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Stability analysis for quality parameters in tomato (*Solanum lycopersicum* L.)

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Abstract
Forty six genotypes of tomato were evaluated at Regional Horticulture Research Station, ASPEE College of Horticulture and Forestry, N.A.U., Navsari in RBD with three replications under three environments created using different planting dates to study the stability behavior of genotypes for different quality traits. The genotype x environments interaction was highly significant for all characters except fruit pH, reducing sugar (%), total sugar (%), lycopene content (mg/100g) and viscosity (cSt) when tested against pooled deviation. Parent JTL-12-08 (TSS) and AVTO-7 (ascorbic acid) while hybrids *i.e.* AT-3 x AVTO-6 and Abhinav (TSS), Abhinav (AIS), JTL-08-16 x JTL-13-20, AVTO-6 x Arka Abha and Abhinav (titrable acidity), JTL-12-12 x AT-3 (ascorbic acid) and AT-3 x JTL-13-20 (non-reducing sugar) were considered as the most stable genotypes for these traits.

Keywords: Tomato, stability, Genotype x Environment interaction

1. 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. India is the second top tomato growing country after China contributed about 11% of the world tomato production. 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.

The major objective of any plant breeding and selection programme is to develop genotypes, which could perform consistently superior in many variables environment. Phenotypically suitable genotypes are usually sought after for the commercial production of crop plants. However, one of the main constraints to the fulfillment of this objective is the genotype-environment interactions (GXE interaction) which make it difficult to correctly identify genotypes that could exhibit stable performance over different environments and are widely adapted so that these may be commercially grown in larger area. Therefore, one of the significant steps in identifying stable genotypes is to subject the population of potential genotypes to multi–environments testing and thereby to generate basic information with respect to likely magnitude of GXE interactions. Such a breeding objective requires the basic information on the nature and extent of GXE interaction in respect of quality component characters.

It was, therefore, felt necessary to study the stability behavior of newly developed tomato varieties/ hybrids (referred as genotypes in this investigation) and their performance under varying environments.

Material and methods
The experimental material consisted of forty six genotypes including 36 hybrids which obtained from nine parental line through half diallel, along with one commercial check (Abhinav). The genotypes were planted using three different dates *viz.*, Oct-2015, Nov-15 and Dec-2015 to create different environment at Regional horticulture Research Station, ASPEE college of Horticulture and Forestry, N.A.U., Navsari. These three transplanting dates were treated as three environments in stability analysis. The experiments were carried out in Randomized Block Design, with three replications. Spacing between rows and plants was 90 and 60cm, respectively.

Data were recorded on five randomly selected plants for Total Soluble Solids (^{0}Brix), Alcoholic Insoluble Solids (%), titrable acidity, Ascorbic acid content (mg/100g), fruit pH, Reducing sugar (%), Non- reducing sugar (%),total sugar (%), lycopene content (mg/100g) and viscosity (cSt). The data were subjected to analysis of variance to test the significance of genotype x environment interactions. Stability parameters, regression (bi) and deviation from regression (S^2 di) were worked out by the method of Eberhart and Russel (1966) [1].

Table 1: Analysis of variance for phenotypic stability pertaining to various characters in tomato.

		Characters				
Source	**d.f.**	**TSS (^{0}Brix)**	**Alcoholic Insoluble Solids**	**Titrable acidity (%)**	**Fruit pH**	**Ascorbic acid (mg /100 g)**
Genotypes (G)	45	1.34**++	0.04**++	0.07**++	0.37**++	42.99**++
Environments (E)	2	0.04**++	0.001**++	0.007**++	0.001	0.53**++
G X E	90	0.001++	0.0002++	0.0002++	0.0001	0.01++
Environments (linear)	1	0.087**++	0.002**++	0.014**++	0.001+	1.06**++
G X E (linear)	45	0.001++	0.0002++	0.0002++	0.0001	0.01++
Pooled deviation	46	0.0001	0.0001	0.0001	0.0002	0.001
Pooled error	270	0.002	0.0002	0.0002	0.0004	0.03
		Characters				
Source	**d.f.**	**Reducing sugar (%)**	**Non reducing sugar (%)**	**Total sugar (%)**	**Lycopene content (mg /100 g)**	**Viscosity (cSt)**
Genotypes (G)	45	0.86**++	0.28**++	1.63**++	1.63**++	6565.21**++
Environments (E)	2	0.26**++	0.01**++	0.33**++	0.92**++	26.79**
G X E	90	0.01**	0.002**++	0.005**	0.01**	1.5
Environments (linear)	1	0.52**++	0.02**++	0.67**++	1.84**++	53.59++
G X E (linear)	45	0.003**	0.002**++	0.005**	0.02**++	1.96++
Pooled deviation	46	0.01++	0.0004	0.004	0.0001	1.03
Pooled error	270	0.001	0.0004	0.003	0.001	1.57

Table 2(a): Stability parameters of individual genotype for TSS (0Brix) and Alcoholic Insoluble Solids (%)

Sr. No.	Genotype	TSS (^{0}Brix)					Alcoholic Insoluble Solids (%)				
		Mean	**b_i**	**b_i=0**	**b_i=1**	**S^2di**	**Mean**	**b_i**	**b_i=0**	**b_i=1**	**S^2di**
	Parents										
1	AVTO-7	4.33	1.91	**	++	-0.004	1.27	0.57			-0.0001
2	JTL-12-08	4.18	1.03	**		-0.001	1.21	0.71			-0.0002
3	JTL-12-12	3.63	1.03	**		-0.001	1.30	3.93	**	++	0.0001
4	JTL-12-11	3.66	1.59	**	++	-0.002	1.18	1.63	**	++	-0.0001
5	AT-3	3.62	1.39	*		-0.002	1.06	0.58			-0.0001
6	JTL-08-16	3.45	1.32			-0.002	1.26	0.57			-0.0001
7	JTL-13-20	3.60	1.24	**		-0.002	1.08	1.63	**	++	-0.0001
8	AVTO-6	4.33	0.31			-0.002	1.30	1.48			-0.0001
9	Arka Abha	3.08	1.00			-0.002	1.06	0.58			-0.0001
	Mean	3.76					1.19				
	Hybrids										
10	AVTO-7 x JTL-12-08	4.78	0.87	**	++	-0.001	1.18	1.63	**	++	-0.0001
11	AVTO-7 x JTL-12-12	5.17	1.28	**	++	-0.001	1.26	0.76	**		0.0004
12	AVTO-7 x JTL-12-11	5.06	1.27			-0.001	1.11	-0.96			-0.0001
13	AVTO-7 x AT-3	4.78	1.40	*		-0.002	1.12	2.11			-0.0002
14	AVTO-7 x JTL-08-16	5.07	1.28	**	++	-0.002	1.04	-1.73	**	++	-0.0001
15	AVTO-7 x JTL-13-20	4.50	1.62	**	++	-0.001	1.06	-0.05			-0.0002
16	AVTO-7 x AVTO-6	5.11	0.13			-0.001	1.12	0.57			-0.0001
17	AVTO-7 x Arka Abha	4.88	0.22	**	++	-0.001	1.28	1.62	**	++	-0.0001
18	JTL-12-08 x JTL-12-12	5.11	0.81			-0.002	1.10	-1.11	**		0.0000
19	JTL-12-08 x JTL-12-11	4.70	0.64	**	++	-0.002	1.10	2.11			-0.0002
20	JTL-12-08 x AT-3	5.32	0.67	**	++	-0.001	1.15	0.72			-0.0002
21	JTL-12-08 x JTL-08-16	5.06	0.56			-0.002	1.19	-0.82			-0.0002
22	JTL-12-08 x JTL-13-20	4.83	0.78	**	++	-0.001	1.06	1.49			-0.0001
23	JTL-12-08 x AVTO-6	5.06	0.76			-0.002	1.24	4.12	*		-0.0001
24	JTL-12-08 x Arka Abha	5.05	-0.03			-0.001	1.31	0.71			-0.0002
25	JTL-12-12 x JTL-12-11	5.18	1.40	*		-0.001	1.04	-1.59			-0.0002
26	JTL-12-12 x AT-3	5.14	1.37	**	++	-0.002	1.40	-1.12	**		0.0000
27	JTL-12-12 x JTL-08-16	6.12	0.81			-0.002	1.18	7.97	**	++	-0.0001
28	JTL-12-12 x JTL-13-20	6.05	1.38	*		-0.002	1.28	-1.12	**		0.0000
29	JTL-12-12 x AVTO-6	5.70	0.87	**	++	-0.001	1.40	1.62	**		-0.0001
30	JTL-12-12 x Arka Abha	4.74	1.59	**	++	-0.001	1.16	0.43	**	++	-0.0001
31	JTL-12-11 x AT-3	4.90	0.42	**	++	-0.002	1.23	-0.20			-0.0001
32	JTL-12-11 x JTL-08-16	5.08	0.28	**	++	-0.001	1.14	-6.59	**	++	0.0029**
33	JTL-12-11 x JTL-13-20	5.12	1.33			-0.002	1.30	0.56			-0.0001
34	JTL-12-11 x AVTO-6	4.81	0.77			-0.002	1.17	2.40	**	++	0.0000

35	JTL-12-11 x Arka Abha	4.88	0.30	*		-0.002	1.25	3.16			0.0000
36	AT-3 x JTL-08-16	5.07	1.39	*		-0.002	1.10	1.63	**	++	-0.0001
37	AT-3 x JTL-13-20	6.04	0.91	**		-0.001	1.42	1.62	**	++	-0.0001
38	AT-3 x AVTO-6	5.25	1.12	**		-0.001	1.30	1.62	**	++	-0.0001
39	AT-3 x Arka Abha	4.22	0.60	**	++	-0.001	1.26	1.62	**	++	-0.0001
40	JTL-08-16 x JTL-13-20	5.56	0.69			-0.002	1.18	1.63	**	++	-0.0001
41	JTL-08-16 x AVTO-6	5.18	0.91	**		-0.001	1.41	0.85	**	++	-0.0001
42	JTL-08-16 x Arka Abha	4.54	0.60	**	++	-0.001	1.38	1.62	**	++	-0.0001
43	JTL-13-20 x AVTO-6	5.19	0.51			-0.002	1.24	0.57			-0.0001
44	JTL-13-20 x Arka Abha	4.50	4.21	**	++	0.001	1.20	0.57			-0.0001
45	AVTO-6 x Arka Abha	4.62	0.64	**	++	-0.002	1.35	2.39	**	++	0.0000
46	Abhinav	5.10	1.01			-0.002	1.40	1.00	**		0.0000
	Mean	5.07					1.22				

Table 2(b): Stability parameters of individual genotype for titrable acidity (%), ascorbic acid (mg /100 g) and non reducing sugar (%)

Sr. No.	Genotype	Titrable acidity (%)					Ascorbic acid(mg /100 g)					Non reducing sugar (%)				
		Mean	b_i	b_i=0	b_i=1	S^2di	Mean	b_i	b_i=0	b_i=1	S^2di	Mean	b_i	b_i=0	b_i=1	S^2di
Parents																
1	AVTO-7	0.53	0.94			-0.0002	27.33	0.93	*		-0.032	2.24	4.34	**	++	0.0003
2	JTL-12-08	0.51	0.75			-0.0001	21.61	1.70	**	++	-0.033	2.06	-1.92	**		-0.0005
3	JTL-12-12	0.69	2.25	*		-0.0001	26.43	1.19	**	++	-0.032	2.19	2.12	**	++	0.0002
4	JTL-12-11	0.78	1.19	**	++	0.0000	27.55	1.40	**	++	-0.032	2.13	-0.11	**	++	-0.0003
5	AT-3	0.71	3.95	**	++	0.0002	25.38	1.33	**		-0.032	1.94	-1.21	**	++	-0.0004
6	JTL-08-16	0.55	-0.37	**	++	0.0001	28.69	1.87	**	+	-0.033	2.00	0.60			-0.0004
7	JTL-13-20	0.52	1.51	**	++	0.0010 **	20.68	1.54	**	++	-0.033	2.15	2.05	**	++	-0.0003
8	AVTO-6	0.45	1.38	**	++	-0.0001	28.7	0.08			-0.033	2.20	0.65	**		0.0103 ***
9	Arka Abha	0.51	1.25			-0.0002	27.19	0.55			-0.033	1.57	0.37	**	++	-0.0003
	Mean	0.58					25.95					2.05				
Hybrids																
10	AVTO-7 x JTL-12-08	0.65	0.81			-0.0002	32.24	0.89	**	++	-0.033	2.33	11.51	**	++	-0.0003
11	AVTO-7 x JTL-12-12	0.69	1.25			-0.0002	28.19	0.53	**	++	-0.032	2.45	2.29	**	++	-0.0003
12	AVTO-7 x JTL-12-11	0.78	1.26	**	++	0.0003	30.44	1.33	**	++	-0.033	2.05	-0.13	**	++	-0.0003
13	AVTO-7 x AT-3	0.56	0.88	**	+	0.0000	31.17	0.82	**	++	-0.032	1.88	1.32	**		-0.0004
14	AVTO-7 x JTL-08-16	0.67	0.94			-0.0002	28.26	0.91	**	++	-0.033	1.82	3.74	**	++	0.0005
15	AVTO-7 x JTL-13-20	0.49	-0.62	**	++	0.0005	30.57	2.16	**	++	-0.033	2.85	-1.21	**	++	-0.0004
16	AVTO-7 x AVTO-6	0.55	-1.25			-0.0002	29.45	1.63	**	++	-0.033	2.74	-2.40	**	++	-0.0004
17	AVTO-7 x Arka Abha	0.68	1.51	**	++	0.0000	32.12	0.47	**	++	-0.033	2.34	1.31	**	++	-0.0002
18	JTL-12-08 x JTL-12-12	0.71	1.56			-0.0002	28.91	0.06			-0.033	2.77	0.95	**	++	-0.0004
19	JTL-12-08 x JTL-12-11	0.82	1.19	**	++	0.0000	26.74	0.23			-0.032	2.09	0.12			-0.0004
20	JTL-12-08 x AT-3	0.78	2.19			-0.0002	23.4	1.72	**	++	0.016	2.18	2.63	**	++	-0.0004
21	JTL-12-08 x JTL-08-16	0.70	-0.32	**	++	0.0004	30.22	-1.43	**	++	-0.032	2.46	0.47	**	++	-0.0004
22	JTL-12-08 x JTL-13-20	0.72	2.13	**	++	-0.0001	20.45	1.27	**	++	-0.032	2.22	0.12			-0.0004
23	JTL-12-08 x AVTO-6	1.02	0.56	**	++	-0.0001	19.34	1.67	**	++	-0.032	2.85	-0.73	**	++	-0.0004
24	JTL-12-08 x Arka Abha	0.85	1.25			-0.0002	27.31	1.19	**	++	-0.033	2.18	2.63	**	++	-0.0004
25	JTL-12-12 x JTL-12-11	0.72	-0.51	**	++	0.0006 *	31.31	1.44	**	++	-0.033	2.38	1.67	**	++	-0.0004
26	JTL-12-12 x AT-3	0.90	1.50	**	++	0.0000	28.68	1.01	**		-0.033	2.82	0.23	**	++	-0.0004
27	JTL-12-12 x JTL-08-16	1.02	0.19			-0.0002	32.08	0.15			-0.033	2.31	2.15	**	++	-0.0004
28	JTL-12-12 x JTL-13-20	1.02	1.57	**	++	0.0002	24.53	1.40	**		-0.033	2.46	1.19	**	++	-0.0004
29	JTL-12-12 x AVTO-6	0.66	1.19	**	++	0.0000	33.40	1.36	**	++	-0.031	2.78	3.72	**	++	-0.0004
30	JTL-12-12 x Arka Abha	0.70	1.31	**	++	0.0001	30.11	0.23	**	++	-0.033	2.29	4.45	**	++	0.0000
31	JTL-12-11 x AT-3	0.75	0.94			-0.0002	31.07	0.12			-0.033	2.35	-0.12			-0.0004
32	JTL-12-11 x JTL-08-16	0.90	1.51	**	++	0.0000	33.38	1.27	**	++	-0.032	2.42	-0.83	**	++	-0.0002
33	JTL-12-11 x JTL-13-20	0.84	0.31			-0.0002	25.09	0.86	**	++	-0.033	2.27	3.48	**	++	-0.0004
34	JTL-12-11 x AVTO-6	0.63	0.44			-0.0001	23.25	0.51	**	++	-0.033	1.93	-1.43	**	++	-0.0004
35	JTL-12-11 x Arka Abha	0.71	1.06			-0.0001	29.75	1.51	**	++	-0.032	2.21	3.13	**	++	-0.0001
36	AT-3 x JTL-08-16	0.91	1.56			-0.0002	31.66	2.51	**	++	-0.033	1.88	0.01		++	-0.0004
37	AT-3 x JTL-13-20	1.03	0.37	**	++	0.0001	26.52	1.46	**	++	-0.033	2.37	0.97	**		-0.0004
38	AT-3 x AVTO-6	0.86	0.63			-0.0002	29.82	1.61	**	++	-0.033	1.8	2.18	**	++	0.0003
39	AT-3 x Arka Abha	0.71	1.25			-0.0002	32.02	0.15			-0.033	2.27	1.21	**	++	-0.0004
40	JTL-08-16 x JTL-13-20	0.79	0.94			-0.0002	23.41	1.25	**	++	-0.033	2.24	-0.47	**	++	-0.0001
41	JTL-08-16 x AVTO-6	0.88	1.31	**	++	0.0001	33.18	0.14	**	++	-0.032	1.89	1.46	**	++	0.0003
42	JTL-08-16 x Arka Abha	0.70	0.63			-0.0002	31.72	1.63	**	++	-0.033	2.06	-1.58	**	++	0.0001
43	JTL-13-20 x AVTO-6	0.75	0.94			-0.0002	22.62	1.59	**	++	-0.033	1.88	0.25	**	++	-0.0004
44	JTL-13-20 x Arka Abha	0.70	0.63			-0.0002	24.28	1.13	**	++	-0.033	1.78	-3.01	**	++	-0.0003
45	AVTO-6 x Arka Abha	0.82	1.00	**		-0.0001	32.07	0.50	**	++	-0.032	2.01	-0.36			-0.0004
46	Abhinav	1.02	1.06			-0.0001	32.06	0.37	**	++	-0.033	2.19	-1.80	**		-0.0004
	Mean	0.78					28.67					2.26				

Results and Discussion

Pooled analysis of variance for various qualitative characters is presented in Table 1. The mean sums of squares due to genotypes were significant to highly significant for all the characters when tested against pooled deviation. Significant to highly significant differences were also observed amongst environments for all the characters except fruit pH and viscosity when tested against pooled deviation. The genotype x environments interaction was highly significant for all characters except fruit pH, reducing sugar (%), total sugar (%), lycopene content (mg/100g) and viscosity (cSt) when tested against pooled deviation. The lack of significant G x E interactions for these characters indicated that genotypes responded consistently over the environments so, there is no need to test these characters further. The mean sum of squares due to environment (linear) was significant to highly significant for all characters when tested against pooled deviation.

Further the mean sum of squares due to genotypes x environments (linear) component significance to highly significant for all the characters except reducing sugar (%) and total sugar (%) when tested against pooled deviations. Thus, linear effects played an important role as compared to non-linear effects in the development of these characters. On the other side, pooled deviation (unpredictable) contributed slightly more to the total characters for reducing sugar. Thus, this study indicated that both linear and non-linear functions play an important role in building up total G x E interaction. These findings are in agreement with those of Mandal *et al*. (2000) [3], Prasanna *et al*. (2007) [4], Ummyiah *et al*. (2015) [6] and Savale and Patel (2016) [5].

To assess the stability of a genotype, linear regression can be regarded as a major response of that particular genotype, and deviation from regression should be considered as a better measure of stability (Jatasra and Paroda, 1979 and Beeker, 1981) [2]. Hence, mean performance of the genotype, together with regression co-efficient (bi) and deviation from regression (S^2di) are discussed here (Table 2 a & b). For TSS, parent JTL-12-08 (bi=1.03) and hybrids *viz*., AT-3 x AVTO-6 (bi=1.12) and Abhinav (bi=1.01) registered high mean value, low S^2di values with bi value nearer to unity which indicated that these genotypes showed average stability for that trait. Whereas hybrid JTL-12-08 x JTL-12-12 (bi=0.81) registered higher mean values, low deviation from regression values and bi value lower than unity. Parent JTL-12-08 (bi=0.71) registered high mean value, low S2di values with less than one bi value. Whereas commercial check Abhinav (bi=1.00) registered high mean value, low S2di value with bi value equal to one which indicated that Abhinav was stable for AIS. While, the hybrids viz., AVTO-7 x JTL-12-12 (bi=0.76), JTL-12-08 x Arka Abha (bi=0.71) and JTL-08-16 x AVTO-6 (bi=0.85) registered high mean value, regression coefficient value lesser than unity with low S2di value.

For titrable acidity, hybrids viz., JTL-08-16 x JTL-13-20 (bi=0.94), AVTO-6 x Arka Abha (bi=1.00) and commercial check Abhinav (bi=1.06) registered high mean value, regression coefficient nearer to one and low S2di value. While, the hybrid JTL-12-08 x Arka Abha (bi=1.25) registered high mean value, greater than one regression coefficient and low S2di value which exhibited as above responsive. Parent AVTO-7 (bi=0.93) and hybrid JTL-12-12 x AT-3 (bi=1.01) registered higher mean values, low deviation from regression values and regression coefficients value nearer to unity for ascorbic acids. And hybrid AT-3 x JTL-13-20 (bi=0.97) exhibited high mean value with low S2di value with bi value nearer to unity for non-reducing sugar.While, the other hybrids *viz.*, AT-3 x Arka Abha (bi=1.21) and AVTO-7 x Arka Abha (bi=1.31) was registered high mean value, greater than one significant regression coefficient and low S^2di value.

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