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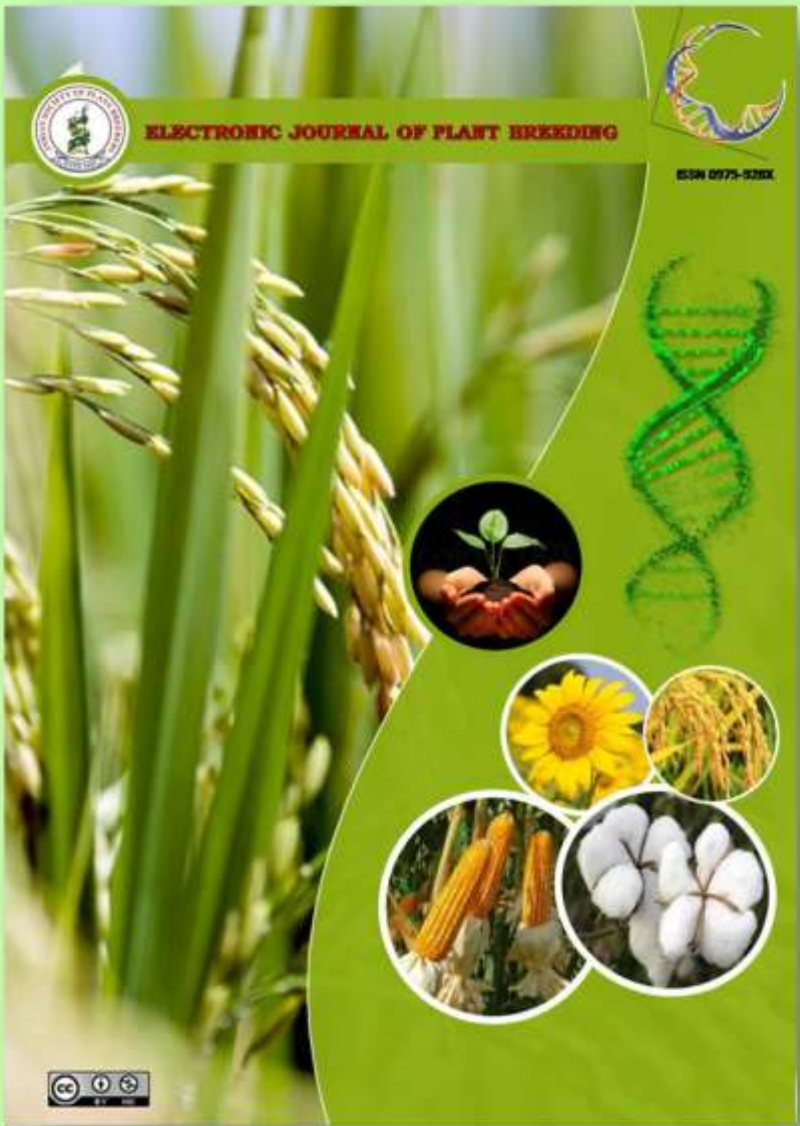

ISSN: 0975-928X

Volume: 10

Number: 4

EJPB (2019) 10(4):1547-1553

DOI:10.5958/0975-928X.2019.00198.4

https://ejplantbreeding.org

Electronic Journal of Plant Breeding, 10 (4): 1547-1553 (Dec 2019) DOI: 10.5958/0975-928X.2019.00198.4
ISSN 0975-928X

Research Article

Heterosis analysis in tomato (*Solanum lycopersicum* L.) for Lycopene, TSS, titrable acidity and Ascorbic acid

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(Received: 20 Feb 2019; Revised: 13 Dec 2019; Accepted: 15 Dec 2019)

Abstract
Heterosis were estimated using ten lines and three testers and their thirty F_1 combinations, crossed in line × tester fashion which were evaluated for four seasons for important quality traits *viz*., lycopene, ascorbic acid, titrable acidity (TA), total soluble solids (TSS) and pericarp thickness. Some of the parents having good potentiality for generating superior F_1 combinations for most of the quality characters under study have been identified. The analysis of variance (ANOVA) indicated significantly higher amount of differences among genotypes for all the five characters studied. In this study, among crosses, the cross NDTVR60 × Floradade exhibited positive desirable heterosis over best parent for lycopene (60.22%) and Selection7 × Floradade (25.12%) for ascorbic acid**.** The cross NDTVR60 × Floradade showed the highest positive heterosis over best parent for titrable acidity (31.37%) whereas cross CO3 × Azad T5 (30.65%) exhibited the significantly highest positive heterosis over best parent for TSS and cross combination DT2 × Azad T5 (56.82%) exhibited positive heterobeltiosis for pericarp thickness.

Key words
Heterosis, Line x Tester, Lycopene, Quality, Tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is a member of Solanaceae family, with genus Solanum and chromosome numbers 2n = 2x = 24 (Jenkins 1948). Tomato is a tropical day neutral and predominantly self-pollinated plant, but a certain percentage of cross pollination also occurs (Kumar *et al*., 2019). It is one of the most important vegetable crops grown throughout the world and known as protective food both because of its special nutritive value as well as also for its wide spread production (Somappa *et al*., 2013).

The postharvest losses of vegetable and fruits in the developing countries account for almost 50% of the total production. In India loses up to 40% of produce occur because of excessive fruit softening (Meli *et al.* 2010). In case of tomato experiences high post-harvest losses due to its natural perishability, storage conditions, precarious transportation and inadequate packaging (Narasimhamurthy and Gowda, 2013).

Tomato is rich in minerals, vitamins, antioxidants and organic acids so universally treated as 'Protective Food' (Kumar *et al*., 2013). The complete fruit of tomato *i.e* pomace, seed and tomato solids have many nutraceutical benefits and is extensively used in food processing industry either as raw or in powder form (Ray *et al*., 2016). The importance of nutrition value in tomato indicates there is need to formulate breeding programme and to develop lycopene, ascorbic acid, titrable acidity and TSS rich cultivars, with high quality of fruit as well as yield.

Knowledge of the extent heterosis for yield and quality component characters is a pre requisite to bring improvement through heterosis breeding. Heterosis in tomato was first observed by Hedrick and Booth (1908) for more number of fruits and higher fruit yield. Since then, heterosis for yield components and quality traits were extensively studied. Heterosis\hybrid vigour is manifested as an improved performance of F_1 hybrids over both the parent were generated through hybridization of two genetically diverse parents. The improvement in different yield and qualitative characters in tomato through heterosis breeding was observed by Tiwari and Lal, (2004). The present investigation was undertaken to study and generate information about heterobeltiosis and standard heterosis.

Material and Methods

The experimental material comprised of genetically ten diverse lines (H-24, DT-2, CO-3, Punjab Upma, Pant T-3, H-86, Selection-7, NDTVR-60, Fla-717, Kashi Amrit) and three testers (Floradade, Kashi Sharad, Azad T-5) and their 30 F_1 hybrids

developed by crossing them in a 'Line×Tester' mating design (Kempthorne 1957) with two check varieties BT-12 (release variety) and Saktiman (hybrid) were used for evaluation.
The experiment was conducted at Vegetable Research Farm, Banaras Hindu University, Varanasi during four seasons *i.e.*, winter 2010-11, rainy 2011, winter 2011-12 and rainy 2012 seasons with respect to five quality characters. Spacing between genotypes 60 cm and plant to plant 45 cm. Recommended cultural practices as well as plant protection measures were followed for healthy crop.

A sample of five representative plants were taken from each genotype per replication for recording data on different characters *viz*., lycopene, ascorbic acid, titrable acidity (TA), total soluble solids (TSS) and pericarp thickness and data were compiled for (ANOVA) for all five traits using method suggested by Panse and Sukhatme (1967). Data were analyzed by Windostat Version 9.3 from Indostat Services, Hyderabad, India.

Results and Discussion

Exploitation of hybrid vigour for lycopene, ascorbic acid, titrable acidity, total soluble solids (TSS) and pericarp thickness content in Line×Tester fashion provides an additional opportunity to improve and develops hybrids for quality traits along with adaptability for specific production environments. The mean value of parents and standard check (BT-12 and Shaktiman) presented in Table 1. Estimates of mean squares for all five characters studied were highly significant indicating wide genetic differences among the genotypes. The heterotic effect in F_1 generation over better parent and standard check are presented in Tables 2 and 3.

Lycopene ($C_{40}H_{56}$) is responsible for red colour into the tomato fruit and deep, uniform red coloured tomato fruits are preferred for both processing and table purpose. Moreover, lycopene is an antioxidant with immuno-stimulatory properties and protect cells against oxidative damage and thereby prevent or reduce the risk of several cancers (Chauhan *et al*., 2011). Parents varied widely in lycopene content and ranged from 3.87 (Selection- 7) to 6.52 mg/100 g (H-86). The hybrid NDTVR60 × Floradade exhibited the highest average mean (7.68 mg/100 g). Significant heterosis varied from -57.80 to 60.22% over better parent as well as -58.21 to 30.46% and -47.13 to 65.04% over both standard parents, respectively. The highest significant heterosis over the better parent was expressed by the crosses NDTVR60 × Floradade (60.22%) whereas NDTVR60 × Floradade expressed highest significant heterosis over both the standard check (30.66%) and (65.04%), respectively. These results are in line with the reports from Kumar *et al.,* (2006) and Kumar and Paliwal (2016).
The F_1 combinations also had reasonably good ascorbic acid content which was significantly higher or lower than their better parent. A significant and high degree of heterosis for ascorbic acid was observed in comparison to better parent and the commercial check. Parents varied widely in ascorbic acid content and ranged from 19.75 (Selection-7) to 26.93 mg/100g (CO-3). The Kashi Amrit × Kashi Sharad exhibited the highest average mean (29.29 mg/100g) while lowest mean by NDTVR60 × Azad T5 (23.80 mg/100g). The highest significant heterosis over the better parent was expressed by the cross Selection7 × Floradade (25.12%). The highest significant heterosis over both the standard check was observed in the cross Kashi Amrit × Kashi Sharad (15.80%) and (21.57%), respectively. These results were in accordance with earlier researcher by Dod *et al*. (1992), Patil and Patil (1988); Bhatt *et al*. (2001) and Solieman *et al*., (2013).

Titratable acidity mean ranged from 0.48 (Selection-7) to 0.68% (H-86). The hybrid NDTVR60 × Floradade exhibited the highest mean (0.67%). Heterosis varied from -28.04 to 31.37% over better parent and -20.00 to 21.82% and -27.07 to 11.05% over both standard check, respectively. The highest significant heterosis over the better parent was expressed by the cross NDTVR60 × Floradade (31.37%). NDTVR60 × Floradade expressed highest significant positive heterosis over both the standard check (21.82.04%) and (11.05%), respectively. Similar result was found by Duhan *et al.* (2005) and Kumar (2018) over better parent and commercial check.

High total soluble solids (TSS) is one of the major factors considered for manufacture of processed products. If 1% increase in TSS content of tomato fruits results in 20% increase in recovery of processed product (Berry and Uddin, 1991). Since high TSS content is correlated with small fruit size and oval shape of fruit (Roy and Choudhury 1972), such fruits have better keeping qualities and transportation. The mean performances of parents and cross combinations are presented in Table 1. Perusal of data revealed that the mean values for TSS at mature stage ranged from 6.78 (Floradade) to 6.34 °Brix (Punjab Upma). The hybrid H-86 × Azad T-5 exhibited the highest average (7.01°Brix). Heterosis varied from -15.06 to 30.64% over better parent as well as -11.89 to 18.55% and -11.09 to 19.62% over both the standard check, respectively. The highest significant heterosis over the better parent was expressed by the cross CO-3 × Azad T-5 (30.65%) and H-86 × Azad T- 5 expressed highest significant heterosis over standard check 18.55% and 19.62%, respectively. A lower range of heterosis for TSS was found in the crosses, probably associated with the lower parental variation in the content of TSS by Mandal *et al*. (1989) and Dod and Kale (1992) while Zhou and Xu (1984) observed phenotypic variation in processing varieties for this trait. These results are in accordance with the findings of Kumari and Sharma (2011), Yadav *et al*., (2013) and Kumar (2018).

Pericarp thickness is a desirable trait as it imparts fruit firmness and such fruits are suitable for canning, better storage and long distance transportation (Roy and Choudhury 1972, Gonzalez 1985 and Kalloo 1988). Pericarp thickness in tomato is one of the important component for transportability and keeping quality (Singh *et al.* 1980). Thicker pericarp helps in reducing post harvest losses and improved shelf-life. Pericarp thickness exhibited variation among treatments which ranged from 3.02 (NDTVR60) to 5.95 (H-86) and hybrid H-86 × Kashi Sharad exhibited the highest mean (6.70). Heterosis varied from -37.62 to 56.82% over better parent and -31.85 to 42.18% and -31.80 to 42.28% over both standard checks, respectively. The highest significant heterosis over the better parent was expressed by the cross DT-2 × Azad T-5 (56.82%). H86 × Kashi Sharad expressed highest significant positive heterosis over both the standard check (42.18%) and (42.28%), respectively. Similar results were reported by Chattopadhyay and Paul (2012) and Savita and Singh (2015)

The best cross combination exhibited highest heterosis in desirable direction are NDTVR60 × Floradade for lycopene (60.22%) and cross Selection 7 × Floradade (25.12%) for ascorbic acid**.** The cross NDTVR60 × Floradade for titrable acidity (31.37%) whereas the cross CO3 × Azad T5 (30.65%) for TSS and the cross combination DT2 × Azad T5 (56.82%) exhibited positive heterosis for pericarp thickness over batter parent.

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Electronic Journal of Plant Breeding, 10 (4): 1547-1553 (Dec 2019) DOI: 10.5958/0975-928X.2019.00198.4
ISSN 0975-928X

Table 1. Mean performance of parental lines of tomato for Lycopene, Ascorbic Acid, Titrable Acidity TSS and Pericarp thickness

Genotypes	Lycopene (mg/100g)	Ascorbic Acid (mg/100 ml)	Titrable Acidity (%) (mg/100 ml)	TSS (°Brix)	Pericarp Thickness (mm)
H24 x Floradade	5.55	28.32	0.50	5.21	4.22
H24 x Kashi Sharad	5.26	27.59	0.54	5.99	3.73
H24 x Azad T5	4.93	25.42	0.54	6.24	5.86
DT2 x Floradade	4.98	25.52	0.56	5.79	5.09
DT2 x Kashi Sharad	6.20	27.35	0.59	6.98	5.47
DT2 x Azad T5	3.99	23.93	0.47	6.88	6.44
CO3 x Floradade	2.75	24.08	0.44	6.66	5.67
CO3 x Kashi Sharad	2.46	25.42	0.45	5.79	3.54
CO3 x Azad T5	6.63	27.41	0.54	6.74	3.92
Punjab Upma x Floradade	5.58	27.32	0.57	6.09	5.47
Punjab Upma x Kashi Sharad	6.04	25.28	0.53	6.48	5.67
Punjab Upma x Azad T5	6.55	25.42	0.54	5.49	5.67
Pant T3 x Floradade	3.49	27.96	0.49	6.50	4.70
Pant T3 x Kashi Sharad	6.94	28.02	0.64	5.79	5.28
Pant T3 x Azad T5	6.25	26.60	0.60	5.28	4.41
H86 x Floradade	5.79	27.40	0.60	6.45	6.44
H86 x Kashi Sharad	6.32	28.52	0.61	6.70	6.70
H-86 x Azad T-5	7.42	28.58	0.66	7.01	6.19
Selection7 x Floradade	6.67	28.34	0.62	5.51	5.67
Selection7 x Kashi Sharad	6.43	29.24	0.61	5.79	5.89
Selection7 x Azad T5	7.37	29.22	0.61	6.07	5.44
NDTVR60 x Floradade	7.68	26.46	0.67	6.18	3.34
NDTVR60 x Kashi Sharad	6.70	24.08	0.61	6.48	3.47
NDTVAR60 x Azad T5	6.43	23.80	0.64	6.70	3.21
Fla7171 x Floradade	5.64	24.83	0.55	5.96	5.72
Fla7171 x Kashi Sharad	7.63	27.84	0.65	6.25	5.94
Fla7171 x Azad T5	7.13	26.87	0.55	6.39	5.16
Kashi Amri x Floradade	6.77	27.31	0.50	5.99	4.51
Kashi Amri x Kashi Sharad	7.28	29.29	0.64	6.30	4.68
Kashi Amri x Azad T5	6.05	26.65	0.59	6.55	4.33
H24	5.63	22.92	0.57	5.04	3.65
DT2	6.21	24.38	0.58	5.73	3.19
CO3	5.25	26.93	0.58	5.16	5.49
Punjab Upma	5.72	25.36	0.64	6.34	4.50
Pant T3	6.14	24.94	0.65	6.22	5.10
H86	6.52	25.93	0.68	5.81	5.95
Selection7	3.87	19.75	0.48	5.41	5.16
NDTVAR60	4.79	20.77	0.51	5.84	3.02
Fla7171	5.07	22.53	0.54	5.05	4.73
Kashi Amrit	5.31	24.38	0.57	5.76	3.95
Floradade	4.32	22.65	0.51	4.78	5.36
Kashi Sharad	5.83	25.45	0.63	5.61	5.26
Azad T5	4.83	24.58	0.59	4.79	4.11
Shaktiman (hybrid) C1	5.89	25.29	0.55	5.91	4.71
BT12 (Release Variety) C2	4.65	24.09	0.60	5.86	4.71
C.D. 5%	0.68	2.55	0.06	0.49	0.41
C.D. 1%	0.89	3.38	0.08	0.65	0.54

Table 2. Estimate for better parent and standard heterosis for Lycopene, Ascorbic Acid and Titrable Acidity

Crosses	Lycopene (mg/100g)			Ascorbic Acid (mg/100 ml)			Titrable Acidity (mg/100 ml)		
	BP	SC 1	SC2	BP	SC 1	SC2	BP	SC 1	SC2
H24 x Floradade	-1.42	-5.72	19.27*	23.58**	11.98*	17.56**	-11.76*	-9.09	-17.13**
H24 x Kashi Sharad	-9.78	-10.65	13.04	8.40	9.08	14.52**	-14.81**	-2.42	-11.05*
H24 x Azad T5	-12.37*	-16.19**	6.02	3.42	0.53	5.53	-9.55	-2.42	-11.05*
DT2 x Floradade	-19.76**	-15.40*	7.02	4.66	0.91	5.94	-4.57	1.21	-7.73
DT2 x Kashi Sharad	-0.05	5.38	33.31**	7.47	8.15	13.53*	-5.82	7.88	-1.66
DT2 x Azad T5	-35.71**	-32.22**	-14.26	-2.67	-5.39	-0.68	-20.79**	-14.55**	-22.10**
CO3 x Floradae	-47.68**	-53.34**	-40.97**	-10.60*	-4.80	-0.06	-23.70**	-20.00**	-27.07**
CO3 x Kashi Sharad	-57.80**	-58.21**	-47.13**	-5.62	0.50	5.51	-28.04**	-17.58**	-24.86**
CO3 x Azad T5	26.29**	12.63*	42.48**	1.77	8.37	13.77*	-8.99	-1.82	-10.50*
Punjab Upma x Floradade	-2.45	-5.21	19.91**	7.74	8.03	13.41*	-11.46*	3.03	-6.08
Punjab Upma x Kashi Sharad	3.66	2.66	29.87**	-0.65	-0.03	4.95	-16.67**	-3.03	-11.60*
Punjab Upma x Azad T5	14.51*	11.27	40.76**	0.24	0.50	5.51	-16.15**	-2.42	-11.05*
Pant T3 x Floradade	-43.21**	-40.77**	-25.07**	12.14*	10.57*	16.08**	-24.62**	-10.91*	-18.78**
Pant T3 x Kashi Sharad	12.98*	17.84**	49.07**	10.11*	10.81*	16.33**	-2.05	15.76**	5.52
Pant T3 x Azad T5	1.74	6.12	34.24**	6.67	5.18	10.42	-7.18	9.70	0.00
H86 x Floradade	-11.29*	-1.70	24.36**	5.67	8.36	13.75*	-11.82**	8.48	-1.10
H86 x Kashi Sharad	-3.17	7.30	35.74**	9.97*	12.77*	18.39**	-9.85*	10.91*	1.10
H86 x Azad T5	13.75*	26.05**	59.46**	10.22*	13.02*	18.65**	-2.46	20.00**	9.39
Selection7 x Floradade	54.59**	13.36*	43.41**	25.12**	12.06*	17.64**	20.92**	12.12*	2.21
Selection7 x Kashi Sharad	10.29	9.23	38.18**	14.88**	15.61**	21.36**	-3.70	10.30	0.55
Selection7 x Azad T5	52.66**	25.25**	58.45**	18.85**	15.53**	21.28**	2.81	10.91*	1.10
NDTVR60 x Floradade	60.22**	30.46**	65.04**	16.81**	4.61	9.82	31.37**	21.82**	11.05*
NDTVR60 x Kashi Sharad	14.92*	13.82*	43.98**	-5.37	-4.77	-0.03	-3.17	10.91*	1.10
NDTVAR60 x Azad T5	33.13**	9.23	38.18**	-3.20	-5.90	-1.22	7.87	16.36**	6.08
Fla7171 x Floradade	11.24	-4.13	21.28**	9.64	-1.81	3.09	1.23	0.00	-8.84
Fla7171 x Kashi Sharad	30.87**	29.61**	63.97**	9.39	10.08	15.57**	3.17	18.18**	7.73
Fla7171 x Azad T5	40.54**	21.12**	53.22**	9.29	6.23	11.53*	-6.74	0.61	-8.29
Kashi Amri x Floradade	27.43**	14.95*	45.42**	12.02*	8.00	13.38*	-12.21*	-8.48	-16.57**
Kashi Amri x Kashi Sharad	24.87**	23.67**	56.45**	15.08**	15.80**	21.57**	1.59	16.36**	6.08
Kashi Amri x Azad T5	14.00*	2.83	30.09**	8.41	5.38	10.63	0.00	7.88	-1.66

*,** = Significant at 0.05 and 0.01 level of probability, respectively

Electronic Journal of Plant Breeding, 10 (4): 1547-1553 (Dec 2019) DOI: 10.5958/0975-928X.2019.00198.4
ISSN 0975-928X

Table 3. Estimate for better parent and standard heterosis for Total Soluble Solids (TSS) and Pericarp thickness

Crosses	Total Soluble Solids (TSS) (^{0}brix)			Pericarp thickness (mm)		
	BP	SC 1	SC2	BP	SC 1	SC2
H24 x Floradade	3.44	-11.89**	-11.09*	-21.27**	-10.40*	-10.34*
H24 x Kashi Sharad	6.83	1.35	2.28	-29.07**	-20.74**	-20.68**
H24 x Azad T-5	23.89**	5.52	6.48	42.69**	24.42**	24.50**
DT2 x Floradade	0.99	-2.09	-1.19	-5.10	8.00	8.07
DT2 x Kashi Sharad	21.74**	18.04**	19.11**	3.99	16.21**	16.29**
DT2 x Azad T-5	20.00**	16.35**	17.41**	56.82**	36.73**	36.83**
CO3 x Floradae	29.22**	12.68**	13.71**	3.16	20.31**	20.40**
CO3 x Kashi Sharad	3.21	-2.09	-1.19	-35.62**	-24.91**	-24.86**
CO3 x Azad T5	30.64**	13.92**	14.96**	-28.58**	-16.70**	-16.64**
Punjab Upma x Floradade	-3.89	3.04	3.98	2.11	16.21**	16.29**
Punjab Upma x Kashi Sharad	2.26	9.64*	10.64*	7.66	20.31**	20.40**
Punjab Upma x Azad T5	-13.46**	-7.22	-6.37	25.83**	20.31**	20.40**
Pant T3 x Floradade	4.56	9.98*	10.98*	-12.38**	-0.28	-0.21
Pant T3 x Kashi Sharad	-6.91	-2.09	-1.19	0.25	12.03**	12.11**
Pant T3 x Azad T5	-15.06**	-10.65*	-9.84*	-13.47**	-6.37	-6.30
H86 x Floradade	11.07*	9.13*	10.13*	8.24*	36.73**	36.83**
H86 x Kashi Sharad	15.26**	13.25**	14.28**	12.55**	42.18**	42.28**
H86 x Azad T5	20.65**	18.55**	19.62**	4.03	31.42**	31.52**
Selection7 x Floradade	1.97	-6.76	-5.92	5.72	20.31**	20.40**
Selection7 x Kashi Sharad	3.21	-2.09	-1.19	11.97**	25.12**	25.21**
Selection7 x Azad T5	12.27**	2.65	3.58	5.49	15.57**	15.65**
NDTVR60 x Floradade	5.88	4.57	5.52	-37.62**	-29.02**	-28.97**
NDTVR60 x Kashi Sharad	11.02*	9.64*	10.64*	-34.01**	-26.26**	-26.20**
NDTVAR60 x Azad T5	14.67**	13.25**	14.28**	-21.83**	-31.85**	-31.80**
Fla7171 x Floradade	18.02**	0.79	1.71	6.65	21.37**	21.46**
Fla7171 x Kashi Sharad	11.41*	5.69	6.66	12.86**	26.11**	26.20**
Fla7171 x Azad T5	26.53**	8.06	9.04*	9.08*	9.62*	9.70*
Kashi Amri x Floradade	4.05	1.35	2.28	-15.92**	-4.32	-4.25
Kashi Amri x Kashi Sharad	9.32*	6.48	7.45	-11.02**	-0.57	-0.50
Kashi Amri x Azad T5	13.66**	10.71*	11.72**	5.36	-8.14	-8.07

*,** = Significant at 0.05 and 0.01 level of probability, respectively

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