International Journal of Plant Breeding ©2013 Global Science Books

Line × Tester analysis in Tomato (*Solanum lycopersicum* L.): Identification of Superior Parents for Fruit Quality and Yield-attributing Traits

Yogendra Kalenahalli Narasimhamurthy • Paramanahally Hanumanthegowda Ramanjini Gowda*

Department of Plant Biotechnology, University of Agricultural Sciences, GKVK, Bangalore-560065, India

Corresponding author: ***ramanjini@yahoo.com**

ABSTRACT

Postharvest losses are the main constraints in tomato production. Several approaches were used for increasing the shelf life of tomatoes. Use of ripening mutants is one such strategy. In the present study the ripening tomato mutants (alcobaca (*alc*), *nor* and *rin*) were crossed with commercially grown varieties such as 'Pusaruby', 'Sankranti' and 'Vaibhav' using Line × Tester mating design, and nine hybrids were developed. One of the hybrid obtained from '*alc* × Vaibhav' showed extended shelf life up to 40 days, when stored at 25±1°C. 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, '*alcobaca*' and 'Vaibhav' were the best general combiners for fruit keeping quality under study, and these may be used as valuable donors in the hybridization program for producing promising combinations. Between the crosses, '*alc* × Vaibhav' is a valuable combiner for fruit keeping quality and yield characters under study could be utilized for improving the postharvest shelf life of tomato breeding programs. The highest heterotic effect over better parent was also exhibited by the crosses '*alc* × Vaibhav' for fruit keeping quality and '*rin* × Vaibhav' for yield per plant. The genetic parameter analyzed by mean values in parents and F_1 indicates that the cross between the commercial variety 'Vaibhav' and ripening mutant *alc* recorded high shelf life and good fruit quality.

Keywords: gene action, hybridization, heterosis, postharvest loss, shelf life

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the world's most important vegetable crop and has been the subject of genetic study for more than a century. It belongs to the family Solanaceae and diversified first in Peru, Mexico where it was domesticated from its ancestor, *Solanum lycopersicum cerasiforme* (Cox 2000). The current world production of tomato is about 129 million tons produced on 3.7 million ha (FAO 2008).

Tomato experiences great post-harvest losses due to its natural perishability, precarious transportation, storage conditions, and inadequate packaging. The postharvest losses of fruits and vegetables in the developing countries account for almost 50% of the produce. In India loses up to 40% of produce occur because of excessive fruit softening (Meli *et al.* 2010).

Several postharvest packaging methods and treatments such as treatments of gibberellic acid (0.1%), calcium chloride (1.5%) and salicylic acid (0.4 mM) (Pila *et al.* 2010), treatment with chlorine and packing in perforated (0.25%) polyethylene bag and kept at ambient (20-25°C and 70-90% relative humidity) condition (Nasrin *et al.* 2008) and black perforated polythene (Rahman *et al.* 2010), showed a decrease in fruit decay and weight loss in tomato. Perhaps these methods are quite laborious and unfeasible in a farmer's field. Advanced technique RNA interference (RNAi) is an efficient way to down regulate the genes involved in ethylene biosynthesis and cell wall degrading enzymes (Carrari *et al.* 2007) to extend the shelf life in tomato (Kramer and Redenbaugh 1994; Xiong *et al.* 2005; Batra *et al.* 2010; Meli *et al.* 2010). However, some consumers do not support genetically engineered crops due to environmental safety and social acceptance (Qaim 2009). Therefore, genetic enhancement of major fruit quality characteristics seems to be the best option and is also one of the safest ways to improve shelf life. Traditional breeding has allowed utilization of several tomato ripening mutants such as, alcobaca (*alc*), non-ripening (*nor*), Never ripe (*Nr*) and ripening inhibitor (*rin*) genes and development of lines and cultivars with delayed ripening (Kopeliovitch *et al.* 1979; Rodriguez *et al.* 2010; Casals *et al.* 2012).

The information on the combining ability status of the genotypes will give an indication as how well they combine with a given genotype to produce potential and productive populations. In this direction, the concept of general (GCA) and specific combining ability (SCA) (Sprague and Tatum 1942) helps the breeder to decide upon the choice of parents for hybridization and to isolate promising genotypes from the segregating population and also gives information on gene action, which helps in understanding the nature of inheritance of the characters. In this context, Line × Tester mating design proposed by Kempthrone (1957) helps the breeders by providing information on the combining ability status of genotypes (parents and hybrids) used and also on the nature of gene action involved. Estimates of combining ability parameters places heterosis breeding on a further scientific footing. In the present investigation, an attempt was made in respect of eight traits through combining ability analysis to obtain information on the magnitude of GCA and SCA variance for the trait as a whole and GCA and SCA effects for individual parents and hybrids respectively.

Received: 26 June, 2012. Accepted: 26 October, 2012.

Original Research Paper

Table 1 Mean performance of tomato parents and hybrids with respect to plant growth, fruit quality and yield traits.

	Plant height (cm)	No. of branches/ plant	No. of fruits/cluster	Lycopene (mg/100 g)	Total soluble sugar (%)	Fruit firmness (lbs/cm²)	Fruit keeping quality (days)	Yield/plant (g)
Lines								
rin	95*	24.5	4.5	0.04*	19.5*	7.88	38*	2525*
alc	103.5	18.5*	4.75	0.73*	29*	7.56	44*	3550*
nor	109.5*	23	4	0.15*	18.5*	8.44	38.5	3175
Mean	102.66	22	4.41	0.31	22.33	7.96	40.16	3083.33
S.Em ±	2.04	1.19	0.33	0.01	0.12	0.25	0.79	80.4097
CD (P=0.05)	4.39	2.56	0.72	0.03	0.27	0.54	1.7	172.88
Testers								
Sankranti	87*	23	4.25	0.81*	26.5*	5*	19	2925
Vaibhav	93.5	21.5	4.75	0.84	23.5*	4.38	18.5	3125*
Pusaruby	95	22.5	5.2	0.95*	30.5*	3.94	14.5*	2475*
Mean	91.83	22.33	4.73	0.86	26.83	4.44	17.33	2841.67
S.Em ±	2.04	1.19	0.33	0.01	0.12	0.25	0.79	80.4
CD (P=0.05)	4.39	2.56	0.72	0.03	0.27	0.54	1.7	172.88
Hybrids								
rin X Sankranti	85*	30*	4.45	0.62*	28.5*	3.38*	34	2575*
rin X Vaibhav	67.5	26.5	4.5	0.48*	30.5*	4.66	35	2460*
rin X Pusaruby	69	25.5	4.5	0.52*	39.5*	4.88	34.5	2675*
alc X Sankranti	77.5*	25	4.25	0.57*	31*	5.94*	35	3475*
alc X Vaibhav	62*	21*	4.25	0.61*	31.5*	5.72	40.5*	3675*
alc X Pusaruby	80*	29*	4.5	1.75*	52.5*	6.21*	35.5	3675*
nor X Sankranti	67.5	21.5*	4	0.53*	29.5*	4.63	33.5*	3175
nor X Vaibhav	64*	24	4	0.63*	29*	4.38	35	3075
nor X Pusaruby	65*	24	4	0.61*	39*	4.31	35.5	3250
Mean	70.83	25.17	4.27	0.7	34.6	4.9	35.39	3115
SEM	**1.52**	**0.82**	**0.12**	**0.01**	**0.16**	**0.19**	**0.54**	**59.94**
CD (P=0.05)	**4.95**	**2.7**	**0.41**	**0.04**	**0.55**	**0.63**	**1.78**	**195.5**

*Significant at *P*=0.05

MATERIALS AND METHODS

Experimental materials

The experimental material for this study consisted of three ripening mutants (alcobaca (*alc*), *nor* and *rin*) used as female parents and 'Sankranti', 'Vaibhav' and 'Pusaruby' were used as male parents. The *rin* is characterized by green to lemon color fruits when it ripens, with little or no lycopene. *alc* is producing yellow to light red fruit. *nor* fruits do not show the characteristic changes associated with ripening, fruit development. Fruits are characterized by orange yellow color. The long shelf life of these mutants facilitates their use for commercial breeding. The testers 'Sankranti' and 'Vaibhav' were high yielding and resistant to leaf curl with medium shelf life, released by University of Agricultural Sciences, Bangalore, India and 'Pusaruby' is low shelf life variety, released by the Indian Agricultural Research Institute (IARI), New Delhi, India. Crosses were made to obtain nine hybrids by Line × Tester (3x3) design during *kharif* 2009.

The parental genotypes and the F_1 generations were evaluated during *rabi* 2009. A randomized complete block design (RCBD) was used. The crop grown according to the standard cultural recommendations for the area and thirty days old seedlings of the plants were transplanted into the experimental plot with a spacing of 90 × 40 cm. All the recommended package of practices of University of Agricultural Sciences, Bangalore was followed to raise a good and healthy crop.

Traits evaluated

In each entry, five plants were randomly selected for recording observations in each replication on plant height (cm), number of branches/plant, number of fruits/cluster, lycopene content (mg/100 g) as per Ranganna (1976), total soluble solids (%) using a hand refractometer (Swastik Scientific Co., Mumbai, India), fruit firmness (lbs/cm^2) using a fruit Penetrometer (Wagner Instruments, New Delhi, India), plant yield was recorded at various pickings and the mean was calculated and expressed in g/plant.

Fruit keeping quality: five tomato fruits at the red ripening stage (breaker stage) were harvested and fruits were stored at 25±1°C and keeping quality in days were taken at weekly intervals. Fruit keeping quality was measured as the number of days taken from fruits harvested at red ripens stage for a day till consumption stage was over.

Data analysis

The analysis of variance was carried out as per the methods described by Panse and Sukhatme (1967). The mean values of all the traits studied were used for combining ability analysis as per the method suggested by Kempthorne (1957) and Arunachalam (1974). Heterosis over better parent (BP) was computed using treatment means of each trait by the method suggested by Hayes *et al.* (1955). The breeding value of the plant material was evaluated by analyzing the data on heterosis or combining ability for all the traits in the F_1. The studied data were analyzed with the program TNAUSTAT software.

RESULTS

Mean performance of parents and hybrids

The mean performance of three lines and three testers used as parents in the present study indicated that no single parental genotype was superior in respect of all the traits studied (**Table 1**). However, lines *viz.*, *rin*, *alc* and *nor* were superior to testers in respect of fruit keeping quality and fruit firmness. Between the lines *alc* recorded extended shelf-life of 44 days followed by *nor* (38.5 days) and *rin* (38 days).

None of the nine hybrids were superior for all the traits studied. However, '*alc* × Pusaruby' was superior for a number of fruits/cluster, lycopene, TSS and fruit firmness. '*rin* × Sankranti' was superior for plant height and number of branches and '*alc* × Vaibhav' was superior for fruit keeping quality and yield/plant.

Analysis of variance for combining ability

The variations among the lines in respect of their general combining ability were significant for all the characters (**Table 2**), where as variance among testers were also sig-

Table 2 Analysis of variance for combining ability in respect of plant growth, fruit quality and yield attributing traits of parents and hybrids of tomato (*Solanum lycopersicum*).

Source of variation	df	Mean sum of squares							
		Plant height (cm)	No. of branches/ plant	No. of fruits/cluster	Lycopene (mg/100 g)	Total soluble sugar (%)	Fruit firmness (lbs/cm^2)	Fruit keeping quality (days)	Yield/plant (g)
Lines(c)	2	128. 67**	26.17**	0.32**	0.34**	0.64**	5.06**	11.72**	1629216.66**
Testers(c)	2	223.16**	8.66*	0.01	0.30*	3.74*	0.35*	10.88*	325*
LXT (c)	4	80.83**	19.33**	0.01	0.31**	0.29**	0.56**	5.13**	16341.66**
Error	8	5.63	1.625	0.03	0.03	0.01	0.07	0.5	7112.5

*Significant at P=0.05; ** Significant at P=0.01

Table 3 Estimates of general combining ability effects of lines and testers for plant growth, fruit quality and yield attributing traits in tomato (*Solanum lycopersicum*).

	Plant height (cm)	No. of branches/plant	No. of fruits/cluster	Lycopene (mg/100 g)	TSS (%)	Fruit firmness (lbs/cm^2)	Fruit keeping quality (days)	Yield/plant (g)
Lines								
rin	3.00 *	2.17 **	0.21 *	-0.16 **	-0.17 *	-0.60 **	-0.89 *	-545.00 **
alc	2.33 *	-0.17	0.06	0.27 **	0.38 **	1.06 **	1.61 **	493.33 **
nor	-5.33 **	-2.00 **	-0.27 **	-0.11 **	-0.21 **	-0.46 **	-0.72 *	51.67
SEM	1.36	0.73	0.1	0.09	0.07	0.15	0.4	48.69
CD (5%)	3.16	1.7	0.23	0.02	0.17	0.36	0.94	112.47
CD (1%)	4.6	2.47	0.34	0.03	0.24	0.52	1.37	163.6
Testers								
Sankranti	5.83 **	0.33	-0.04	-0.13 **	-0.49 **	-0.25	-1.22 **	-40
Vaibhav	-6.33 **	-1.33 *	-0.02	-0.13 **	-0.42 **	0.02	1.44 **	-45
Pusaruby	0.5	1	0.06	0.26 **	0.91 **	0.23	-0.22	85.00 *
SEM	1.36	0.73	0.1	0.09	0.07	0.15	0.4	48.69
CD (5%)	3.16	1.7	0.23	0.02	0.17	0.36	0.94	112.47
CD (1%)	4.6	2.47	0.34	0.03	0.24	0.52	1.37	163.6

*Significant at P=0.05; ** Significant at P=0.01

nificant for all the characters except for a number of fruits/ cluster. However, the variance due to Line × Tester interaction was significant for all the characters except for a number of fruits/cluster indicating a predominance of non-additive gene action in genetic control of all these characters.

General combining ability effects of parents

Estimation of GCA effects of lines and testers indicated that, no single line or tester was a good general combiner for all the characters studied (**Table 3**). However, the line '*alc*' was considered as a good general combiner, as it exhibited significant GCA effects in the desired direction for lycopene, TSS, fruit firmness, fruit keeping quality and yield/plant. Among the testers, 'Pusaruby' exhibited significant GCA effects of lycopene, TSS and yield/plant. But, 'Vaibhav' was recorded significant GCA effects for fruit keeping quality.

Specific combining ability effects of hybrids

No single cross exhibited superior SCA for all the characters studied (**Table 4**). Nevertheless, the cross '*alc* × Pusaruby' was having good SCA for five characters *viz.*, plant height, no. of branches, no. of fruits/cluster, lycopene and TSS. The next best cross was '*alc* × Vaibhav' which had significant SCA effect on fruit firmness and fruit keeping quality.

Heterosis

All the traits except number of branches, number of fruits/ cluster and yield/plant exhibited significant better parent heterosis in majority of the crosses indicating a predominance of non additive gene action in the genetic control of these traits (**Table 4**). The hybrids (H × H) involving both parents (male and female parents) having high overall GCA status and hybrids (H × L) involving high (female) and low (male) overall GCA status produced hybrids with overall high (H) heterotic status. On the other hand, hybrids involving L × H and L × L overall GCA status had low (L) overall heterotic status. This clearly indicated the need for using parents having high overall GCA status or at least using the parents having high GCA status as female to produce hybrids with overall heterotic status.

DISCUSSION

In recent years, there has been much renewed interest in the possibility of breeding not only for higher yield but also better quality crops. One of the potential approaches is a combination of traditional breeding methods with spatial profiling and introgression breeding. The compositional approach in order to improve organoleptic properties, particularly in breeding tomato are driven by the given interests for nutritional attributes (increase in lycopene content and flavonoids), increased shelf life and fruit quality. From the past experience in different crops, it has been noticed by many breeders that *per se* performance of parents is not always a true indicator of its potential in hybrid combinations. The information on the combining ability status of the genotypes will give an indication as how well they combine with a given genotype to produce potential and productive populations. In this direction, the concept of general and specific combining ability (Sprague and Tatum 1942) helps the breeder to decide upon the choice of parents for hybridization and to isolate promising genotypes from the segregating population and also gives information on gene action which helps in understanding the nature of inheritance of the characters.

The estimates of GCA effects of parents helped in identifying superior parents to be utilized for production of superior genotypes in segregating populations by the concentration of desirable genes with additive effects. The result implies that two lines (*rin* and *alc*) and two testers (Sankranti and Vaibhav) were good general combiner indicating their ability in transmitting additive genes in the desirable direction to their progenies. No single cross exhibited superior specific combining ability for all the characters under study. Nevertheless, the cross '*alc* × Pusaruby' was having good specific combining ability for five characters *viz.*, plant height, no. of branches, no. of fruits/cluster, lycopene and TSS. The next best cross was '*alc* × Vaibhav' has a significant effect on fruit firmness and fruit keeping

Table 4 Selected crosses with superior heterosis over better parent, SCA and GCA effects, mean performance and type of combination.

Characters	Crosses with heterotic performance over better parent	Heterosis over better parent	SCA effects	*Per se* performance	Type of combination
Plant height (cm)	*rin* X Sankranti	10.53**	5.33**	85	H x H
	alc X Pusaruby	-22.71**-	6.33**	80	H x L
	alc X Sankranti	-25.12**	-1.5	77.5	H x H
No. of branches	*alc* X Pusaruby	28.89**	3.00*	29	H x L
	rin X Sankranti	22.45**	2.33*	30	H x H
	alc X Sankranti	8.7	-0.33	25	H x H
No. of fruits per cluster	*rin* X Sankranti	-1.11	0.01	4.45	H x H
	rin X Vaibhav	-5.26	0.04	4.5	H x H
	nor X Sankranti	-5.88	0.04	4	L x H
Lycopene (mg/100 g)	*alc* X Pusaruby	84.20**	0.52**	1.75	H x L
	rin X Sankranti	-23.27**	0.21*	0.62	H x H
	nor X Vaibhav	-24.18**	0.17*	0.63	L x H
TSS (%)	*alc* X Pusaruby	72.13**	0.51**	52.5	H x L
	rin X Vaibhav	29.79**	0.19	30.5	H x H
	rin X Pusaruby	29.51**	-0.24*	39.5	H x L
Fruit firmness	*alc* X Pusaruby	-17.88**	0.02	6.21	H x L
(lbs/cm^2)	*alc* X Sankranti	-21.49**	0.23	5.94	H x H
	alc X Vaibhav	-24.30**	0.25	5.72	H x H
Fruit keeping quality	*alc* X Vaibhav	7.95**	2.06**	40.5	H x H
(days)	*nor* X Pusaruby	-7.79**	1.06	35.5	L x L
	rin X Vaibhav	-7.89**	-0.94	35	H x H
Yield/plant (g)	*rin*X Pusaruby	5.94	20	2675	H x L
	alc X Vaibhav	3.52	111.67	3675	H x H
	alc X Pusaruby	3.52	-18.33	3675	H x L

*Significant at P=0.05; ** Significant at P=0.01; H, overall high specific combiner; L, overall low specific combiner

quality. The results were in conformity with Nguyen *et al.* (1997), Laxman (2001), Biradar *et al.* (2004) and Talekar *et al.* (2010). In general, maximum crosses showing significant SCA effects were invariably associated with better *per se* performance for respective traits. The good specific combiners for different characters involved parents with high x high, high x low, low x high and low x low general combination. In majority of the cases, the crosses exhibiting high SCA effects were found to have both or one of the parents as good general combiners for the characters studied revealing non additive gene action in the genetic control which was in accordance with the results of Jagadeshwar and Shinde (1992), Kadam *et al.* (2000) and Singh and Asati (2011). Talekar *et al.* (2010) used sweet sorghum (*Sorghum bicolor* L.) crop for combining ability studies of juice yield and its attributing traits.

Heterosis is usually expressed in the form of increased yield which in turn is dependent on the contribution of many component characters (Garg and Cheema 2011). All the component characters of yield were studied for heterosis manifestation in order to assess the worth of a cross. When significant heterosis over better parent is observed in the majority of the crosses for any trait indicates involvement of non additive gene action in the genetic control of that trait. Assuming that epistasis is absent, the cause of heterosis can only be attributed to the dominance gene action. This was in agreement with previous findings of Sharma *et al.* (1996), Padma *et al.* (2002), Patgonkar *et al.* (2003), Premlakshmi *et al.* (2006), Sharma *et al.* (2006), Kumar *et al.* (2009) and Kumari and Sharma (2011).

In conclusion, from the results of the breeding program, we were able to improve fruit quality and yield attributing traits in tomato. Heterosis breeding is the only technically feasible method to exploit hybrid vigor for effective improvement in yield potential. The hybrids were characterized by higher fruit keeping quality, fruit firmness, lycopene and yield components compared to the parents.

ACKNOWLEDGEMENTS

The authors are grateful to Rashtriya Krushi Vikas Yojana (RKVY), Govt. of India for providing financial assistance of Rs. 20 lakhs for this work. We thank the Indian Institute of Horticulture (IIHR), Hesaraghatta, Bangalore, India for supply of tomato germplasm.

REFERENCES

Arunachalam V (1974) The fallacy behind the use of modified line x testers design. *Indian Journal of Genetics* **34**, 280-287

Batra A, Sane VA, Trivedi PK, Sane AP, Pravendra N (2010) Suppression of ACC oxidase expression in tomato using a heterologous gene from banana prolongs shelf-life both on vine and post-harvest. *Current Science* **99**, 1243-1250

Biradar BD, Vastrad SM, Sajjanar GM (2004) Identification of combiner involving newly derived male sterile and restorer lines for yield and related traits in rabi sorghum (*Sorghum bicolor* L. Moench). *Indian Journal of Genetics* **64**, 237-238

Carrari F, Asis R, Alisdair RF (2007) The metabolic shifts underlying tomato fruit development. *Plant Biotechnology Journal* **24**, 45-55

Casals J, Pascual L, Canizares J, Cebolla-Cornejo J, Casanas F, Nuez F (2012) Genetic basis of long shelf life and variability into Penjar tomato. *Genetic Resources and Crop Evolution* **59**, 219-229

Cox S (2000) I Say Tomayto, You Say Tomahto. Available Online: http://lamar.colostate.edu/~samcox/Tomato.html

FAO (2008) Statistical databases. Available online: www.fao.org

Garg N, Cheema DS (2011) Heterosis breeding: a tool to improve yield potential of tomato (Solanum lycopersicum L.) under high temperature stress conditions. In: Sandhu SK, Pathak D, Sidhu N, Bhardwaj R, Rang A (Eds) *Proceedings of International Conference on Preparing Agriculture for Climate Change*, February 6–8, 2011, Ludhiana, India, pp 38-89

Hayes HK, Immer FR, Smith DC (1955) *Methods of Plant Breeding*, McGraw-Hill Publishing Co., Inc., New York, 551 pp

Jagadeshwar K, Shinde VK (1992) Combining ability in rabi sorghum (*Sorghum bicolor* L. Moench). *Indian Journal of Genetics* **52**, 22-25

Kadam DE, Patel FB, Bhor TJ, Harer PN (2000) Line × tester analysis in sweet sorghum hybrids. *Journal of Maharashtra Agricultural University* **25**, 316-319

Kempthorne (1957) *An Introduction to Genetic Statistics*, John Wiley and Sons. Inc., New York, pp 458-471

Kopeliovitch E, Mizrahi Y, Rabinowitch HD, Kedar N (1979) Effect of the fruit-ripening mutant genes *rin* and *nor* on the flavor of tomato fruit. *Journal of American Society Horticultural Science* **107**, 361-364

Kramer MG, Redenbaugh K (1994) Commercialization of a tomato with an antisense polygalacturonase gene: The FLAVR SAVR^{TM} tomato story. *Euphytica* **79**, 293-297

Kumar KHY, Patil SS, Dharmatti PR, Byadagi AS, Kajjidoni ST, Patil RH (2009) Estimation of heterosis for tospovirus resistance in tomato. *Karnataka Journal of Agricultural Science* **22**, 1073-1075

Kumari S, Sharma MK (2011) Exploitation of heterosis for yield and its contributing traits in tomato (*Solanum lycopersicum* L.). *International Journal of Farm Sciences* **1**, 45-55

Laxman S (2001) Studies on heterosis and combining ability in sorghum (*Sorghum bicolor* L. Moench) through line × tester analysis. *The Journal of Research ANGRAU* **29**, 12-17

Meli VS, Ghosh S, Prabha TN, Chakraborty N, Chakraborty S, Datta A

(2010) Enhancement of fruit shelf life by suppressing N-glycan processing enzymes. *Proceedings of the National Academy of Sciences* **107**, 2413-2418

Nasrin TAA, Molla MM, Alamgir M, Hossaen, Alam MS, Yasmin L (2008) Effect of postharvest treatments on shelf life and quality of tomato. *Bangladesh Journal of Agricultural Research* **33**, 579-585

Nguyen DC, Nakamura S, Yoshida T (1997) Combining ability and genotype × environment interaction in early maturing grain sorghum for summer seedlings. *Japanese Journal of Crop Science* **66**, 698-705

Padma E, Shekar CR, Rao BV (2002) Heterosis and combining ability in tomato (*Lycopersicon esculentum* Mill). *The Andhra agricultural Journal* **49**, 285-292

Panse VG, Sukathme PV (1967) *Statistical Methods for Agricultural Workers*, ICAR, NewDelhi, 145 pp

Patgaonkar DR, Ingavale MT, Mangave K, Kadam DD (2003) Heterosis studies for fruit characters in heat tolerant lines of tomato (*Lycopersicon esculentum* Mill.). *South Indian Horticulture* **51**, 134-136

Pila N, Gol NB, Rao TVR (2010) Effect of post harvest treatments on physicochemical characteristics and shelf life of tomato (*Lycopersicon esculentum* Mill.) fruits during storage. *American-Eurasian Journal of Agricultural and Environmental Science* **9**, 470-479

Premlakshmi V, Thyagaraj T, Veeraragavathatham D, Arumugam T (2006) Heterosis and combining ability analysis in tomato [*Lycopersicon esculentum* (Mill.) Wettsd] for yield and yield contributing traits. *Vegetable Science* **33**, 5-9

Qaim M (2009) The economics of genetically modified crops. *Annual Review of Resource Economics* **1**, 665-693

Rahman MM, Islam MN, Wazed MA, Arfin MS, Hossain MFB (2010) Determination of post harvest losses and shelf life of tomato as influenced by different types of polythene at refrigerated condition (10°C). *International Journal of Sustainable Crop Production* **5**, 62-65

Ranganna S (1976) *Manual of Analysis of Fruits and Vegetable Products*, McGraw Hill, New Delhi, 77 pp

Rodriguez GR, Pratta GR, Liberatti DR, Zorzoli R, Picardi LA (2010) Inheritance of shelf life and other quality traits of tomato fruit estimated from F1's, F2's and backcross generations derived from standard cultivar, nor homozygote and wild cherry tomato. *Euphytica* **176**, 137-147

Sharma DK, Chaudhary DR, Sharma PP (1996) Nature of gene action governing economic traits in tomato (*Lycopersicon esculentum* Mill). *Haryana Journal of Horticultural Science* **25**, 225-229

Sharma HR, Sharma D, Thakur AK (2006) Studies on analysis of genetic divergence in tomato (*Lycopersicon esculentum* Mill.). *Journal of Horticultural Science* **1**, 52-54

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

Sprague GF, Tatum LA (1942) General versus specific combining ability in single crosses of corn. *Journal of the American Society of Agronomy* **3**, 923-932

Talekar S, GururajRao MR, Ramesh S, Kulkarni RS, Sandeep RG (2010) Combining ability studies for juice yield and its attributing traits in sweet sorghum (*Sorghum bicolor* L.). *Indian Journal of Crop Science* **5**, 137-140

Xiong AS, Yao QH, Peng RH, Li X, Han PL, Fan HQ (2005) Different effects on ACC oxidase gene silencing triggered by RNA interference in transgenic tomato. *Plant Cell Report* **23**, 639-646