07*	0.00	0.05*	0.15**	0.00	-0.02	0.05**	-0.08
P2 × P3	2.32**	-2.33**	0.51**	-0.68*	0.10**	0.27**	0.14**	-0.04	0.27**	0.19**	0.25**	-0.48**
P2 × P4	-0.92**	0.37	-0.85**	-0.27	-0.11**	0.10	-0.11**	-0.07	-0.18**	-0.15*	-0.15**	-0.14**
P3 × P4	-1.02**	0.83**	-0.27**	0.82**	-0.02 ns	0.12*	0.00	0.07	0.14**	0.01	-0.14**	0.04

*Significant at 5% level of probability; ** Significant at 1% level of probability

mic effects cannot be ignored also and the F_1 hybrids having desirable reciprocal effects should also be kept under consideration during future breeding. In case of number of branches per plant, two hybrids (P1 × P3 and P2 × P3) had significant positive SCA effects (Tab. 5). For leaf length and width, hybrid combination P2 × P3 had the highest significant positive SCA effects (Tab. 5).

Heterosis relative to mid (MPH) and high (HPH) parents

Heterosis estimates of hybrids in relation to high and mid parent are presented in Tab. 6 and 7. The hybrid combination P3 × P2 had the highest MPH (68.4%) and HPH (39.5 %) for plant height at first flower, while highly negative heterosis values (MPH and HPH) were observed in hybrid combinations P1 × P2, P2 × P1, P4 × P1, P4 × P2

Tab. 5. Estimates of specific combining ability (SCA) and reciprocal (RE) effects of hybrids for plant height, plant spreading, number of branches per plant, leaf length and width in petunia

Hybrids	Plant height (cm)		Plant spreading (cm)		Number of branches per plant		Leaf length (cm)		Leaf width (cm)	
	SCA	RE	SCA	RE	SCA	RE	SCA	RE	SCA	RE
P1 × P2	0.37	2.23**	2.39*	6.33**	-0.49**	0.88**	-0.24**	0.18*	-0.04**	0.17**
P1 × P3	3.22**	-1.83**	1.94	0.00	1.11**	3.90**	-0.23**	0.07	-0.02**	0.22**
P1 × P4	-2.01**	-1.17*	-4.11**	-1.83	-0.06	0.05	-0.25**	-0.35**	0.01**	0.05
P2 × P3	0.72**	-0.33	3.44**	-8.83**	0.44**	-2.68**	0.60**	-1.47**	0.12**	-0.27**
P2 × P4	-1.51**	1.00*	-5.61**	-2.33*	-0.61**	-0.48	-0.48**	-0.08	-0.07**	-0.08*
P3 × P4	-0.79**	-0.40	1.94	2.33*	-0.38**	2.47**	0.09**	0.00	0.00	0.08*

*Significant at 5% level of probability; ** Significant at 1% level of probability

Tab. 6. Estimates of heterosis relative to mid (MPH) and high parents (HPH) for 6 plant and flower traits in petunia

Hybrids	Plant height at first flower (cm)		Number of leaf to first flower (cm)		Flower diameter (cm)		Flower tube length (cm)		Internode length (cm)		Stem diameter (cm)	
	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH
P1 × P2	-3.5*	-14.4**	0.5	0.5	35.8**	32.1**	7.9**	6.7**	25.3**	20.5**	7.8	0.0
P1 × P3	15.1**	6.4**	32.4**	27.0**	25.2**	24.8**	3.9 ns	-0.4	32.8**	15.3**	14.2**	11.2**
P1 × P4	28.5**	-8.9**	7.5**	-2.7*	31.3**	28.0**	13.7**	4.9*	27.6**	2.8	8.9*	-5.5
P2 × P3	40.4**	16.3**	6.8**	2.4	37.3**	33.9**	12.3*	8.7**	43.1**	20.1**	4.8	-5.2
P2 × P4	5.7**	-18.2**	-4.5	-13.5**	27.7**	28.0**	6.3*	-0.9	6.6	-16.7**	10.9*	3.2
P3 × P4	19.3**	-19.2**	20.3**	13.2**	29.6**	26.8**	16.2**	11.7**	56.7**	43.4**	8.3*	-8.0*
P2 × P1	-25.1**	-33.6**	14.1**	14.1**	34.0**	30.3**	-0.2	-1.3	3.0	-3.8	5.9	-1.8
P3 × P1	18.9**	9.9**	-1.4	-5.4**	34.2**	33.8**	1.2	-3.1	66.4**	44.4**	-3.5	-6.0
P3 × P2	68.4**	39.5**	18.3**	13.5**	27.3**	24.2**	14.6**	10.9**	60.3**	34.6**	32.4**	19.8**
P4 × P1	-37.2**	-55.5**	25.1**	13.2**	31.3**	28.0**	4.1	-4.0*	29.3**	4.2	13.6**	-1.4
P4 × P2	-19.5**	-38.1**	0.3	-9.2**	24.0**	23.6**	10.2**	2.7	21.3**	-5.1	20.5**	12.1**
P4 × P3	-23.5**	-48.1**	5.0**	-1.2	25.0**	22.4**	12.1**	7.8**	55.5**	42.3**	6.1	-9.9**

*Significant at 5% level of probability; ** Significant at 1% level of probability
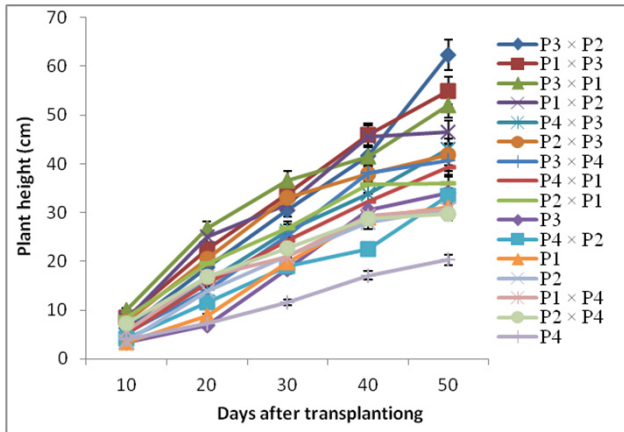
Fig. 1. The trend of increasing in plant height of parents and their 12 hybrids of petunia generated using a diallel cross design
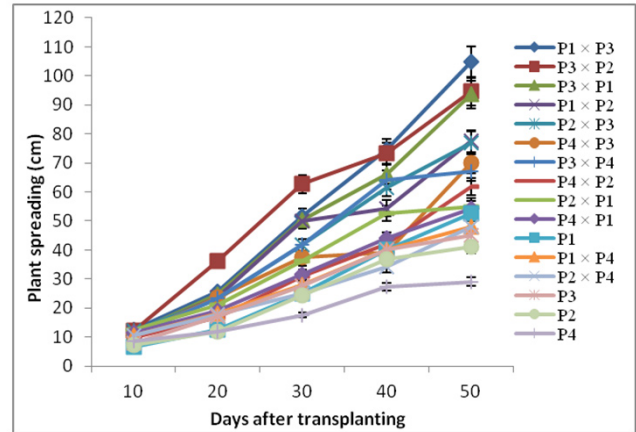

Fig. 2. The trend of increasing in plant spreading of parents and their 12 hybrids of petunia generated using a diallel cross design

and P4 × P3 that could be used for development of dwarf compact hybrids (Tab. 6). Heterosis values for number of leaf to first flower ranged relative to the parental mean (-4.5 to 32.4%) and relative to the high parent (-13.5 to 27.0%). For this trait high positive heterotic effect (MPH=32.4%. HPH=27.0%) was found in the hybrid combination P1 × P3, while hybrid combination P2 × P4 had the highest negative significant heterosis estimates (MPH= -4.5%. HPH= -13.5 %) (Tab. 6).

For flower diameter highly significant positive heterotic effects were observed in all of the hybrid combinations and the highest positive values of heterosis were recorded in hybrid P2 × P3 (MPH=37.3%. HPH =33.9%) (Tab.

6). Similar results were obtained by Hussein and Misiha (1978) in petunia and Lou *et al*. (2010) in zinnia. In case of flower tube length, hybrid P3 × P4 had the highest positive significant heterotic effects relative to the parental mean (16.2%) and high parent (11.7%) (Tab. 6).

Highly significant positive heterotic effects for internode length relative to parental mean were recorded in 10 hybrid combinations ranged from 3.0 to 66.4%. For this trait hybrid combinations P3 × P1 and P2 x P4 had the highest positive (44.4%) and negative (-16.7%) heterosis values (HPH), respectively (Tab. 6). Heterosis estimates (MPH) for stem diameter were highly positive significant in all of the hybrid combinations except for P3 × P1. Het-
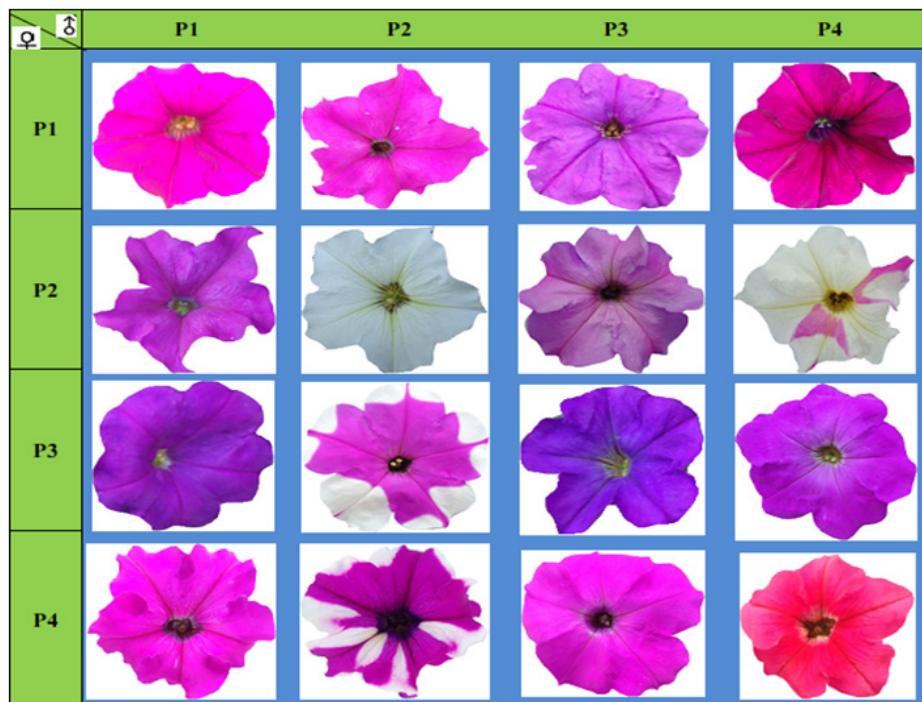

Fig. 3. Flowers of the four parents (diagonal), 6 hybrids (upper of diagonal) and 6 reciprocal hybrids (lower of diagonal) of petunia. The letters P1 to P4 indicate the four parental lines of the diallel cross

Tab. 7. Estimates of heterosis relative to mid (MPH) and high parents (HPH) for 5 plant characteristics in petunia

Crosses	Plant height (cm)		Plant spreading (cm)		Number of branches per plant		Leaf length (cm)		Leaf width (cm)	
	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH	MPH	HPH
P1 × P2	60.7**	42.4**	92.4**	77.6**	73.0**	28.3**	2.9	-11.4*	10.7**	6.0*
P1 × P3	75.7**	57.8**	78.8**	78.8**	97.4**	77.4**	0.0	-2.5	10.7**	12.0**
P1 × P4	62.5**	27.5**	16.9*	-2.4	18.3**	16.6**	4.9	-12.7**	17.5**	1.2
P2 × P3	41.5**	39.4**	65.6**	52.9**	13.5**	-21.4**	3.0	-9.3*	4.3	1.2
P2 × P4	41.1**	1.5	19.4*	6.9	14.1**	-14.6**	16.0**	11.4*	16.2**	3.9
P3 × P4	62.5**	18.1*	90.1**	58.8**	40.4**	24.5**	28.6**	9.3*	22.8**	4.7
P2 × P1	37.8**	22.1*	43.9**	32.9**	38.2**	2.4	-5.1	-18.4**	-1.9	-6.0*
P3 × P1	94.8**	75.0**	78.8**	78.8**	-3.9	-13.6**	-2.6	-5.1	-4.8	-3.6
P3 × P2	44.6**	42.4**	133.1**	115.3**	103.9**	41.2**	69.7**	49.3**	24.2**	17.6**
P4 × P1	80.0**	41.2**	32.4**	10.6	16.8**	15.1**	20.9**	0.6	13.3**	-2.4
P4 × P2	28.4**	-7.6	41.1**	7.1	33.6**	0.0	20.5**	15.8**	23.5**	10.5**
P4 × P3	67.7**	21.9**	70.4**	42.4**	-24.6**	-33.1**	28.6**	9.3*	15.9**	-1.2

* Significant at 5% level of probability; ** Significant at 1% level of probability

erosis values relative to high parent ranged from -8.0 to 19.8% (Tab. 6). Raghava (1984) observed highest heterosis over mid and better parent was exploited in the China aster hybrid Crego Giant Pink × AST-16.

Highly significant positive heterotic effects for plant height and plant spreading relative to parental mean were manifested in all of the hybrid combinations. The highest positive values of heterosis were recorded in P3 × P1 (MPH=94.8%. HPH =75.0%) for plant height and P3 × P2 for plant spreding (MPH= 133.1%. HPH =115.3%), respectively (Tab. 7). These results are in agreement with those of Hussein and Misiha (1987) in petunia, Premalakshmi *et al.* (2006) in tomato and Butorac *et al.* (2001) in burley tobacco (*Nicotiana tabacum* L.). Moreover, the trend of increasing in plant height and plant spreading for parents and their hybrid combinations were shown in Fig. 1 and 2. Fifty days after transplanting, the highest plant height was recorded in hybrid combinations P3 × P2 (62.4 cm) followed by P1 × P3 (55 cm) and P3 × P1 (52 cm). In contrast, the lowest plant height was recorded in parent P4 (20.3 cm) followed by hybrid combinations P2 × P4 (29.8 cm) and P1 × P4 (30.4 cm) (Fig. 1). These hybrids displayed dwarf compact habits which is the standard breeding goal for potted plants. With plant spreading, the highest and lowest values were observed in hybrid combination P1 × P3 (105 cm) and parent P4 (29 cm), respectively (Fig. 2).

Heterosis estimates (MPH) for number of branches per plant were highly positive significant in all of the hybrid combinations except for P3 × P1 and P4 × P3. Heterosis values for number of branches per plant ranged both relative to the parental mean (-24.6 to 103.9%) and relative to the high parent (-33.1 to 77.4%) (Tab. 7). Similar results were reported by Singh and Misra (2010) in marigold and Tiwari and Lal (2004) in tomato. The hybrid combination P3 × P2 had the highest positive and highly significant heterosis values for leaf length (MPH= 69.7%. HPH

=49.3%) and leaf width (MPH= 24.2%. HPH =17.6%) (Tab. 7).

Flowers of the four parents (on the diagonal) and of the progeny of diallel crosses were presented in Fig. 3.

Conclusions

The variances for general combining ability and specific combining ability were significant and highly significant for all studied traits which indicate the presence of additive as well as non-additive gene effects. The relative magnitude of these variances indicated that additive gene effects were more prominent for all the characters except for plant height at first flower, flower diameter and flower tube length. Estimates of GCA effects showed that parent P3 was the best general combiner for all traits except for flower diameter that parent P2 was the best. Results of SCA showed hybrid combination P2 × P3 had the highest SCA effects for plant height at first flower, number of leaf to first flower, internode length, stem diameter, plant spreding, leaf length and width. Reciprocal effects were also significant in all measured traits revealed that plasmagenes from mitochondria and plastids contribute to the trait inheritance. Heterosis values for all traits were highly significant relative to both the parental mean and the high parent and it is apparent that heterosis effects represent an important resource in hybrid breeding of *Petunia hybrida*.

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