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Full Length Research Paper

Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*)

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Magnitude of heterosis, combining ability effects and its variances were estimated 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 (India). These 43 genotypes (10 lines and 3 testers and 30 resulting F_1 hybrids) were evaluated for growth, yield and quality (T.S.S 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 combiner for most of the traits in which VR-20 was have 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.

Key words: Analysis of variance (ANOVA), heterosis, general combining ability (GCA), specific combining ability (SCA), Line × Testers.
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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is native of Peru Ecuador Bolivia Region of Andes, South America (Rick, 1969). It is a tropical day neutral plant. It is self-pollinated crop but a certain extent of cross pollination may take place. It is a warm loving crop so easily tolerate heat and drought stress. In India, total tomato area and production was about 0.86 million hectare and 16.82 million tonnes, respectively during 2010 to 2011 (Indian Horticulture Database, 2011). India is the second top tomato growing country after China contributed about 11% of the world tomato production (Anonymous, 2011). Tomato is mainly consumed as salad, cooked or processed into several preferred by products like ketchup, juice, puree, sauce and whole canned fruit. Tomato is a rich source of antioxidants (mainly lycopene and β-carotene), Vitamin A, Vitamin C and minerals like Ca, P and Fe in diet (Saleem et al., 2013).

Information about magnitude of general combining ability (GCA) in parents and specific combining ability (SCA) in F_1's crosses is imperative for crop improvement

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Table 1. Genotypes of tomato employed in the investigation.

S/N	Genotypes	Specific traits	Source
1	RCMT-1	Indeterminate and higher number of fruits	IIVR, Varanasi, India
2	RCMT-2	High yielding and prolonged shelf life	IIVR, Varanasi, India
3	LCT-6	Higher number of fruits with high TSS	IIVR, Varanasi, India
4	Azad-T-5	Medium attractive fruits with high TSS	CSAUA&T, Kanpur, India
5	KS-229	Indeterminate variety with high TSS	IIVR, Varanasi, India
6	Potato Leaf	High yielding and Potato leaf type	IIVR, Varanasi, India
7	Pant-T-7	High yielding, attractive red colour variety	GBPUA&T, Pantnagar, India
8	IC-I77371	Indeterminate and higher number of fruits	IIVR, Varanasi, India
9	NDTVR-60	High yielding and prolonged shelf life	NDUA&T, Faizabad, India
10	Co-3	Medium size, determinate variety	TNAU, Coimbatore, India
11	Arka Vikas	Medium round, drought tolerant variety	IIHR, Bangalore
12	NDT-5	Large fruited variety	NDUA&T, Faizabad, India
13	VR-20	High yielding and prolonged shelf life	IIVR, Varanasi, India

programmes (Sprague and Tatum, 1942). GCA reveals the existence of additive gene effects while SCA reveals non-additive gene effects. Information about GCA effects are beneficial while choosing best combiner parents and SCA effects information reveal best cross combinations for further judgement. Judicious application of information relevant to standard heterosis and SCA are fruitful for selecting best hybrids for desired traits.

The present experiment was carried out to identify best combiner parents and best cross combinations for developing promising hybrids for yield and quality components using Line x Tester mating design

MATERIALS AND METHODS

The present investigation was carried out during Rabi season (August – January) of 2008-09 and 2009-10 at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India which is situated at 25°15′ N latitude and 63°03′ E longitude, having elevation of 129.23 m above mean sea level under semi-arid region with an annual mean rainfall of approximately 1100 mm. Major parts of the rain occurs from July to September. Generally, hot summer season commences from mid April to mid June. The soil of experimental field was alluvial type of soil with average fertility level and pH in the range of 6.6 to 7.4. The experimental materials were procured from Indian Institute of Vegetable Research, Varanasi (India) and N.D.U.A. & T., Faizabad (India) followed by selfing for maintenance. The experimental materials including ten lines and three testers was sown in crossing block to derive 30 F_1's following Line × Tester mating design during Rabi season of 2008-09. One popular locally adapted standard variety named DVRT-2 was used as check variety in present experiment. The thirteen parents including ten lines and three testers (Table 1) along with its 30 derived F_1s were grown out in randomized complete block design (RCBD) with three replications for possible evaluation during Rabi season of 2009-10. Each parent and F_1's was transplanted in three rows of 2.70 meter each. In each row 25 days old seedlings were transplanted, keeping row to row and plant to plant spacing 60 × 45 cm, respectively. Recommended package and practices were applied to raise good crops. Data of ten randomly selected plants of each genotypes and its crosses in each replication was recorded for yield and its seven component traits *viz*. plant height (cm), number of primary branches per plant, number of fruits per plant, length of fruit (cm), fruit diameter (cm), average fruit weight (g), fruit yield per plant (kg), yield (q/ha) and two quality parameters viz. shelf life (days) and total soluble solid (TSS) (°brix) and averaged replication wise mean data was used for statistical analysis.

Shelf life was observed by storing the fruit at room temperature (25°C). TSS reading was observed with help of refractometer in °brix. The reading was taken from firm and freshly harvested fruit. The analysis of variance (ANOVA) for RCBD was estimated crosswise according to Panse and Sukhtame (1989) and ANOVA for line × tester analysis was done according to Kempthorne (1957) and Singh and Chaudhary (1985). Heterosis over better parent (heterobeltiosis) and standard/check variety (DVRT-2) were estimated (Table 3).

$$\text{Standard heterosis (\%)} = \frac{F_1 - SV}{SV} \times 100$$

$$\text{Heterobeltiosis(\%) (\%)} = = \frac{F_1 - FBP_1 - BP}{BP\ BP} \times \times 100100$$

Where, F_1 = mean performance of cross, BP = mean performance of better parent and SV = mean performance of standard variety (DVRT-2). Significance of heterosis is tested with the help of standard error using 't' test.

RESULTS AND DISCUSSION

The analysis of variance for combining ability exhibited the presence of significant variation for all studied traits indicating a wide range of variability among experimental materials. The ratio of general combing ability (GCA) and specific combing ability (SCA) variance revealed preponderance of non- additive genetic variances for all studied traits (Table 2).

The GCA effect reveals breeding value of each parent. Among lines, LCT-6 and among testers, NDT-5 exhibited positive significant GCA effects for plant height and number of fruits per plant (Table 4) in consonance with

Table 2. Analysis of Variance (ANOVA) for combining ability in parents and F_1s for yield and quality components in tomato.

Source	D.F.	Plant height (cm)	No. of primary branches per plant	No. of fruits per plant	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit yield per plant (kg)	
Replication	2	11.28	0.67	4.24	0.05	0.07	0.75	0.01	
Treatment	42	783.52**	7.44**	73.51**	1.11**	1.66**	593.32**	0.37**	
Parent	12	479.72**	6.01**	42.68**	0.09	0.34**	4.99*	0.27**	
Parent *vs* cross	1	12.15	29.90**	13.05*	0.34*	0.16*	741.27**	1.25**	1
Cross	29	935.84*	7.25**	88.35**	1.55**	2.26**	831.69**	0.38**	
Error	84	9.73	0.24	1.97	0.05	0.03	2.52	0.01	
Line (Female)	9	835.84	7.32	111.50	2.07	4.65**	1213.60	0.88**	1
Tester (Male)	2	32.15*	0.45	139.00	0.67	0.43	415.21	0.16	
Line × Tester	18	732.51**	7.97**	71.14**	1.39**	1.27**	687.01**	0.15**	
GCA variance (σ^2g)		-15.31	-0.21	2.77	0.00	0.07	6.53	0.02	
SCA variance (σ^2s)		-34.44	0.22	-13.45	-0.23	-1.13	-175.53	-0.24	
σ^2g/σ^2s		0.44	-0.97	-0.21	0.00	-0.06	-0.04	-0.08	
Error	58	13.29	0.32	2.45	0.06	0.03	0.07	94.23	

*, **Significant at 5 and 1% level, respectively.

Avdikos et al. (2011) and Singh and Asati (2011). Among lines, LCT-6 showed positive significant GCA effects for number of primary branches per plant. Among lines, KS-229 and among testers, Arka Vikas exhibited positive significant GCA effect for fruit length. The line KS-229 and tester NDT-5 showed positive significant GCA effect for fruit diameter as similar reported by Saleem et al. (2013). Among lines, RCMT-1 and among testers, VR-20 revealed positive significant GCA effect for number of seed per fruit. Among lines, KS-229 and among testers, VR-20 revealed positive significant GCA effect for average fruit weight. Three lines CO-3, NDTVR-60 and Potato leaf and among testers, NDT-5 represented positive significant GCA effect for fruit yield per plant and yield per hectare indicating significant additive gene effect as similar reported by, Prabuddha et al. (2008) and Kumar et al. (2010) (Table 4). The line IC-I77371 represented positive significant GCA effect for shelf life. The line Pant T-7 and tester NDT-5 represented positive significant GCA effect for T.S.S. (°brix). On the basis of GCA effects across twelve characters, Potato Leaf, Pant-T-7, IC-177371 and NDTVR-60 were identified as most promising best combiner parents for inclusion in hybridization programme for improving yield and quality components.

Out of 30 derived crosses, the cross combination LCT-6 × Arka Vikas displayed maximum standard heterosis (50.50%) for plant height followed by cross LCT-6 × NDT-5 (43.33%) (Table 3). The cross LCT-6 × Arka Vikas displayed the highest heterobeltiosis (45.94%) for plant height followed by LCT-6 × NDT-5(38.99%) in consonance with Singh and Asati (2011). The cross LCT-6 × NDT-5 displayed the maximum standard heterosis for number of primary branches

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Table 3. Identification of superior crosses in Tomato based on heterosis and mean performance of respective crosses.

Traits	Range of heterosis% over		No. of significant heterotic crosses over		Three superior crosses based on heterobeltiosis (%)	Mean performance of crosses	Three superi on standard
	BP	SP	BP	SP			
Plant height (cm)	-47.60% (RCMT -1 × A.Vikas) to 45.94% (LCT-6x A. Vikas)	-42.77% (Azad-T-5xA.Vikas) to 50.50% (LCT-6x A. Vikas)	22	21	LCT-6×A.Vikas (45.94) LCT-6 × NDT-5(38.99) CO-3 × NDT-5 (38.24)	120.40 114.70 94.30	LCT-6xA.Vika LCT-6 × NDT CO-3 × NDT-
No. of primary branches /plant	-59.33% (Azad T-5 × NDT-5) to25.22% (LCT-6 × NDT-5)	-55.56% (Azad T-5 × NDT-5) to 36.81% (LCT-6 × NDT-5)	25	11	LCT-6 × NDT-5(25.22) AzadT5xA.Vikas(12.55) LCT-6x A. Vikas (1.40)	12.31 10.58 9.63	LCT6 xNDT-5 AzadT5xA.Vik KS229 × NDT
No. of fruits/ plant	-65.78%(RCMT-1x VR-20) to 40.20% (LCT-6 × NDT-5)	-52.50% (RCMT-1x VR-20) to 58.50% (Azad T-5 × VR 20)	23	20	LCT-6 × NDT-5 (40.20) AzadT5X VR 20 (37.53) NOTVR60x NDT5 (25.24)	27.00 31.70 23.20	AzadT5XVR2 LCT-6x A. Vik Potato Leaf x
Fruit length (cm)	-44.97% (LCT-6x A.Vikas) to 27.28% (KS-229 × A. Vikas)	-42.99% (LCT-6xA. Vikas) to 40.77% (KS-229 × A. Vikas)	11	17	KS229 × A.Vikas (27.28) PotatoLeaf xA.Vikas (22.11) IC-177371 × A Vikas(17.26)	5.49 4.93 4.80	KS229xA.Vik Potao Leaf × IC-177371 ×
Fruit diameter (cm)	-49.93% (LCT-6x A. Vikas) to 29.70% (CO3 ×NDT5)	-42.50% (LCT-6x A. Vikas)to 41.67% (KS229 ×NDT -5)	23	23	CO3 ×NDT5 (29.70) NOTVR60x A.Vikas (17.71) KS229x NDT-5 (17.57)	5.15 4.65 5.67	KS229 ×NDT KS229 × A.Vi CO-3 × NDT-
Average fruit weight (g)	-61.35% (LCT6 ×NDT5) to 26.58% (KS229 ×A.Vikas)	-60.21%(LCT6 ×NDT5) to29.58% (KS229 ×A.Vikas)	15	16	KS229 ×A.Vikas (26.58) LCT-6 XVR-20 (22.87) RCMT-1 × NDT-5 (10.88)	103.70 101.20 90.37	KS229 ×A.Vik LCT-6 XVR-2 CO3 XA. Vika
Fruit yield/ plant (kg)	-68.45% (RCMT-1 ×VR20) to 34.82% (RCMT-1× NDT-5)	-55.52% (RCMT-1 ×VR20) to 29.57% (CO-3 ×A.Vikas)	16	16	RCMT-1× NDT-5(34.82) LCT-6 × V-20 (33.74) CO-3 × NDT-5 (31.65)	1.47 1.51 1.95	CO-3 ×A.Vika CO-3 × NDT- PotatoLeaf ×
Yield (q/ha)	-68.45%(RCMT-1× VR-20) to 34.82% (RCMT-1×NDT-5)	-55.52% (RCMT-1× VR-20) to 29.57 % (CO-3×A.Vikas)	30	29	RCMT-1×NDT-5 (34.82) LCT-6 × VR-20 (33.74) CO-3 × NDT-5 (31.65)	514.80 531.30 684.30	CO-3×A.Vika CO-3 × NDT- PotatoLeaf xN
Shelf life (in days)	-55.53% (LCT-6× A.Vikas) to 33.67% (RCMT-1 ×A. Vikas)	-48.61% (LCT-6× A.Vikas) to 24.72% (Potatoleaf ×VR-20)	13	7	RCMT-1 ×A. Vikas(33.67) CO-3 XA. Vikas(10.61) IC-177371 × A.Vikas(8.67)	8.33 12.83 14.20	Potatoleaf ×V CO-3 × A. Vik RCMT-2 XND

Table 3. Contd.

T.S.S. (^{o}brix)	-29.95% (RCMT-2 × A. Vikas) to 27.91% (LCT-6 ×NDT-5)	-27.50% (RCMT-1 ×A. Vikas) to 37.50 % (LCT-6 ×NDT-5)	15	10	LCT-6 ×NDT-5 (27.91) RCMT-2 × VR-20 (17.07) CO-3 × NDT-5(8.95)	5.50 3.56 4.30	LCT-6 ×NDT- RCMT-2 XVR RCMT-1 XVR

Table 4. Estimation of GCA effect for yield and quality components in Line × Tester analysis in tomato.

S/N	Parent	Plant height (cm)	No. of primary branches/plant	No. of fruits/ plant	Fruit length (cm)	Fruit diameter (cm)	Average fruit weight (g)	Fruit yield/ plant (kg)
					Lines			
1	RCMT-2	-10.50**	-1.64**	-3.03**	-0.64**	-0.59**	-12.99**	-0.46**
2	RCMT-1	-7.19**	-0.55	-7.28**	-0.31**	-0.51***	5.88**	-0.40**
3	LCT-6	20.08**	1.42**	5.89**	-0.81**	-1.18**	-18.34**	-0.28**
4.	Azad-T-5	-11.75**	-1.12**	1.63**	-0.21**	-0.63**	-17.57**	-0.23**
5	KS-229	-0.69	0.01	-1.88**	0.69**	1.04**	13.13**	0.13**
6	Potato leaf	6.74**	0.71**	1.78**	0.30**	-0.17**	3.44	0.26**
7	Pant-T-7	3.95**	0.24	0.08	0.36**	0.39**	5.73**	0.17**
8	IC-I77371	-5.36**	0.41*	-0.26	0.28**	0.50**	5.71**	0.14**
9	NDTVR-60	-1.54	0.51**	1.07*	0.08	0.52**	6.55**	0.27**
10	Co-3	6.27**	0.001	1.97**	0.25**	0.64**	8.32	0.39**
	SE±	1.04	0.16	0.46	0.07	0.05	0.52	0.004
	CD at 5%	2.08	0.32	0.93	0.15	0.10	1.05	0.007
	CD at 1%	2.77	0.43	1.24	0.20	0.14	1.41	0.001
					Testers			
1	Arka Vikas	-5.28**	-0.05	-1.51**	0.15**	-0.03	0.31	-0.08**
2	NDT-5	11.92**	0.14	2.46**	-0.06	0.13**	-3.86**	0.06**
3	VR-20	-6.64**	-0.08	-0.95**	-0.14**	-0.09**	3.55**	0.01**
	SE±	0.56	0.08	0.25	0.04	0.02	0.29	0.002
	CD at 5%	1.14	0.17	0.51	0.08	0.05	0.58	0.004
	CD at 1%	1.51	0.23	0.68	0.11	0.07	0.77	0.005

*, ** Significant at 5 and1%, respectively.

the maximum extent of standard heterosis for fruit diameter (41.67%) followed by KS229 × A.Vikas (41.25) in consonance with Singh and Asati (2011).

The cross CO-3 × NDT-5 displayed highest heterobeltiosis for fruit diameter (29.70%) followed by NDTVR-60 × Arka Vikas (17.71%) in consonance with Joshi et standard hetero fruit weight was

Table 5. Promising top two crosses based on SCA effect and mean performance of respective crosses in tomato.

Character	Best specific combiners	Specific combining ability (SCA)	Mean performance of respective crosses
Plant height (cm)	LCT- 6 × Arka Vikas	29.00**	120.40
	RCMT-1 × VR 20	22.39**	85.17
No. of primary branches /plant	Azad T-5 × ArkaVikas	3.34**	10.58
	LCT-6 × NDT-5	2.32**	12.31
No. of fruits/ plant	Azad T-5 xVR-20	9.74**	31.70
	LCT-6 × NDT-5	9.36**	27.00
Fruit length (cm)	RCMT-2 × VR 20	1.31**	4.49
	LCT-6 × NDT-5	0.86**	4.02
Fruit diameter (cm)	RCMT-2 × VR 20	1.51**	5.00
	Azad T-5 × ArkaVikas	0.72**	4.23
Average fruit weight (g)	LCT-6 × VR 20	40.19**	101.20
	KS-229 × Arka Vikas	14.31**	103.70
Fruit yield/ plant (kg)	Azad T-5 × VR-20	0.39**	1.74
	RCMT -1 × NDT-5	0.24**	1.47
Yield (q/ha)	Azad T-5 × VR-20	13.92**	610.10
	RCMT -1 × NDT-5	8.67**	514.80
Shelf life (in days)	RCMT-2 × NDT-5	4.45**	14.33
	Co-3 × Arka Vikas	2.99**	12.67
T.S.S. (^{O}brix)	RCMT-2 × VR 20	1.03**	4.80
	LCT-6 × NDT-5	0.98**	5.50

*, **Significant at 5 and1%, respectively.

Vikas (29.58 and 26.58%, respectively). The cross CO-3 × Arka vikas displayed highest standard heterosis for fruit yield per plant (29.57%) followed by CO-3 × NDT-5(22.14%) in consonance with Saleem et al. (2013). Highest heterobeltiosis for fruit yield per plant was displayed by RCMT-1 × NDT-5 (34.82%) followed by LCT-6 × VR-20 (33.74%). The cross CO-3 × Arka Vikas(29.57%) displayed maximum standard heterosis for yield (q/ ha) followed by CO-3 × NDT-5 (22.14%) and Potato Leaf xNDT-5 (20.66%) as similar reported by Banerjee and Kalloo (1989). The cross RCMT-1 × NDT-5(34.82%) exhibited highest heterobeltiosis for yield (q/ha) followed by LCT-6 × VR-20 (33.74%) in consonance with Singh et al. (2008). The cross Potato Leaf × VR-20 displayed highest standard heterosis for shelf life (24.72%) followed by CO-3 × Arka Vikas (21.67%) and RCMT-2 × NDT-5 (19.44%) (Table 3). Maximum heterobeltiosis for shelf life was displayed by RCMT-1 × Arka Vikas (33.67%) followed by CO-3 × A. Vikas (10.61%). The cross LCT-6 × NDT-5 exhibited highest standard heterosis and heterobeltiosis for T.S.S (ºBrix) (37.50 and 27.92%, respectively) followed by RCMT-2 × VR-20 (20.00 and 17.07%, respectively) as similar reported by Makesh et al. (2003) and Avdikos et al. (2011).

The ideal cross combination to be exploited is one having high magnitude of SCA effects in desired direction in addition to involving such a parent having either high × high or high × low or low × low GCA effects indicating existence of additive, dominance or epistatic gene interaction. The cross LCT-6 × Arka Vikas revealed a good specific combiner for plant height (29.00) followed by Azad-T-5 × NDT-5 (22.33) in consonance with Singh and Asati (2011) (Table 5). The cross Azad-T-5 × Arka Vikas (3.34) and LCT-6 × NDT-5 (2.32) possesses highest SCA effect for number of primary branches per plant. The cross Azad-T-5 × VR-20 exhibited the maximum SCA effect for number of fruits per plant (9.74) followed by RCMT-1 × Arka Vikas (9.36). The cross RCMT-2 × VR-20 showed positive and significant SCA effect for fruit length (1.31%). Out of thirty cross combinations, the cross RCMT-2 × VR-20 exhibited the maximum SCA effect for fruit diameter (1.51%) followed

by Azad-T-5 × Arka Vikas (0.72%) (Table 5) as similar reported by Rao et al. (2007). The cross LCT-6 × VR-20 exhibited highest positive and significant SCA effect for average fruit weight (40.19%) followed by KS-229 × Arka Vikas (14.31%) as similar reported by Saleem et al. (2013). The cross Azad-T-5 × VR-20 exhibited maximum positive SCA effect for fruit yield per plant (0.39%) followed by RCMT-1 × NDT-5 (0.24%). The cross RCMT-2 × NDT-5 exhibited maximum positive and significant SCA effect for shelf life followed (4.45%) by CO-3 × Arka Vikas (2.99%). Maximum positive and significant SCA effect for T.S.S (^{o}brix) exhibited by RCMT-2 × VR-20 (1.03%) followed by LCT-6 × NDT-5 (0.98%) in consonance with Singh and Asati (2011). On the basis of SCA effect across ten traits, RCMT-2 × VR-20, LCT-6 × VR-20 and Azad-T-5 × VR-20 could be considered as most promising specific combiner for most of the characters in which VR-20 played a tremendous role.

Based on present studied on 30 F_1s crosses and 13 parents after selfing (ten lines and three testers), it could be concluded that the parents Potato Leaf, Pant-T-7, IC-177371 and NDTVR-60 have good GCA preferred as a parent in hybridization programmes while the crosses RCMT-2 × VR-20, LCT-6 × VR-20 and Azad-T-5 × VR-20 have better SCA for most of the desirable traits. Significant maximum yield over standard check (DVRT-2) was found in crosses CO-3 × Arka Vikas, CO-3 × NDT-5, NDTVR-60 × NDT-5 and RCMT-1 × NDT-5. These promising hybrids may be tested for yield and other quality traits under different agro-climatic conditions for commercial exploitation of hybrid vigour.

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