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# Identification of Heterotic Crosses Based on Combining Ability in Vegetable Amaranthus (*Amaranthus tricolor* L.)

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## ABSTRACT

The present study is an effort to study heterosis, combining ability variances and effects on yield and its components in five nearly homozygous morphologically contrasting distinct accessions of vegetable Amaranth based on half diallel mating design to isolate promising crosses having high foliage yield and nutritional components. Both additive and non-additive variances were important for a majority of the characters except for chlorophyll content in $F_2$ generation. Genetic analysis revealed a preponderance of non-additive gene action for all the traits. It was noticed that none of the parents were good general combiner for all the traits in both the generations except AV-26 and AV-28 which showed significant values for most of the traits suggesting that these accessions can be used in a multiple crossing programme for isolating high yielding varieties. The crosses AV-49×AV-62 and AV-28×AV-62 were observed promising for most of the traits which can be commercially exploited for the production of $F_1$ hybrids. The crosses AV-49×AV-62 and AV-28×AV-62 having high foliage yield with increased plant height, branches per plant and leaf size can be used as transgressive segregants to obtain highest returns from Amaranthus breeding. However, the cross combinations showed no inbreeding depression can be exploited in advance generations to develop nutritionally rich high yielding varieties.

**Key words:** Amaranth, diallel, heterosis, transgressive segregants, vegetables

## INTRODUCTION

Genus *Amaranthus* belongs to family Amaranthaceae with more than 50 species distributed all over the world (Sreelathakumary and Peter, 1993; Shukla *et al*., 2010). Based on the mode of utilization and nature, genus is classified into four groups i.e., grain, vegetable, ornamental and weedy Amaranth (Sauer, 1967; Rastogi and Shukla, 2013). Among the diverse group of tropical leafy vegetables, vegetable Amaranth occupies significant place based on nutritional qualities. Vegetable Amaranth has fast growing capacity along with high foliage yield potential in a short duration. Due to its low production cost, Amaranth is considered as a cheapest dark-green leafy vegetable and therefore it is also known as poor man's vegetable (Varalakshmi, 2004). Vegetable Amaranth is nutritionally outstanding among most of the leafy vegetables grown worldwide. Its leaves contain high amount of β-carotene, iron, calcium, vitamin C and folic acid along with dietary fiber (Sun *et al*., 2002; Oboh and Akindhaisi, 2004; Oboh, 2005; Oboh and Rocha, 2007;

Adefegha and Oboh, 2011). In developing countries vegetable Amaranth provides an unconventional source of nutrition for vegetarians (Prakash and Pal, 1991; Shukla *et al.*, 2003, 2006). Vegetable Amaranth also has potential to serve as an antioxidant and this is due to presence of carotenoids and ascorbic acid etc. (Prior and Cao, 2000).

Amaranth has capacity to survive on different types of soil and agro climatic conditions (Katiyar *et al.*, 2000; Shukla and Singh, 2000). Vegetable Amaranth ranked equal or even superior in taste and nutritional quality when compared with spinach. Amaranth spp. is a self pollinated crop but 5-6% cross pollination also exist. In grain Amaranth interspecific or intervarietal crossing program causes large amount of variations at genotypic level (Lee *et al.*, 2008; Ray and Roy, 2009) but in vegetable Amaranth, no efforts were done to create genetic variability through any hybridization program due to complexity of its floral arrangement.

Keeping in view, the enormous potential of vegetable Amaranth, for the first time an attempt has been done to create genetic variability through intraspecific hybridization following half diallel mating design to isolate promising crosses having high foliage yield and nutritional components.

## MATERIALS AND METHODS

Five morphologically contrasting distinct accessions of vegetable Amaranth (*Amaranthus tricolor*) i.e., AV-7, AV-28, AV-49, AV-26 and AV-62 were selected from a large collection of germplasm maintained by the department of Genetics and Plant Breeding, National Botanical Research Institute, Lucknow for the last several years (Table 1). The 10 crosses were obtained through 5×5 half diallel mating design using these accessions in year 2006-07. The manual crossing among the accessions is not practically feasible in vegetable Amaranth due to very small size of flowers and complexity in the arrangement of flower biology. So, the contrasting accessions mainly distinct in leaf color, size etc., was chosen. These accessions were sown in such a way that each accession gets a chance near to each other. The inflorescence of each combination was covered with cloth bags. The seeds obtained of each combination were sown in nursery in the following year. The plants with intermediate leaf color and size were selected and transplanted in rows. The experiment comprised of one row of each cross and two rows of each parent in three replications in RBD were planted at the field of National Botanical Research Institute, Lucknow, situated at a height of 129 m above sea level and at 26°40’-26°45’ N latitude and 80°45-80°54’ E longitudes. The field of experiment falls under subtropical zone and contains sandy loam soil. Generally, 8-10 plants of each cross and parent were planted in a row. During full vegetative growth, the plants showing dominant intermediate leaf color and size were considered $F_1$s and were selfed to get $F_2$ seeds in the consecutive year 2007-08 (Fig. 1). The data on five morphological and three quality traits namely

Table 1: Salient features and origin of the accessions used in hybridization program in vegetable Amaranthus (*Amaranthus tricolor* L.)

| Accessions | Origin | Salient features |
|---|---|---|
| AV-7 | Lakhimpur (Tarai), U.P | Medium plant height, green variegated leaves, green stem, large leaf, inflorescence-terminal/auxiliary, branched, medium foliage and seed yield |
| AV-28 | Almora, Uttaranchal | Medium plant height, dark green leaves, reddish stem, medium leaf size, inflorescence-terminal/auxiliary, profusely branched, low foliage and seed yield |
| AV-49 | NBRI, Lucknow, U.P, India | Plant height low, green leaf, green stem, large leaf, inflorescence-terminal/auxiliary, profusely branched, medium foliage and medium seed yield |
| AV-26 | Gorakhpur, U.P | High plant height, reddish-green leaves, reddish stem, medium leaf size, inflorescence-terminal/auxiliary, profusely branched, low foliage and medium seed yield |
| AV-62 | NBRI, Lucknow, U.P, India | Medium plant height, purple leaf, purple stem, large leaf, inflorescence- terminal/auxiliary, profusely branched, low foliage and medium seed yield |

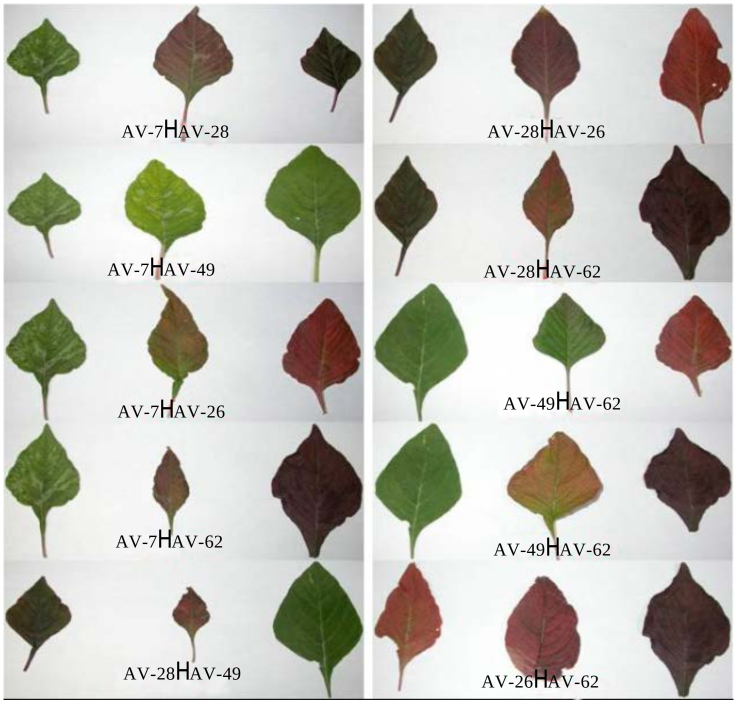

Fig. 1: Leaf colour and size of parents (Both sides) and their respective hybrids (Middle) in vegetable Amaranthus (*Amaranthus tricolor* L.)

plant height (cm), number of branches per plant, leaf size (cm$^2$), stem diameter (cm), inflorescences/plant, carotenoid (mg g$^{-1}$), fiber (%) and chlorophyll (mg kg$^{-1}$) content were recorded on three plants/replication. However, due to less number of plants in $F_1$ generation the foliage yield could not be recorded. In year 2008-09, the five parents and 10 $F_2$s were planted in 2 m$^2$ plot with row-to-row and plant-to-plant distance of 25 and 15 cm, respectively. The experiment was conducted in a randomized block design with three replications. The data was recorded on three plants per replication on five morphological and three quality characters in $F_2$s only. Foliage yield (kg plot$^{-1}$) was recorded for parents and $F_2$s. The foliage yield (kg plot$^{-1}$) comprised of sum of total four cuttings on the interval of 10 days. Carotenoid and chlorophyll were estimated according to method suggested by Jensen (1978) and fiber content was estimated using the method given by Watson (1994).

**Statistical analysis:** The raw data was compiled by taking means of all replicates for each trait. The genetic components were estimated according to Hayman (1954), while the estimates of variance for GCA and SCA and their effects were computed according to model-1 (fixed effect model) and method-II proposed by Griffing (1956) separately for both the years. Data on morphological and quality traits of parents used for the statistical analysis was common in both the years. Heterosis was estimated over mid-parent and better parent.

## RESULTS AND DISCUSSION

The analysis of variance showed significant differences among the treatments (parents, $F_1$s and $F_2$s) for all the traits studied which indicated the presence of substantial genetic variability among the accessions (Table 2). The ANOVA for general combining ability showed highly significant values for all the characters in both generations except for stem diameter, fiber and chlorophyll content in $F_2$generation. In case of specific combining ability, all characters were significant in both the generations except for chlorophyll content in $F_2$ generation (Table 3). The foliage yield also had

Table 2: Analysis of variance for eight traits in vegetable amaranth (*Amaranthus tricolor* L.)

| Sources | df | PH (cm) | BPP | Lsz. ($cm^2$) | SD (cm) | Inf. | Caro. ($mg\ g^{-1}$) | Fibre (%) | Chl. ($mg\ kg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| Treatments | 14 | 709.647** | 232.396** | 929.263** | 1.072** | 388.323** | 0.320** | 41.473** | 180152.282** |
| Replicates | 2 | 5.112 | 0.898 | 0.231 | 0.054 | 1.689 | 0.013 | 0.169 | 2614.093 |
| Parents | 4 | 519.117** | 288.947** | 437.089** | 0.373** | 290.696** | 0.075** | 1.534 | 52753.841** |
| $F_1$ | 9 | 677.144** | 232.092** | 1247.446** | 1.285** | 402.151** | 0.367** | 55.452** | 53827.113** |
| $F_2$ | 9 | 1313.630** | 91.662** | 287.362** | 0.650 | 321.688** | 0.522 | 1.932** | 6089761687.051 |
| $F_1$ vs parent | 1 | 1764.292** | 8.923 | 34.299** | 1.947** | 654.373** | 0.884** | 75.423** | 1826672.548** |
| $F_2$ vs parent | 1 | 2016.589** | 4075.822** | 1417.552** | 9.960** | 1883.115** | 4.555** | 254.621** | 2024716030.830 |
| $F_1$ vs $F_2$ | 1 | 161920.800 | 2233.018 | 9265083.653 | 1.557 | 158.709 | 0.691 | 303.576 | 2203891659.998 |
| Error | 28 | 5.332 | 3.120 | 1.931 | 0.031 | 2.386 | 0.001 | 0.741 | 3528.821 |
| Total | 44 | 229.422 | 75.970 | 296.914 | 0.363 | 125.152 | 0.103 | 13.675 | 59685.616 |

*,**: Significance at 5 and 1%, PH: Plant height (cm), BPP: Branches per plant, Lsz: Leaf size ($cm^2$), SD: Stem diameter (cm), Inf.: Inflorescence, Caro.: Carotenoid content ($mg\ g^{-1}$), Chl.: Chlorophyll ($mg\ kg^{-1}$)

Table 3: Analysis of Variance for combining ability, their estimates and average degree of dominance for eight traits in vegetable amaranth (*Amaranthus tricolor* L.)

| Sources | PH (cm) | BPP | Lsz. ($cm^2$) | SD (cm) | Inf. | Caro. ($mg\ g^{-1}$) | Fibre (%) | Chl. ($mg\ kg^{-1}$) | FY ($kg\ plot^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| **GCA** | | | | | | | | | |
| F1 | 364.706** | 137.364** | 650.585** | 0.500** | 317.764** | 0.060** | 7.746** | 3970.942* | - |
| F2 | 33.701** | 77.262** | 91.846** | 0.354 | 216.250** | 0.014** | 0.157 | 867831376.586 | 0.431** |
| **SCA** | | | | | | | | | |
| F1 | 185.286** | 53.505** | 173.421** | 0.300** | 54.111** | 0.125** | 16.255** | 82482.687** | - |
| F2 | 517.043** | 170.980 ** | 155.000** | 0.435* | 111.536** | 0.156** | 9.208** | 1547293523.687 | 0.242** |
| **Error** | | | | | | | | | |
| F1 | 1.777 | 1.040 | 0.643 | 0.010 | 0.795 | 0.005 | 0.247 | 1176.273 | - |
| F2 | 1.534 | 1.024 | 0.689 | 0.149 | 15.646 | 0.000 | 0.067 | 1356333002.168 | 0.008 |
| **GCA/SCA** | | | | | | | | | |
| F1 | 1.968 | 2.567 | 3.751 | 1.666 | 5.872 | 0.481 | 0.476 | 0.048 | - |
| F2 | 0.065 | 0.451 | 0.592 | 0.813 | 1.938 | 0.091 | 0.017 | 0.560 | 1.780 |
| **√SCA/GCA** | | | | | | | | | |
| F1 | 0.718 | 0.624 | 0.516 | 0.776 | 0.413 | 1.441 | 1.449 | 4.558 | - |
| F2 | 3.197 | 1.488 | 1.299 | 1.108 | 0.718 | 3.322 | 7.568 | 1.335 | 0.749 |
| **$\sigma^2g$** | | | | | | | | | |
| F1 | 51.846 | 19.474 | 92.848 | 0.070 | 45.281 | 0.008 | 1.071 | 399.238 | - |
| F2 | 4.495 | 10.891 | 13.022 | 0.029 | 28.657 | 0.002 | 0.013 | -69785954.202 | 0.060 |
| **$\sigma^2s$** | | | | | | | | | |
| F1 | 183.509 | 52.465 | 172.778 | 0.289 | 53.316 | 0.125 | 16.008 | 81306.414 | - |
| F2 | 515.510 | 169.957 | 154.311 | 0.286 | 102295.890 | 0.156 | 9.141 | 190960467.687 | 0.233 |
| **$\sigma^2g/\sigma^2s$** | | | | | | | | | |
| F1 | 0.282 | 0.371 | 0.537 | 0.242 | 0.849 | 0.068 | 0.066 | 0.004 | - |
| F2 | 0.008 | 0.064 | 0.084 | 0.101 | 0.000 | 0.013 | 0.001 | 0.365 | 0.257 |
| **$(\sigma^2s/\sigma^2g)^{0.5}$** | | | | | | | | | |
| F1 | 1.881 | 1.641 | 1.364 | 2.031 | 1.085 | 3.822 | 3.866 | 14.270 | - |
| F2 | 10.709 | 3.950 | 3.442 | 3.134 | 59.746 | 8.793 | 27.599 | 1.654 | 1.970 |

*,**: Significance at 5 and 1%, PH: Plant height (cm), BPP: Branches per plant, Lsz: Leaf size ($cm^2$), SD: Stem diameter (cm), Inf.: Inflorescence, Caro.: Carotenoid content ($mg\ g^{-1}$), Chl.: Chlorophyll ($mg\ kg^{-1}$), FY: Foliage yield ($kg\ plot^{-1}$)

highly significant differences for general and specific combining ability in $F_2$ generation only. The significant values of variances due to general combining ability as well as specific combining ability suggested that both additive and non additive gene action were important in controlling the expression of these characters. Significant mean square values for GCA and SCA were also reported by Gopinath *et al.* (1966) and Shoaei and Honarnejad (2003). The estimate of component of combining ability variance viz., $\sigma^2$g (general combining ability) and $\sigma^2$s (specific combining ability) were obtained for all the traits. A ratio of $\sigma^2$g and $\sigma^2$s plays a very significant role in demonstrating the importance of additive and non additive gene interaction. If value of ratio is 1:1, it clearly indicated that both gene actions are equally important for expression of particular trait, where as any deviation from 1:1 ratio indicated the relative importance of any one of these two components. The value of $(\sigma^2 s/\sigma^2 g)^{1/2}$ is the measure of degree of dominance, when it was unity it indicated complete dominance whereas the value above and below unity indicate over dominance and partial dominance, respectively. The higher magnitude of $\sigma^2$s than $\sigma^2$g was obtained for all the traits which indicated the preponderance of non additive gene action. Ratio of $\sigma^2$g and $\sigma^2$s was very low. Degree of dominance was also higher than one which indicated over dominance and conform preponderance of non additive gene action for the expression of the traits. Similar results were also reported in grain Amaranth in which majority of characters which contributed towards seed yield were controlled by non additive type of gene action (Prajapati *et al.*, 2009). Karademir *et al.* (2009) found preponderance of non-additive gene action for carotenoid and chlorophyll content while Sreekala and Raghava (2003) and Subhashchandra *et al.* (2010) reported importance of additive gene action.

**General combining ability effect:** Analysis of combining ability provided very exclusive approach to identify superior parents which can be further exploited in breeding programme. This can be possible by analyzing the expected performance of their crosses and progenies in their hybrids combinations (Ojo *et al.*, 2007; Dhillon, 1975). The GCA effect plays a crucial role in selection of parents because it is controlled by fixable additive gene. The parents with high GCA will give better transgressive segregants in later generations (Singh and Dixit, 2007; Dar *et al.*, 2010, 2011). Combining ability variances provide a way by which investigation of history of generation involved in the crossing program become easier.

The positive significant value of GCA effect was considered as desirable for all the traits. It was noticed among the parents, AV-7 for branches per plant, leaf size, stem diameter, inflorescence and fiber in $F_1$ and branches per plant, leaf size and inflorescence in $F_2$; AV-28 for branches per plant, inflorescence, carotenoid, fiber in $F_1$ and plant height, branches per plant, leaf size, inflorescence, carotenoid, fiber, foliage yield in $F_2$; AV-49 for plant height, leaf size, stem diameter in $F_1$ and leaf size in $F_2$; AV-26 for plant height, branches per plant, leaf size, stem diameter, inflorescence, carotenoid, fiber in $F_1$ and plant height, branches per plant, leaf size, stem diameter, carotenoid in $F_2$; AV-62 for chlorophyll in $F_1$ and foliage yield in $F_2$ were found good general combiners (Table 4). It was noticed that none of the parents were good general combiner for all the traits in both the generations except AV-26 and AV-28 which showed significant value for most of the traits. This suggests that AV-26 and AV-28 can be used as one of the parent to produce good hybrid combination with any of the parent. The high general combiner AV-28 for foliage yield and its component traits identified in this study may be used in a multiple crossing programme for isolating high yielding varieties (Wammanda *et al.*, 2010).

Table 4: Estimates of GCA effects for eight traits in vegetable amaranth (*Amaranthus tricolor* L.)

| Sources | PH (cm) | BPP | Lsz. (cm) | SD (cm) | Inf. | Caro. (mg $g^{-1}$) | Fibre % | Chl. (mg $kg^{-1}$) | FY (kg $plot^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| **AV-7** | | | | | | | | | |
| $F_1$ | -5.387** | 1.063** | 6.985** | 0.190** | 6.987** | 0.002 | 0.971** | -1.528 | - |
| $F_2$ | 0.246 | 2.139** | 0.653* | -0.058 | 6.206** | -0.014** | 0.049 | -8205.239 | -0.418** |
| **AV-28** | | | | | | | | | |
| $F_1$ | -2.373** | 2.603** | -3.066** | -0.185** | 4.206** | 0.052** | 0.543** | 0.883 | - |
| $F_2$ | 2.570** | 0.822* | 0.746* | -0.243 | 4.949** | 0.043** | 0.205* | -8035.247 | 0.179** |
| **AV-49** | | | | | | | | | |
| $F_1$ | 2.052** | -0.349** | 5.120** | 0.122** | -7.368** | -0.150** | -1.528** | 14.276 | - |
| $F_2$ | -1.314** | -2.035** | 1.324** | 0.154 | -7.102** | -0.048** | -0.199* | 12283.116 | 0.057 |
| **AV-26** | | | | | | | | | |
| $F_1$ | 11.607** | 5.413** | 6.583** | 0.247** | 3.258** | 0.096** | 0.661** | -38.195** | - |
| $F_2$ | 1.455** | 3.679** | 3.436** | 0.303* | -1.046 | 0.052** | 0.020 | -8153.127 | -0.009 |
| **AV-62** | | | | | | | | | |
| $F_1$ | -5.900** | -4.730** | -15.62** | -0.374** | -7.083** | 0.000 | -0.647** | 24.563* | - |
| $F_2$ | -2.957** | -4.606** | -6.160** | -0.156 | -3.006* | -0.032** | -0.075 | 12110.497 | 0.190** |
| **SE** | | | | | | | | | |
| $F_1$ | 0.713 | 0.545 | 0.429 | 0.055 | 0.477 | 0.012 | 0.266 | 18.332 | - |
| $F_2$ | 0.662 | 0.541 | 0.444 | 0.206 | 2.114 | 0.004 | 0.139 | 19685.622 | 0.049 |

*.**: Significance at 5% and 1%, PH: Plant height (cm), BPP: Branches per plant, Lsz.: Leaf size ($cm^2$), SD: Stem diameter (cm), Inf.: Inflorescence, Caro.: Carotenoid content (mg $g^{-1}$), Chl.: Chlorophyll (mg $kg^{-1}$), FY: Foliage yield (kg $plot^{-1}$)

**Specific combining ability effect:** SCA estimates are presented in Table 5. The best specific combiners for all the traits were those which have maximum significant and positive values. It was noticed that the cross AV-49×AV-62 proved to be best specific combiner followed by AV-28×AV-62 among the 10 crosses for most of the characters in both the generations. These two crosses gave highest foliage yield in $F_2$ generation which could be due to increase in plant height, number of branches per plant and leaf size. Shukla *et al.* (2010) reported that the foliage yield is directly correlated with plant height, number of branches and leaf size. The foliage yield of these crosses in $F_1$ generation can be presumed to be better than other cross combinations. Based on visual evaluation of plants in $F_1$ generation, the crosses AV-49×AV-62 and AV-28×AV-62 were more vigorous than other cross combinations which indicated that the foliage yield of these crosses would also be better than the other crosses in $F_1$. For leaf size crosses AV-7×AV-49 and AV-28×AV-62 showed highest SCA values in $F_1$ and $F_2$ generations. The cross AV-7 X AV-28 showed highest value of SCA for stem diameter and chlorophyll content in $F_1$ generation and in case of inflorescences per plant this cross showed highest value for both generations. The crosses AV-49×AV-26 and AV-49×AV-62 showed highest value of SCA for stem diameter and chlorophyll in $F_2$ generation respectively. The cross AV-49×AV-62 showed highest significant SCA value for foliage yield followed AV-26×AV-62. For carotenoid, cross AV-7×AV-28 showed highest value in $F_1$ generation but all the crosses showed negative values in $F_2$ generation. In case of fibre content cross AV-26×AV-62 showed highest value for SCA in $F_1$ but in $F_2$ all the crosses showed negative values. In these hybrids all kinds of parental combinations like high×high, high×low, medium× medium and medium×low were invested which suggested that either additive×additive or additive×dominance genetic interactions were predominant in these crosses. The superiority of these crosses may be due to complementary or duplicate type of gene interactions. Similar results were

Table 5: Estimates of SCA effects for eight traits in vegetable amaranth (*Amaranthus tricolor* L.)

| Sources | PH (cm) | BPP | Lsz. (cm) | SD (cm) | Inf. | Caro. (mg $g^{-1}$) | Fibre (%) | Chl. (mg $kg^{-1}$) | FY (kg $plot^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| **AV-7×AV-28** | | | | | | | | | |
| $F_1$ | 14.154** | 0.148 | -6.666** | 0.415** | 4.877** | 0.711** | 4.560** | 122.347** | - |
| $F_2$ | 17.566** | -5.391** | -2.621** | -0.208 | 7.338 | -0.248** | -0.986** | 6864.580 | -0.113 |
| **AV-7×AV49** | | | | | | | | | |
| $F_1$ | 4.729** | 0.434 | 21.138** | 0.408** | -8.548** | -0.265** | 4.097** | -269.909** | - |
| $F_2$ | -32.382** | -10.867** | -18.105** | -0.671 | -11.945** | -0.174** | -2.849** | -14013.164 | -0.245* |
| **AV-7×AV-26** | | | | | | | | | |
| $F_1$ | -4.160** | -5.328** | 3.489** | 0.182 | 3.158** | -0.099** | -0.869 | -137.188** | - |
| $F_2$ | 15.348** | -13.915** | -3.110** | -0.288 | -4.667 | -0.258** | -2.201** | 7126.103 | 0.094 |
| **AV-7×AV-62** | | | | | | | | | |
| $F_1$ | -11.985** | -8.185** | -13.354** | -0.897** | -1.834 | 0.156** | -2.451** | -106.411** | - |
| $F_2$ | -11.906** | -6.629** | -10.288** | -0.462 | -3.707 | -0.181** | -2.706** | -13641.328 | -0.265* |
| **AV-28×AV-49** | | | | | | | | | |
| $F_1$ | 0.381 | 2.561* | -18.431** | -0.683** | -4.434** | -0.265** | -0.808 | -288.073** | - |
| $F_2$ | 7.461** | -9.550** | -15.683** | -0.687 | -2.355 | -0.213** | -2.071** | -13072.783 | -0.318** |
| **AV-28×AV-26** | | | | | | | | | |
| $F_1$ | 0.493 | 1.132 | 17.596** | -0.243 | 0.273 | -0.266** | 2.803** | -216.096** | - |
| $F_2$ | -9.642** | 1.402 | -2.834** | -0.170 | -16.077** | -0.327** | -1.924** | 6944.158 | -0.176 |
| **AV-28× AV-62** | | | | | | | | | |
| $F_1$ | 18.000** | 10.942** | -0.033 | 0.112 | -5.720** | -0.113** | - 0.956 | -280.138** | - |
| $F_2$ | 0.770 | -6.979** | 15.446** | -0.310 | 1.550 | -0.243** | -1.162** | -14000.236 | 0.622** |
| **AV-49×AV-26** | | | | | | | | | |
| $F_1$ | 12.401** | -4.582** | 3.713** | 0.117 | 0.180 | 0.318** | -3.427** | 1.779 | - |
| $F_2$ | -37.091** | -10.074** | 5.235** | 0.233 | -4.359 | -0.226** | -1.487** | -13666.463 | -0.147 |
| **AV-49×AV-62** | | | | | | | | | |
| $F_1$ | -8.758** | -5.439** | -7.952** | -0.328** | -2.145* | 0.116** | -1.852** | -240.361** | - |
| $F_2$ | 20.655** | 4.545** | -1.569 | 0.026 | -2.733 | -0.136** | -0.658* | 108573.413** | 1.070** |
| **AV-26×AV-62** | | | | | | | | | |
| $F_1$ | 19.020** | 11.466** | -5.672** | -0.554** | -12.772** | 0.463** | 8.059** | -10.605 | - |
| $F_2$ | -18.115** | -9.836** | -6.158** | -0.790 | -8.788* | -0.246** | -0.777** | -13683.440 | -0.087 |
| **SE** | | | | | | | | | |
| $F_1$ | 1.593 | 1.219 | 0.958 | 0.122 | 1.066 | 0.026 | 0.594 | 40.992 | - |
| $F_2$ | 1.480 | 1.209 | 0.992 | 0.462 | 4.728 | 0.009 | 0.310 | 44018.389 | 0.110 |

*.**: Significance at 5% ans 1%, PH: Plant height (cm), BPP: Branches per plant, Lsz.: Leaf size ($cm^2$), SD: Stem diameter (cm), Inf: Inflorescence, Caro.: Carotenoid content (mg $g^{-1}$), Chl.: Chlorophyll (mg $kg^{-1}$), FY: Foliage yield (kg $plot^{-1}$)

earlier reported by Dhaliwal and Sharma (1990), Katre and Jambhale (1996) and Ramalingam *et al.* (1997). The crosses governed by the additive and additive×additive gene actions are expected to produce desirable segregants that can be exploited successfully in varietal improvement program.

**Estimation of heterosis:** Among ten crosses, eight crosses showed positive and significant values of heterosis over mid parent for plant height, four for number of branches and leaf size, two for stem diameter, one for inflorescences/plant, five for fiber and carotenoid content. None of the crosses showed positive significant values for chlorophyll content. However over better parent four crosses showed positive and significant value for plant height, two for number of branches, four for leaf size, five for fiber content and three for carotenoid content. None of the crosses showed positive significant values for stem diameter, inflorescences/plant and chlorophyll content.

Highest value of heterosis over mid as well as over better parent was for cross AV-28×AV-62 for plant height and number of branches/plant, cross AV-28×AV-26 for leaf size, AV-7×AV-28 for stem diameter and inflorescence/plant and cross AV-26×AV-62 for fibre content. For carotenoid, cross AV-26×AV-62 showed highest value for mid parent and cross AV-7×AV-28 showed highest value for better parent (Table 6). The crosses which showed highest value of heterosis consist of parent with high×high, high×low and low×low GCA effect. Highest value of heterosis showed by crosses when both parents exhibited high GCA effect indicated additive×additive gene interaction and fixable in nature (Yadav *et al.*, 2009). These combinations can be utilized for further varietal improvement programme by adopting recurrent breeding and biparental mating. The cross combination which involve high×low combiner indicated favorable additive effect along with complimentary gene actions. The crosses in which both parents had low GCA effect but in combination still showed high heterosis that might be due to the interaction between favorable genes contributed by significant parent. High×low and low×low type of combinations exhibited additive×dominance and dominance×dominance interactions and these can be exploited through heterosis breeding. The positive value of heterosis shows capacity of hybrid to develop high yielding genotype (Turi *et al.*, 2006). Positive values for plant height, number of branches per plant, stem diameter and fibre content were reported by Mirza (1986), Rauf *et al.* (2005) and Mendez-Natera *et al.* (2007). Some researchers also reported negative heterosis for these traits (Desalegn *et al.*, 2004).

Table 6: Heterosis (%) over mid parent (MP) and better parent (BP) for eight traits in vegetable amaranth (*Amaranthus tricolor* L.)

| | PH (cm) | | | BPP | | | Lsz. ($cm^2$) | | | SD (cm) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crosses | MP | BP | ID | MP | BP | ID | MP | BP | ID | MP | BP | ID |
| AV-7×AV-28 | 28.41** | 21.71** | 4.15 | 2.99 | -13.13** | 70.94 | -21.00** | -34.13** | 18.25 | 22.60** | 11.67 | 58.29 |
| AV-7×AV-49 | 8.33** | 1.70 | 53.35 | -16.46** | -33.33** | 100.00 | 51.19** | 49.57** | 87.19 | 17.83** | 10.14 | 65.61 |
| AV-7×AV-26 | 3.64* | -6.76** | 3.32 | -22.77** | -24.27** | 89.73 | 23.92** | 11.92** | 47.33 | 6.80 | -4.82 | 42.39 |
| AV-7×AV-62 | -8.72** | -12.79** | 12.89 | -40.91** | -60.61** | 87.15 | -67.76** | -78.88** | 5.62 | -62.39** | -63.33** | -5.48 |
| AV-28×AV-49 | 12.38** | 0.34 | 9.82 | 20.31** | 11.59 | 100.00 | -58.65** | -65.08** | 26.75 | -50.39** | -53.62** | 37.38 |
| AV-28×AV-26 | 17.00** | 0.36 | 31.18 | 18.60** | -0.97 | 50.97 | 63.91** | 50.50** | 50.71 | -28.31** | -36.11** | 18.40 |
| AV-28×AV-62 | 39.06** | 37.87** | 25.62 | 98.04** | 46.38** | 100.00 | -41.65** | -57.41** | -178.54 | -29.91** | -31.67** | 46.71 |
| AV-49×AV-26 | 20.94** | 15.54** | 65.41 | -21.47** | -37.86** | 89.07 | 21.26 ** | 10.68** | 26.09 | 0.95 | -10.04 | 7.39 |
| AV-49×AV-62 | -2.84 | -12.59** | -12.44 | -33.33** | -48.33** | 16.07 | -54.40** | -69.96** | -42.31 | -36.75** | -38.33** | -19.51 |
| AV-26×AV-62 | 32.02** | 13.89** | 50.95 | 64.44** | 8.82* | 100.00 | -32.30** | -53.26** | 5.32 | -53.74** | -62.22** | 29.20 |
| | Inf. | | | Caro. ($mg\ g^{-1}$) | | | Fibre% | | | Chl. ($mg\ kg^{-1}$) | | |
| | MP | BP | ID | MP | BP | ID | MP | BP | ID | MP | BP | ID |
| AV-7×AV-28 | 9.79* | 2.08 | 4.10 | 79.65** | 65.58** | 64.47 | 85.74** | 75.56** | 75.95 | -23.80** | -31.84** | -60.53 |
| AV-7×AV-49 | -62.90** | -76.04** | 100.00 | -37.29** | -52.34** | 71.22 | 59.20** | 47.41** | 88.47 | -88.60** | -90.36** | -127.39 |
| AV-7×AV-26 | 0.51 | -6.25 | 55.56 | -5.07 | -11.08** | 39.28 | 25.13** | 16.56* | 77.12 | -68.00** | -70.70** | -467.11 |
| AV-7×AV-62 | -35.77** | -54.17** | 15.95 | 32.80** | 4.91 | 65.48 | -5.20 | -15.56 | 76.31 | -59.58** | -64.65** | -47.98 |
| AV-2×AV-49 | -51.79** | -67.86** | 7.44 | 0.30 | -23.77** | 19.45 | 1.28 | -0.83 | 68.85 | -91.94** | -92.44** | -2130.18 |
| AV-28×AV-26 | -12.62** | -13.10** | 97.25 | -17.53** | -22.76** | 66.54 | 74.21** | 71.67** | 79.38 | -86.02** | -88.43** | -1016.93 |
| AV-28×AV-62 | -61.60** | -71.43** | -104.12 | -17.53** | -17.02** | 69.36 | 15.30 | 8.33 | 59.63 | -88.91** | -89.19** | -133.59 |
| AV-49×AV-26 | -30.96** | -54.26** | 97.39 | 23.12** | 15.32** | 57.05 | -31.08** | -32.08** | 47.14 | -48.31** | -59.31** | -83.37 |
| AV-49×AV-62 | -100.00** | -100.00** | 0.00 | 8.42* | -14.35** | 24.06 | -24.17** | -28.75** | 36.84 | -82.32** | -83.01** | -111133.34 |
| AV-2×AV-62 | -100.00** | -100.00** | 0.00 | 83.40** | 44.89** | 74.45 | 136.81** | 122.50** | 79.21 | -46.00** | -56.18** | -22.64 |

*.**: Significance at 5% ans 1%, PH: Plant height (cm), BPP: Branches per plant, Lsz.: Leaf size ($cm^2$), SD: Stem diameter (cm), Inf: Inflorescence, Caro.: Carotenoid content ($mg\ g^{-1}$), Chl.: Chlorophyll ($mg\ kg^{-1}$)

Majority of cross combinations showed inbreeding depression for all the traits except cross AV-49×AV-62 for plant height , AV-28×AV-62 and AV-49×AV-62 for leaf size, AV-7×AV-62 and AV-49×AV-62 for stem diameter and AV-28×AV-62 for inflorescence and all cross combinations for chlorophyll content. It was interesting that the inbreeding depression clearly indicated cross combinations involving parent AV-62 showed no inbreeding depression in next generations.

The present study concluded that the parent AV-26 was good general combiner for plant height, branches per plant and carotenoid content in both generations and was also present in the cross combinations involving this parent exhibited highest SCA values for these traits. The crosses AV-49×AV-62 and AV-28×AV-62 having high foliage yield with increased plant height, branches per plant and leaf size can be used as transgressive segregants to obtain highest returns from Amaranthus breeding. However, the cross combinations showed no inbreeding depression can be further exploited in advance generations to develop nutritionally rich high yielding varieties.

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