International Journal of Farm Sciences **5(1)** : 233-250, 2015

Review

Hybrid breeding in tomato

MONIKA SHARMA, MN ADARSH, POONAM KUMARI, MANISHA THAKUR, RAMESH KUMAR, RAJNISH SHARMA* and NIDHISH GAUTAM**

Department of Vegetable Science
***Department of Biotechnology**
Dr YS Parmar University of Horticulture and Forestry
Nauni, Solan 173230 HP, India
****Division of Floriculture and Landscaping**
IARI, Pusa 110012, New Delhi, India
Email for correspondence: adarshm464@gmail.com

ABSTRACT

Hybrid technology has become one of the main factors contributing to the significant global rise in agricultural output over the last few decades. In hybrid breeding an efficient pollination control system is required to avoid the unwanted self-pollination or sib-pollination of the female parental line. With the ease of use of cost effective mechanisms to produce large scale hybrids utilizing selected parental lines is another important factor which ultimately determines the commercial viability of the hybrid varieties. In tomato although crosses can be developed through manual emasculation followed by manual pollination of emasculated flowers or pistillate flowers commercial hybrid seed production is economically feasible in which a large number of F_1 seeds are obtained from one manually pollinated crossed fruits. With the invent of male sterility mechanisms and their proposed utilization in hybrid seed production several mechanisms and methods have been evolved for the development of experimental and commercial hybrids.

Keywords: Hybrid; heterosis; gene action; combining ability; tomato

INTRODUCTION

In many crops hybrids have become the predominant form of cultivar (Duvick 2005, Wang et al 2005). When the first maize hybrids were introduced in the market in 1920s they yielded about 15 per cent more than the best open-pollinated varieties grown at the same time (Duvick 1999). Later a six fold increase in yield was observed in US corn between 1930 and 1990 (Stuber 1994). Now a days in developed countries many allogamous (cross-fertilizing) crops are predominately produced as hybrid cultivars like maize, sunflower, brassicas, cucurbits, carrots, beets and onions. Further hybrid cultivars have also become common in certain autogamous (selffertilizing) crops like tomato, brinjal, pepper etc.

The hybrids are not limited to increased seed yield or biomass. There are many other beneficial factors such as improved physical stability, higher responsiveness to fertilizers, better root penetration and seed filling that are valuable advantages as well. Economically the improved tolerance to abiotic stresses (eg drought and heat) in hybrids has been particularly significant. It has been thought that the drought tolerant hybrid properties may have an impact in the light of the climatic changes that are predicted to impair crop production in the future (Bruce et al 2002, deVries 2000).

Tomato (*Solanum lycopersicum* L) belonging to family Solanaceae is one of the most commercially important vegetables which is widely grown throughout the world. It is originated in Central and South America. It is the largest vegetable crop in the world next to potato with its significant importance in processed products. In India fresh fruits of tomato are in greater demand round the year. These fruits are used to produce ketchup, paste, puree, juice and soup. The crop plays an important role in economic upliftment of the farmers living in hills in the form of off-season produce especially in Himachal Pradesh (Kumari and Sharma 2012). In these areas tomatoes are produced as off-season vegetable ie during June to November and in the markets of north Indian plains these fetch very remunerative price to the farmers. But the national average fruit yield of tomato is less compared to other countries like Japan. Therefore there is an immense scope for its improvement which can be achieved through breeding high yielding varieties and hybrids with improved cultivation technology.

Being a self-pollinated crop it has a tremendous potential for heterosis breeding. The commercial exploitation of hybrid vigour has received greater importance on account of several advantages of hybrids over pure line varieties with response to marketable fruit yield and its component traits. Choice of parents is of greater importance for exploitation of heterosis. Combining ability studies are more reliable as they help in selection of parents in terms of hybrid performance and elucidate the nature and magnitude of various types of gene actions involved in the expression of quantitative traits. The performance data obtained from general combining ability (GCA) of parents and specific combining ability (SCA) of crosses help us to select suitable parents and related crosses respectively.

The line x tester approach given by Kempthorne (1957) is one of the most appropriate methods for screening the material for combining ability and also an important technique used to understand the genetic potential of parents and their hybrids. Thus selection would be easier in hybridization programme for developing superior F_1 hybrids having a complex of valuable attributes viz earliness, uniformity, high yield, resistance to diseases and adaptability to different environmental conditions.

Gene action

It is the behaviour or mode of expression of genes in a genetic population. The concept of gene action in plant breeding helps in the proper selection of parents for the hybridization programmes along with the appropriate breeding procedure for the improvement of various quantitative characters. Hence insight into the nature of gene action involved in the expression of various quantitative characters is essential to a plant breeder for starting a judicious breeding programme.

Frankenberger et al (1981) evaluated twenty one tomato genotypes for shoot forming capacity from leaf disc explants. Quantitative differences in shoot forming capacity were present among the genotypes. A diallel cross was performed using 6 parental genotypes selected for diversity in shoot forming capacity. The linear regression of hybrid shoot formation on mid-parent values revealed a high heritability for shoot forming capacity (h^2= 0.98). General combining ability effects and measuring additive gene action accounted for a large part of the shoot forming variability within the F_1 hybrids of the diallel cross. Specific combining ability and measuring dominance or epistasis were also significant. In the Jinks and Hayman analysis recessive genes were associated with high shoot forming capacity in 2 of 3 high shoot forming genotypes.

Dane et al (1991) evaluated selected tomato *(Lycopersicon esculentum* Mill*)* genotypes for their fruit setting ability under high temperature field conditions. A temperature controlled greenhouse study was conducted to determine the per cent fruit set from the total number of flowers and fruit produced per plant. Ratings for set obtained under high temperature field conditions were significantly (P= 0.001) correlated with per cent fruit set determined under similar greenhouse conditions. Most of the Asian Vegetable Research and Development Center (AVRDC) selections, Beaverlodge lines, Nagcarlan and Red Cherry could be considered heat tolerant. Small-fruited abundantly flowering genotypes were less affected by heat stress than large-fruited cultivars. Prolonged periods of high temperature caused drastic reductions in pollen fertility in most genotypes except Red Cherry and *L esculentum* var *cerasiforme* (PI 190256). Stigma browning and stigma exertion commonly occurred on all lines except AVRDC CL-5915-553 and PI 190256. Diallel analysis indicated that pollen fertility and fruit set under high field temperatures were primarily under additive gene control.

Bhatt et al (2001) conducted a study on a 15 × 15 diallel set of tomato excluding reciprocals to find out the extent of heterosis, combining ability and nature of gene action for yield with two important quality traits viz ascorbic acid (vitamin C) and total soluble solids (TSS). Significant differences among genotypes were obtained for all three traits. Positive high significant heterosis was found for yield (41.97, 157.84 and 28.94%), for ascorbic acid (16.68, 5.57 and 161.33%) and for TSS (25.97, 11.93 and 19.02) over the top, the better parent and the commercial control respectively. The magnitude of variance due to general as well as specific combining ability was highly significant indicating the importance of both additive and non-additive gene action. However degree of dominance (o^{-2} g/o^{-2} s) revealed the prevalence of a non-additive gene effect. Cross combinations Arka Vikas × Sel-12 (13.19), KS-10 × Pant T-3 (1.66) and EC 818703 × EC 13042 (0.88) were best specific combiners for ascorbic acid, total soluble solids and yield/plant. Predominance of non-additive gene action plays a greater role in the inheritance of ascorbic acid and total soluble solids in tomato under hill conditions.

Joshi and Kohli (2006) studied gene effects for processing quality attributes in tomato by involving 45 cross combinations obtained from crossing 10 diverse lines of tomato in half-diallel fashion. The studies revealed that the ratio of additive variance to dominance variance revealed the predominance of non-additive gene actions for total soluble solids, ascorbic acid content, fruit shape index, stem end scar size and number of locules. The high per se performance along with high GCA estimates of lines CLN-1351E and FT-5 suggested that these lines may be utilized for incorporating high total soluble solids, smaller stem end scar size and lower number of locules. Line EC-401927 appeared to be good general combiner for ascorbic acid content and may be utilized in future tomato breeding programmes. The crosses UHF-II x EC-401927 and CLN5915–206D4–2-2–0 x FT-5 exhibited highest SCA estimates for total soluble solids and number of locules respectively. However the combination CLN1462A x FT-5 gave significant SCA estimates in desirable direction for ascorbic contents and stem end scar size in tomato. Hence these combinations could be effectively utilized for developing hybrids having high quality for processing purposes. Heritability estimates in narrow sense was observed low for total soluble solids, ascorbic acid content, fruit shape index and stem end scar size suggesting that direct selection for these traits may be ineffective as the trait was largely governed by dominant genes. Hence heterosis breeding is suggested for future improvement of processing quality traits in tomato.

Garg et al (2008) evaluated seventy nine genotypes of tomato (15 lines, four testers and their 60 F_1 hybrids produced in line × tester fashion) under normal (E_1) and late planting (E_2) conditions in the Department of Vegetable Crops, Punjab Agricultural University, Ludhiana, Punjab to determine the nature of gene action controlling yield, quality and shelf-life characteristics and to identify a few good combiner genotypes which may be used in further breeding programmes to extend the fruit availability period of tomato in north Indian plains. The lines were significantly different from testers for most of the characters thereby justifying the choice of testers. Additive gene action was predominant for days to ripening, total yield per plant, marketable yield per plant, number of fruits per plant, average fruit weight, fruit shape index and lycopene in both the environments whereas non-additive genetic variance predominated in controlling firmness index, number of locules, pericarp thickness, alcohol insoluble solids (AIS), dry matter, total soluble solids (TSS), titratable acidity, TSS/acid ratio, pH, ascorbic acid and shelf-life under both normal and late planting conditions. The best general combining ability (GCA) effects among females in respect of yield per plant were shown by Spectrum in E_1 and by LT-42 in E_2. Among the testers the best GCA values in both the environments were possessed by *nor*-RM-1 for total yield per plant, marketable yield per plant, number of fruits per plant, dry matter and TSS; by *rin*-RM-2 for firmness index, pericarp thickness and alcohol insoluble solids; by *alc*-IIHR-2050 for average fruit weight, number of locules and shelf-life and by *alc*-IIHR-2052 for lycopene. The GCA of ripening mutants had a nice consonance with their per se performance for most of the characters indicating that additive gene action was operative in these mutants for majority of the traits.

Saleem et al (2009) conducted line x tester experiment to evaluate the performance of 30 hybrids along with 13 parents in tomato. Variance due to treatments, crosses and lines x testers was significant for days to fruiting, fruit weight, fruit length, fruit width, number of fruit per plant and yield per plant. The estimate of variance of GCA, SCA, their ratio and degree of dominance indicated preponderance of non-additive gene action for all the traits suggesting that selection might not be made in the early generations and recurrent selection with periodic inter-crossing appeared to be the best method. Narrow sense heritability was low in all traits but moderate for fruit weight while genetic advance was low to high in aforementioned traits. Contribution of lines towards the total variance was more than that of testers. Line x tester interactions contributed more in days to fruiting, number of fruit per plant and yield per plant than that of lines and testers. Based on mean performance and GCA effects line 88572 and UC-134 and tester Nagina were better for yield and its various components. Considering mean performance, SCA effects and heterobeltiosis three hybrids 88572 × Riogrande, Picdeneto × Riogrande and H-

24 × Riogrande were superior for yield and were recommended for further evaluation.

Singh and Asati (2011) crossed thirteen diverse lines of tomato with three testers in line x tester mating fashion to study combining ability effects and heterosis for plant height, number of primary branches per plant, fruit weight, bacterial wilt incidence and yield per plant during Rabi season of 2005-06 at Horticultural Research Farm, ICAR Research Complex for NEH Region, Umiam, Meghalaya. The analysis of variance revealed the predominance of non-additive gene action for all the traits. In respect of both GCA and SCA effects the parents and hybrids differed significantly. Among the parents Sel-2 and BT-117-5-3-1 were the best general combiners for yield per plant and other characters under study and these may be used as valuable donors in the hybridization programme for producing promising combinations in bacterial wilt prone areas. Among the crosses BT- 207 × KT-15, Type-I × KT-15 and FEB-2 × BT-117-5-3-l were the most valuable combiners for yield per plant and other characters under study could be utilized in bacterial wilt resistant breeding programmes. The highest heterotic effect over better parent was also exhibited by the cross Type-1 × KT-15 for yield per plant and plant height under bacterial wilt condition.

Narolia et al (2012) studied genetic variability, heritability and genetic advance for thirteen quantitative characters in 55 genotypes of tomato during Rabi season 2008–09. The analysis of variance indicated significant differences among the genotypes for all characters. Variability was high for all the characters studied except number of branches per plant and days to 50 per cent flowering for which variability was moderate and low respectively. High heritability coupled with high genetic advance as per cent of mean was observed for all the characters except days to 50 per cent flowering indicating the presence of additive gene action in the expression of these characters. High estimates of genotypic coefficient of variation, heritability and genetic advance were recorded for plant height, days to 50 per cent flowering, number of flowers per cluster, number of flower clusters per plant, number of fruits per plant, average fruit weight, number of locules per fruit, acidity, total soluble solids, ascorbic acid content, shelf-life and fruit yield per plant suggesting the scope for improvement of these characters through selection.

Shalaby (2013) studied on determining heterosis and the type of gene action controlling some economical traits of tomato. Six populations of the cross CastleRock × CLN 2498E (P_1, P_2, F_1, F_2, BC_1 and BC_2) were used to study the genetic parameters of tomato traits. Means of the six populations widely differed for most of the studied traits. One or more of the three scaling tests (A, B and C) were significant for some studied traits indicating that additive dominance model was inadequate to know the role of the type of gene action in the inheritance of these traits. Additive gene effects were found to be important in the inheritance of average fruit weight. Dominance and dominance × dominance gene effects were important in the inheritance of plant height, number of branches per plant fruit firmness and early yield. Heterosis relative to better parent was present for number of branches per plant, early yield, total yield and fruit firmness. The heritability estimates in broad sense were high for early yield, total yield, average fruit weight, fruit firmness and TSS content. However heritability estimates in narrow sense were high for early yield, average fruit weight and moderate for TSS content. The estimated potence ratio (P) was larger than one for all studied traits except for average fruit weight and TSS content.

El-Gabry et al (2014) estimated general and specific combining ability (GCA and SCA) using five tomato cultivars and their F_1 hybrids using diallel cross system without reciprocals. Heritability percentages in narrow sense were also calculated for the different studied characters of tomato. The obtained results indicated that a particular cultivar or hybrid cannot be used to evaluate all studied characters with equal efficiency. However the best general combiner parent which appeared to have the significant highest positive values of GCA was found to be the cultivar Super Marmand for the characters plant height, number of flowers per clusters, ascorbic acid content and total soluble solids; the cultivar Edkawy for number of primary branches, number of locules per fruit and fruit weight; the parental cultivar Peto-86 for number of fruits per plants, fruit shape index and pericarp thickness and Super Strain-B for fruit firmness and total fruits yield per plant. The results also illustrated that the best hybrid combinations that reflected the highest positive values of SCA were found to be Peto-86 × Edkawy for plant height and total soluble solids; CastelRock × Peto-86 for fruit shape index, fruit weight and total fruits yield per plant; Super Marmand × CastelRock for number of flowers per cluster and number of fruits per plant; Super Strain-B × Super Marmand for ascorbic acid and TSS percentage and Super Strain-B × Peto-86 for fruit firmness. Narrow sense heritability estimates were found to be in the range from -37.33 per cent (not different from zero) for the number of flowers per cluster up to 86.69 per cent for fruit firmness characters.

Combining ability

The combining ability analysis is the most important and efficient tool in choosing the desirable parents for hybridization programmes (Sharma et al 2013). The concept of combining ability was enunciated by Sprague and Tatum (1942). They partitioned the genetic variances into two components viz variance due to general combining ability (GCA) and variance due to specific combining ability (SCA). The

GCA is defined as the average performance of lines/strains in a set of cross combinations and the SCA as those instances in which certain cross combinations do relatively better or worse than would be expected on the basis of average performance of the parental lines involved crops combination. It is also expressed that GCA is mainly the result of additive gene effects and additive × additive interactions while SCA is consequences of dominance, epistatic deviation and genotype × environmental interactions. This also revealed that in cases where the estimates of SCA variance (σ^2 SCA) were large than those of GCA variance (σ^2 GCA) the importance of epistatic and dominance effects are more than the additive gene effects.

Sharma et al (1999) estimated the general and specific combining ability in tomato through line × tester analysis involving 12 lines (females) and 2 testers (males). The combining ability analysis revealed that the variances due to lines and crosses were significant for all the traits studied. The mean squares due to testers and lines × testers were significant for all the traits except fruit weight, plant height and days to maturity respectively. Among parents, the lines BTL-33 and BTL-11 and tester Roma proved the best general combiners for yield and its component traits. The best specific cross combinations were BTN-46 × Roma, BTL-11 × AC-402 and BTR-49 × Roma. The best cross combinations did not necessarily involve good general combiners as their parents. Based upon the contribution of lines, testers and their interactions it was evident that the variability among the crosses was mainly due to the contribution of lines only.

Dharmatti et al (2001) estimated the general combining ability of the 15 parents (five female + ten male) and specific combining ability of 50 crosses for seven characters in summer tomato using a Line × Tester analysis. The results revealed that the GCA/SCA ratios were less than unity for all the characters indicating the predominant role of non-additive gene action. The general combining ability effects revealed that the parents 20/2, 20/5 and 20/6 Alcobasa were the best general combiner for fruit yield. The top four high significant positive SCA effect and per se values for fruit yield per plant were shown by the crosses 20/6 Alcobasa x L-58, 20/2 Alcobasa x L-15, 20/4 Alcobasa x L-58 and 20/5 Alcobasa x N-2298MF6. In general high heterosis was noticed by the crosses with parents having high GCA status.

Chadha et al (2001) studied the combining ability for yield and yield components of tomato made over two environments in a set of 10 lines and four testers. The pooled analysis showed that both GCA and SCA were influenced by the environment implying that the parents and crosses must be evaluated over a wide range of environments to have unbiased estimate. The lines Hisar Arun and Pusa Gaurav and the testers Solan Gola and Roma held great promise to enhance the marketable yield in tomato. Out of 40 F_1s studied three crosses each were found to be good specific combiners for days to 50 per cent flowering and per cent marketable fruits, six for marketable yield/ plant and two for marketable fruits/plant over both the environments. Hisar Arun x Solan Gola and Pusa Gaurav x Roma were the best specific combiners. No additive gene action was preponderant for marketable yield/plant and per cent marketable fruits while additive for days to 50 per cent flowering, marketable fruits/ plant and locules/fruit.

Dhaliwal et al (2002) investigated the experimental material consisting of 66 one way F_1 hybrids produced in a diallel cross mating and their twelve parents. The experiment was laid out in an RBD using three replications. The ANOVA for combining ability and the components of variation analysis revealed the involvement of both additive and non-additive gene effects in the inheritance of fruit weight (g), number of marketable fruits, marketable yield (kg/plant) and total yield (kg/plant). None of the parents involved was found to be good general combiner for all the characters studied. Based upon the information obtained from the combining ability components of variation and graphical analyses it was concluded that yield in tomato can be improved both through pure line breeding as well as through heterosis breeding. Parents viz X 332, S 285, C 122 and S 284 were identified as good combiners for yield and its component characters. From the present set of crosses X 332 x I 181 and S 284 x I 181 may be pursued further for isolating high yielding true breeding lines. Two hybrids namely P 254 x S 285 and S 284 x I 181 which performed significantly better than the two check hybrids TH 802 and TH 2312 were recommended for commercial exploitation.

Rodríguez et al (2004) determined the gene action for mean fruit weight, pericarp weight and locule content weight. A complete diallel using 10 experimental lines was evaluated during Spring-Summer 1998 in a greenhouse at Lomas de Cristo, Mexico and in a non-recirculating, open hydroponic system using Steiner's Universal Solution applied via drip irrigation at 0.7 atm osmotic pressure. The experimental design was a 10 x 10 partially balanced lattice with two replications. To estimate mean fruit weight, pericarp weight and locule content weight fruits were collected mature, weighed individually, cut equatorially to extract locule contents and fruit parts weighted separately. Genetic variance analysis was done following Griffing's method 1. Additive genetic effects prevailed; narrow sense heritability was low ie 18 to 25 per cent. Improvement of these characters in selection requires the appropriate breeding method using a low pressure selection index. The best parents (CJPL-8-7-4, CJPL-2-2-1) were equal in their general combining ability for the three characters studied. Mean fruit weight components permit improvement for soluble solids and fruit flavour along with increased fruit weight. Significant reciprocal effects indicated that mean fruit weight and its components were influenced by the male parent. Parents with the highest reciprocal effects estimates for crossing should be identified before initiating a selection process. Equilibrium exists between pericarp weight and locule content weight, an increase for one results in a decrease for the other.

Joshi et al (2005) revealed that line x tester analysis for shelf-life and related traits line FT-5, 102, Magna and Cal-ace were good general combiners for fruit firmness, number of locules per fruit, pericarp thickness and shelf-life. Among testers V-16 was good general combiner for all the characters except number of locules per fruit. The ratio of GCA/SCA variances observed less than unity for all the characters depicting the predominance of non-additive genetic variance. Amongst crosses H-711492 × 101 and 260 × V-16 exhibited the maximum heterosis over better parent for whole fruit firmness and pericarp thickness respectively. Whereas cross combination FT-5 × V-16 recorded highest significant heterobeltiosis and SCA estimates for shelf-life. Hence this cross combination can be commercially utilized for the development of hybrids having longer shelf-life.

Sirohi and Gaurav (2008) obtained 36 F_1s of tomato from a diallel cross of heat tolerant lines that were grown along with parents and check hybrid TH2312 during spring season of 2006. Highly significant GCA and SCA variances observed for different characters except TSS indicated the importance of both additive and non-additive gene action in the expression of these characters. The estimates of component of genetic variance indicated predominant role of non-additive gene effects for the characters studied. Under high temperature conditions EC534-1-2-1 and PS-6-1-1 were best general combiners for most of the traits for instance endosperm utilization efficiency, setting percentage per cluster, harvesting span, total yield and marketable yield per plant. The cross 1-7-1-1 × UC82B was good specific combiner for setting percentage per cluster, days from fruit setting to turning stage, fruit weight, harvesting span, total fruit and marketable yield per plant.

Singh et al (2010) conducted an experiment with 45 F_1s and F_2s developed through diallel technique excluding reciprocals along with ten parents namely Pant Bahar, Punjab Chhuhara, Pusa Ruby, Pusa Gaurav, Azad Type-2, Azad Type-3, Kalyanpur Type-1, Angoorlata, KS-16 and KS-29 in randomized block design (RBD) with three replications. The study revealed that the significant general combining ability effects were shown by parents KS-29, Pant Bahar and Kalyanpur Type-1 and they were good general combiners for fruit yield in both the generations. Most of the crosses showed high SCA effects for fruit yield in both the F_1 and F_2 generations. The cross combinations KS-16 x KS-29, Kalyanpur Type-1 x KS-29 and Pant Bahar x KS-16 were found to be the best specific combiners for fruit yield. In F_1 and F_2 generations for fruit yield/plant (kg) the best specific combiners was KS-29 (6.30) followed by Angoorlata (4.29), Pant Bahar (3.79) and Kalyanpur Type-1 (2.37) and KS-29 (4.66) followed by Angoorlata (4.32), Pant Bahar (3.19), Kalyanpur Type-1 (2.35) and Pusa Ruby (2.26). Specific combining ability (SCA) effects for fruit yield/plant of crosses in F_1 generation were significant in 35 of the crosses with the range from 14.71 to 17.13.

Dhaliwal and Cheema (2011) crossed newly developed genetic stocks (14) with variable fruit size and resistance to leaf curl virus in a diallel mating design and the resulting 91 F_1 hybrids were evaluated to study genetics of fruit weight and total yield and to identify promising hybrids for cultivation under leaf curl virus infestation conditions. Combining ability and components of variation analysis revealed presence of both additive and non-additive gene effects in the inheritance of both the characters. Six parents were observed to be good general combiners for both fruit weight and total yield. Of the 91 F_1 hybrids evaluated 18 and 17 showed positive specific combining ability (SCA) effects for fruit weight and total yield respectively. Six hybrids had good SCA effects for both the characters. Of the five hybrids with significantly positive yield heterosis over their respective better parents, three namely 58-18-1-1 x 56-4-6-1, 56-14-6 x 56-12-7-1 and 54-26-1-1 x 57-9-6-1 with high total mean yield and appropriate fruit size have the potential to be commercially cultivated under severe leaf curl virus infested conditions. Two crosses namely 54-26-1-1 x 57-9-6-1 and 58-11-1-1 x 56-12-7-1 have been identified to be pursued further to recover high yielding true breeding lines.

Yadav et al (2013) estimated the magnitude of heterosis, combining ability effects and its variances by line × tester analysis including 30 F_1 cross combinations using 13 parents after selfing (ten lines and three testers) at Vegetable Research Farm, BHU, Varanasi, UP. These 43 genotypes (10 lines and 3 testers and 30 resulting F_1 hybrids) were evaluated for growth, yield and quality (TSS and shelf-life) contributing traits. Ratio of general combining ability (GCA) and specific combining ability (SCA) variance revealed preponderance of non-additive genetic variances for all studied traits. On the basis of GCA effects across ten traits Potato Leaf, Pant T-7, IC-177371 and NDTVR-60 were identified as most promising parental lines for inclusion in hybridization programmes. Outstanding crosses based on SCA effect across ten traits were RCMT-2 × VR-20, LCT-6 × VR-20 and Azad T-5 × VR-20. These crosses could be considered as most promising specific combiners for most of the traits in which VR-20 was found to be best general combiner. The most promising crosses showing significantly standard heterosis for maximum yield were CO-3 × Arka Vikas, CO-3 × NDT-5, NDTVR-60 × NDT-5 and RCMT-1 × NDT-5. These elite hybrids may be tested for yield and other quality traits under different agro-climatic conditions for commercial exploitation of hybrid vigour.

Heterosis

The term heterosis was first used by Shull in 1914. It is the superiority of an F_1 hybrid over both its parents in terms of yield and some other character. Generally heterosis is manifested as an increase in vigour, size, growth rate, yield or some other characteristic. In many cases the superior parent of the hybrid may be inferior to the best commercial variety. In such cases it will be desirable to estimate heterosis in relation to the best. Hybridization between inbreds developed from the same variety or from closely related varieties produced only a small degree of heterosis.

Yongjian and Hejin (1995) crossed with RedAgate 140 developed by the authors and Macelo introduced from foreign country. From the segregated progenies three stable inherited processing tomato lines had *Tm2nv* gene and yellow seedling gene. Crossing with these lines a number of combinations were obtained. The cross 8746 x Red Agate 140 and 9076 x Red Agate 140 were proved in the variety test to be highly productive and resistant to diseases and the physico-chemical components of them were all suitable for processing. In the experiment no reciprocal effect of heterosis was observed. Since 1990 seed production has been conducted in small scale.

Tanksley et al (1998) evaluated for 17 processing traits including fruit yield, size, soluble solids concentration, color, firmness and viscosity. Eight of those traits differed significantly among the nearly-isogenic lines (NILs). Most notably the NIL heterozygous for *Tm-2^a* yielded on average 16 per cent more than the NIL homozygous for the susceptible allele and 33 per cent more than the NIL homozygous for *Tm-2^a*. Viscosity was lower in the heterozygous NIL and the homozygous and heterozygous resistant NILs had softer fruit with larger stem scars compared to the homozygous susceptible NIL. These results indicate that the presence of the *Tm-2^a* locus affects many traits of importance for processing tomatoes and may be used in the heterozygous state to significantly increase yield. Whether the observed effects are due to the *Tm-2^a* gene itself or genes associated via linkage drag could not be determined.

Bekov (1999) carried out the investigation at the Scientific Research

Institute for Vegetable Growing and has stated that the usage of the named signal marks allows to conduct selecting process more effectively, to accelerate the creation of sorts and hybrids of intensive type, to save financial and labour expenses, to obtain more valuable initial materials etc. As a result of researches the varieties of tomatoes were obtained (about 120 specimens). They (varieties) combine practically valuable marks with signal ones in seeds, fruits and stems which are of great scientific and practical interest for selecting different varieties and hybrids of intensive type with high productivity and which are suitable for transportation with long term of storage of fruits (gene carriers *nor, nr, rin*), for selecting varieties and hybrids, favouring the increase of labour productivity while reaping the harvest and the ones, resistant to falling down (gene carriers *j 2 j-2in*); in breeding heterosis hybrids and also in their seed production (gene carriers *bs, bs-2*) and so on.

Facunda (2006) obtained eight processing tomato lines homozygous for the Sw-5 gene that confers resistance to tomato spotted wilt virus in a breeding program. The recurrent parent used to obtain lines 1, 2 and 8 was the processing tomato FM-6203 (FM-6203 was substituted for the processing tomato Gevora after the second backcrossing cycle). The recurrent parent used to obtain lines 3 and 4 was the processing tomato H-324-1 and the recurrent parental used to obtain lines 5, 6 and 7 was the processing tomato Peelmech. Using hybrids of these lines specific and general combining ability was tested in 2003 in a trial located in Las Vegas del Guadiana (Badajoz, Spain). No significant differences were detected between hybrids for commercial yield but there were differences in precocity, plant size, fruit firmness, fruit coverage by leaves, percentage of imperfect fruits (differences were detected for the defects: blossom end rot, fruit diameter less than 40 mm, fruit harvested with the peduncle, and sunscald). In spite of the differences observed more than a half of the tested hybrids had from medium to high specific combining ability. The general combining ability study showed that there were only a few differences between the eight processing tomato lines. These differences were enough to detect that line 3 had the best general combining ability for yield because hybrids produced from it achieved 107±7 t/ha of commercial yield average. Furthermore lines 4, 7 and 8 had the best general combining ability for quality because hybrids produced from them achieved 5.1±0.1, 5.2±0.1, and 5.1V0.1°Brix on average respectively.

Koutsika-Sotiriou et al (2008) studied to discriminate the breeding value of tomato source material ie commercial hybrids or well adapted varieties by estimating tolerance to inbreeding of hybrids or estimating heterosis of diallel hybrids between varieties, determining undesirable traits and determining general combining ability (GCA) and specific combining ability (SCA) effects from diallel crosses between hybrids and between varieties. Two hybrids and four varieties were assessed. One hybrid showed 0·03 inbreeding vigour which was not combined with undesirable traits in the F_2 generation. However negative GCA and positive SCA values did not support the hybrid as source material provided that hybrids with low inbreeding depression, positive GCA and negative SCA correspond to an F_2 capable of developing recombinant lines. The assessment of the varieties showed positive GCA and 0·34 heterosis in one variety indicating agreement between yield and GCA and that high-yielding varieties may produce high yielding hybrids. In conclusion the proposed mating design taking into account the tolerance to inbreeding for hybrids and the heritability of general worth for both resources provides a mechanism for ensuring continued improvement in plant performance through plant selection programmes.

Kumari et al (2010) crossed five diverse cultivars of tomato namely KS-16, Azad T-3, Angoorlata and KS-29, KS-7 in all possible combinations excluding reciprocals to identify the nature of various quantitative traits for devising the suitable breeding methods for their improvement. Observations were recorded on five randomly selected plants from each treatment for yield and other contributing traits viz days to flowering, days to maturity, number of fruits per bunch, weight per fruit (g), fruit length (cm), fruit width (cm), number of fruit bearing branches, total number of fruits per plant, plant height (cm) and total yield (kg/plant). Heterosis over mid parent and superior parent was calculated as per standard method. In the present study four heterotic crosses over superior parents based on yield and their performance in related parameters in order of merit were KS-16 x Azad T-3, Azad T-3 x KS-7, Angoorlata x KS-7 and KS-16 x Angoorlata whose value ranged from 65.181 to 98.62 per cent. On the basis of per se performance and sea effect also the crosses KS-16 x Azad T-3, Azad T-3 x KS-7, Angoorlata x, KS-7 and KS-16 x Angoorlata were found to be most specific crops combination. Thus these four hybrids may be recommended for commercial exploitation after further evaluation.

Gul et al (2010) conducted a study in tomato using an 8 × 8 diallel set excluding reciprocals to quantify the magnitude of heterosis for yield and its five yield components: number of flowers per cluster, number of fruits set per cluster, fruit length, fruit width, fruit weight and fruit yield per plant. Seven accessions and one locally approved variety were crossed in half diallel fashion and the resulting F_1 progeny along with their parents were evaluated in a 6 × 6 Triple Lattice Design at Agricultural Research Institute, Mingora (NWFP), Pakistan during 2007 - 2008 crop season. Highly significant differences were observed among the genotypes for all the studied traits. Highly significant heterosis of positive nature was found for flowers per cluster (53.1 and 37.2%), fruits per cluster

(38.9%), fruit length (32.7 and 15.5%), fruit weight (48.7 and 45.0%) and yield per plant (34.9%) over the mid and better parents respectively. Positive significant heterosis was observed for flowers per cluster (7.4%), fruits per cluster (10.0 and 10.0%), fruit length (8.9%), fruit width (8.7 and 7.9%), fruit weight (14.3 and 12.5%) and yield per plant (24%) over the mid and better parents respectively. Four hybrids possessed significantly useful heterobeltiosis for fruit weight. Three single cross hybrids and four of the parental genotypes were selected for use in subsequent tomato breeding programmes.

Avdikos et al (2011) conducted two experiments the first for evaluating the F_4 mass lines with the HS lines obtained by crossing in the F_3 generation and the second for evaluating the F_5 mass lines with the HS lines obtained by crossing in the F_4 generation and the second generation HS lines which were selected from the first experiment. F_1 and F_4 generations were used as controls respectively. The HS lines of cv Sahara over yielded 18-56 per cent the F_4 mass line while Iron HS lines presented greater uniformity in yield components and also outperformed qualitatively. The effectiveness of mass selection showed positive realized heritability only for fruit number of cv Iron. In this study where evaluation and selection was practiced in the absence of competition the expected response in heterosis via HS depended on s2g. The differences of s2g of F_1 from mass and HS lines were positive for both hybrids while when the control was the F_4 generation mass lines showed a lower performance and some HS lines showed a higher performance. This means that HS lines have favourable alleles and heterosis. In this sense Sahara's and Iron's HS lines increased 50.2 and 5.3 per cent the charge of favourable alleles respectively compared to the corresponding control. The selected advanced lines were assessed in two farming systems at two different locations; the organic one where two HS-lines one from each hybrid out yielded significantly the control; and the conventional one where all lines performed equally to the control. The results assume the evidence that stable hybrids incorporate individual buffering into inbred line cultivars.

Chattopadhyay and Paul (2012) evaluated a total of 25 entries consisting of 13 diversified genotypes of tomato along with their 12 F_1 hybrids during two consecutive Rabi seasons. Data on fruit quality characters were recorded and per cent mid-parent heterosis and better parent heterosis were determined. Pronounced heterosis over better parent was observed for number of locules per fruit, fruit length etc. Heterosis over mid-parent and better parent however for most of the characters was in negative direction. Some of the parents having good potentiality for generating high cross combination for most of the quality traits under study have been identified. Selection of crosses on the basis of performance per se seems to be reliable than selection based on the manifestation of heterosis alone.

Droka et al (2013) studied the generation mean analysis in six generations of tomato involving four parents viz Pusa Sheetal, Pusa Sadabahar, Booster and Pusa Rohini showed importance of dominance x dominance followed by additive gene effect, additive x dominance and dominance with a small proportion of additive x additive gene effect. Breeding method ie pedigree followed by selection can simultaneously be exploited both for additive and non-additive gene effects. Appreciable heterosis was observed for all the characters studied over their respective better parents. The range of heterosis for yield/plant varied from 16.01 to 29.04 per cent over the respective better parents. Hybrid Pusa Sadabahar x Pusa Rohini was found to be best performing for yield which exhibited superior performance for the characters like number of flowers per truss, number of primary branches per plant, internodal length, fruit diameter, days to first harvest and yield per plant. The next best cross was Pusa Sheetal x Booster as it showed superior performance for characters like days to 50 per cent flowering, number of fruit-set per truss and number of fruits per plant. These hybrids can be commercialized to get an early yield in tomato.

CONCLUSION

The first studies of JG Koelreuter in the eighteenth century that were confirmed by Darwin for vegetables (1876) and Beal for maize (1880) the concept of hybrid vigour gained increasing attention in plant breeding. The success of hybrid breeding will only be realized if reasonably priced technical solutions are available. The benefit characters of hybrids are not only limited to increased seed yield or biomass but also improve physical stability, higher responsiveness to fertilizers, better root penetration and seed filling are valuable advantages as well. The improved tolerance to abiotic stresses (eg drought and heat) in hybrids has been particularly relevant which is economic. Moreover hybrid seeds are important tools for capturing the value of products that have been created by breeders. They broadened the genetic diversity of parental lines which ensure continued genetic gains.

REFERENCES

Avdikos ID, Tsivelika N, Gallidou A, Koutsika-Sotiriou M and Traka-Mavrona E 2011. Exploitation of heterosis through recurrent selection scheme applied in segregating generations of a tomato breeding program. Scientia Horticulturae **130(3):** 701-707.

Beal WJ 1880. Indian corn. 19th Annual Report, Michigan State Board of Agriculture, pp 279-289.

Bekov R 1999. Usage of genetic marks by tomato selection of the perspective varieties and heterosis hybrids. Acta Horticulturae **487:** 373-376.

Bhatt RP, Biswas VR and Kumar N 2001. Heterosis, combining ability and genetics for vitamin C, total soluble solids and yield in tomato (*Lycopersicon esculentum*) at 1700 m altitude. The Journal of Agricultural Science **137(1):** 71-75.

Bruce WB, Edmeades GO and Barker TC 2002. Molecular and physiological approaches to maize improvement for drought tolerance. Journal of Experimental Botany **53:**13-25.

Chadha S, Kumar J and Vidyasagar 2001. Combining ability over environments in tomato. Indian Journal of Agricultural Research **35(3):** 171-175.

Chattopadhyay A and Paul A 2012. Studies on heterosis for different fruit quality parameters in tomato. International Journal of Agriculture, Environment and Biotechnology **5(4):** 405-410.

Dane FA, Hunter G and Chambliss OL 1991. Fruit set, pollen fertility, and combining ability of selected tomato genotypes under high-temperature field conditions Journal of the American Society for Horticultural Science **116(5):** 906-910.

Darwin C 1876. The effects of cross and self-fertilisation in the vegetable kingdom. Murray, London.

de Vries 2000. Climate changes leads to unstable agriculture. Trends in Plant Science **5:** 367.

Dhaliwal MS and Cheema DS 2011. Genetic analysis of fruit weight and total yield in tomato and development of F1 hybrids for cultivation under leaf curl virus infested conditions. Crop Improvement **38(1):** 60-66.

Dhaliwal MS, Surjan S, Badhan BS and Cheema DS 2002. Diallel analysis of yield and its component characters in tomato. Journal of Research **39(2):** 206-212.

Dharmatti PR, Madalgeri BB, Patil RV, Mannikeri IM, Patil G and Patil G 2001. Combining ability studies in tomato. Karnataka Journal of Agricultural Sciences **14(2):** 417-422.

Droka D, Kumar R, Joshi S and Yadav RK 2013. Genetic studies of quality traits in tomato (*Solanum lycopersicum* L) under low temperature. Vegetable Science **39(2):** 189-191.

Duvick DN 1999. Heterosis: feeding people and protecting natural resources. Crop Science Society of America/Soil Science Society of America, Madison.

Duvick DN 2005. The contribution of breeding to yield advances in maize (*Zea mays* L). Elsevier Academic Press, San Diego.

El-Gabry MAH, Solieman TIH and Abido AIA 2014. Combining ability and heritability of some tomato (*Solanum lycopersicum* L) cultivars. Scientia Horticulturae **164(6):** 153-157.

Facunda GJ 2006. Evaluation of hybrids from eight processing tomato lines resistant to tomato spotted wilt virus. Acta Horticulturae **724:** 51-57.

Frankenberger EA, Hasegawa PM and Tigchelaar EC 1981. Diallel analysis of shoot-forming capacity among selected tomato genotypes. Zeitschrift für Pflanzenphysiologie **102(3):** 233-241.

Garg, N Cheema, DS and Dhatt AS 2007. Genetics of yield, quality and shelf-life characteristics in tomato under normal and late planting conditions. Euphytica **159(2):** 275-288.

Gul R, Rahman H, Khalil IH, Shah SMA and Ghafoor A 2010. Heterosis for flower and fruit traits in tomato (*Lycopersicon esculentum* Mill). African Journal of Biotechnology **9(27):** 4144-4151.

Joshi A and Kohli UK 2006. Combining ability and gene action studies for processing quality attributes in tomato (*Lycopersicon esculentum* Mill). Indian Journal of Horticulture **63(3):** 289-293.

Joshi A, Thakur MC and Kohli UK 2005. Heterosis and combining ability for shelf-life, whole fruit firmness and related traits in tomato. Indian Journal of Horticulture **62(1):** 33-36.

Kempthorne O 1957. An introduction to genetic statistics. John Wiley and Sons, Inc, New York, pp 458-471.

Koutsika-Sotiriou MS, Traka-Mavrona EA and Evgenidis GL 2008. Assessment of tomato source breeding material through mating designs. The Journal of Agricultural Science. **146(3):** 301-310.

Kumari N, Srivastava JP, Singh B and Deokaran 2010. Heterotic expression for yield and its component in tomato (*Lycopersicon esculentum* Mill). Annals of Horticulture **3(1):** 98-101.

Kumari S and Sharma MK 2012. Line x tester analysis to study combining ability effects in tomato (*Solanum lycopersicum* L). Vegetable Science **39(1):** 65-69.

Narolia RK, Reddy RVSK and Sujatha M 2012. Genetic architecture of yield and quality in tomato (*Solanum lycopersicum* L). Agricultural Science Digest **32(4):** 281-285.

Rodriguez GE, Carballo CA, Baca CGA, Martinez GA and Rosas RM 2004. Genetic parameters of mean fruit weight and their components of tomato. Acta Horticulturae **637:** 145-148.

Saleem MY, Asghar M, Haq MA, Rafique T, Kamran A and Khan AA 2009. Genetic analysis to identify suitable parents for hybrid seed production in tomato (*Lycopersicon esculentum* mill.). Pakistan Journal of Botany **41(3):** 1107-1116.

Shalaby TA 2013. Mode of gene action, heterosis and inbreeding depression for yield and its components in tomato (*Solanum lycopersicum* L). Scientia Horticulturae **164(17):** 540-543.

Sharma BB, Sharma VK, Dhakar MK and Punetha S 2013. Combining ability and gene action studies for horticultural traits in garden pea: a review. African Journal of Agricultural Research **8:** 4718-4725.

Sharma DK, Chaudhary DR and Sharma PP 1999. Line x tester analysis for study of combining ability of quantitative traits in tomato. Indian Journal of Horticulture **56(2):** 163-168.

Singh AK and Asati BS 2011. Combining ability and heterosis studies in tomato under bacterial wilt condition. Bangladesh Journal of Agricultural Research **36(2):** 313-318.

Singh SP, Thakur MC and Pathania NK 2010. Reciprocal cross differences and combining ability studies for some quantitative traits in tomato (*Lycopersicon esculentum* Mill) under mid hill conditions of western Himalayas. The Asian Journal of Horticulture **4(2):** 473-477.

Sirohi SPS and Gaurav SS 2008. Combining ability in diallel cross analysis involving heat tolerant lines of tomato (*Lycopersicon esculentum* Mill). Annals of Horticulture **1(1):** 17-22.

Sprague GF and Tatum LA 1942. General vs specific combining ability in single crosses of corn. Journal of American Society of Agronomy **34:** 923-932.

Stuber CW 1994. Heterosis in plant breeding. Plant Breeding Review **12:** 227-251.

Tanksley SD, Bernachi D, Beck-Bunn T, Emmatty D, Eshed Y, Inai S, Lopez J, Petiard V, Sayama H, Uhlig J and Zamir D 1998. Yield and quality evaluations on a pair of processing tomato lines nearly isogenic for the *Tm2a* gene for resistance to the tobacco mosaic virus. Euphytica **99(2):** 77-83.

Wang Y, Xue Y and Li J 2005. Towards molecular breeding and improvement of rice in China. Trends in Plant Science **10:** 610–614.

Yadav SK, Singh BK, Baranwal DK and Solankey SS 2013. Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*). African Journal of Agricultural Research **8(44):** 5585-5591.

Yongjian Z and Hejin X 1995. Breeding and utilization of new processing tomato materials with *tm2*^{nv} gene. Acta Horticulturae **402:** 227-232.

Received: 2.1.2015 ***Accepted: 7.2.2015***