Environment and Ecology 38 (3A) : 524—533, July—September 2020
ISSN 0970-0420

Phenotypic Stability of Tomato Genotypes Grown in Different Seasons in Middle Gangetic Plains of Bihar

Khushbu Kumari, Shirin Akhtar, Randhir Kumar, Tirthartha Chattopadhyay, Basudev Kole, Swaraj Kumar Dutta

Received 20 April 2020; Accepted 13 June 2020; Published on 4 July 2020

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is the most popular solanaceous vegetable that can be grown year round in the middle Gangetic plains of India, although the main season of its cultivation is autumn-winter season and temperature has profound influence on its cultivation. With this overwhelming significance of environment on tomato in view, twenty five diverse genotypes were grown in three seasons, summer, rainy and autumn-winter in the year 2018-2019 to observe the phenotypic stability for different traits and identify the stable genotype (s). The mean performance of genotypes under the three seasons had great variation. The autumn-winter season was identified as the best suited season for growing tomatoes while summer was the least preferred. Further stability analyses revealed that no genotype was stable for all traits. The stable genotypes for different traits were EC 520075, EC 528372, WIR 13708 for number of primary branches, BRDT-1 and IIHR 2463 for number of flowers per truss, IIHR 2463 for number of fruits per truss polar diameter and TSS, Sun Cherry for average fruit weight, CLN B, EC 520047, EC 520060, EC 520075, EC 528380, IIHR 2606, IIHR 2463, Sun Cherry, Superbug SPS and WIR 13708 for locule number. Superbug SPS and VRT 101 A could be identified for earliness over all seasons, while for yield, CLNB for summer season, EC 520047 for rainy season and BRDT-1 for autumn-winter season were the best performers. Among the quality traits, for TSS, EC 520047 and EC 520060 were most promissing , for lycopene CLN 1621 L and EC 520075 and for beta carotene EC 620421 and EC 5200075 were the most promising genotypes identified over the three seasons.

Keywords Tomato, Stability, Morphological traits, Quality parameters.

Khushbu Kumari, Shirin Akhtar, Randhir Kumar
Department of Horticulture (Vegetable & Floriculture), Bihar Agricultural College, Bihar Agricultural University, Sabour, Bhagalpur, Bihar 813210, India

Tirthartha Chattopadhyay
Department of Plant Breeding and Genetics, Bihar Agricultural College, Bihar Agricultural University, Sabour, Bhagalpur, Bihar 813210, India

Basudev Kole
Department of Statistics, Mathematics and Computer Application, Bihar Agricultural College, Bihar Agricultural University, Sabour, Bhagalpur, Bihar 813210, India

Swaraj Kumar Dutta
Department of Agronomy, Bihar Agricultural College, Bihar Agricultural University, Sabour, Bhagalpur, Bihar 813210, India
E-mail : shirin.0410@gmail.com
*Corresponding author

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), the most favorite

crop of vegetable researchers, is also the most popular non-tuberous solanaceous vegetable in the world. It is widely used for culinary purposes, consumed raw as salad, or processed into several by products like juice, puree, ketchup, sauce, chutneys. Ripe tomatoes are rich sources of nutritive quality compounds, especially carotenoids such as lycopene, β-carotene (provitamin A) and ascorbic acid besides minerals like calcium, phosphorus and iron (Beecher 1998). Tomato and its products, when consumed regularly, help in reduction of carcinogenesis, particularly, prostate and mouth cancer (Giovannucci 2002) and also lower the risk of chronic desgenerative diseases. The antioxidants in tomato, viz., carotenoids, particularly lycopene, beta-carotene, ascorbic acid, vitamin E, phenolic compounds and flavonoids are the reason for the health benefits (Frusciante et al. 2007). It is extensively grown worldwide in tropical, subtropical and temperate regions, depite being basically a warm loving crop. In India, the cultivation of this crop is widespread in West Bengal, Uttar Pradesh, Madhya Pradesh, Bihar, Gujarat, Odisha, Maharashtra, Tamil Nadu, Chhatisgarh and Karnataka, West Bengal being the leading producer. The crop is cultivated in an area of 0.809 million hectares in the country, producing 19.697 million metric tonnes yield with an average national productivity of 24.36 metric tonnes per hectare (Anonymous 2017). Bihar ranks fourth in total production in the country and the area, production and productivity are 0.046 million hectares, 1.011 million metric tonnes and 21.85 metric tonnes per hectare, respectively in Bihar (Anonymous 2017). The major tomato producing districts in Bihar are Vaishali, Muzaffarpur, Nalanda, Begusarai,Patna, Samastipur, Purbi Champaran, Bhagalpur, Sitamarhi and Saran, which come under the middle Gangetic plains.

Tomato is a day neutral crop, but temperature exerts its influence on the fruit set and development and quality of tomato. The optimum temperature for the crop growth is 21-24˚C. Its germination is hampered when soil temperature goes below 10˚C or above 35˚C; fruit setting is hampered when temperatures dip below 13˚C night temperature or sore above 32˚C (Swarup 2006). Optimum temperature for lycopene synthesis is 21-24˚C, below 10˚C and above 30˚C the lycopene production is hampered; at 34˚C the lycopene production stops, but it resumes when temperature goes down; above 40˚C the mechanism of lycopene synthesis is destroyed (Thamburaj and Singh 2003). Besides extremities of temperature, the vegetable is also severely affected by the frost, drought and low light intensity. However, there is demand of tomatoes throughout the year and tomatoes available in market during July fetch greatest wholesale price followed by November, whereas the price is minimum during February (Anonymous 2017). The different seasons creates altogether different environment for the crop. Under such circumstances, the performance of the any genotype may not remain constant throughout the year under the influence of different climatic factors, since phenotypic expression of any trait is the summation of general population mean, effect of genotype, effect of environment and genotype-environment interaction (Singh 2015). G × E interaction suppresses the actual expression of the genotype and hence genetic progress in breeding program may be hampered (Tables 1—5). Owing to the G × E interaction the genotypes may show inconsistent response when grown under different environment which may be due to change in location or season or growing condition or time, resulting in change in their rank among a set of genotypes or even change in performance without change in rank (Crossa 2012, Ortiz et al. 2006). Breeders aim at stable varieties that perform consistently irrespective of the environment of growing, being able to adjust its genotypic or phenotypic state in response to transient fluctuations in environment, thus yielding high and stable economic returns.

Therefore, there is necessity to study the performance of tomato varieties and breeding lines under varying environments and study phenotypic stability of the different genotypes for yield and quality attributes and also to identify stable genotype (s).

MATERIALS AND METHODS

Twenty five diverse lines of tomato were collected from different institutes of India and maintained at the Department of Horticulture (Vegetable and Floriculture), Bihar Agricultural University, Sabour, Bhagalpur. These lines differed in growth habit, fruit color, fruit size and shape and were used in the study. These genotypes were grown in three different seasons viz.,

Table 1. Environmental index and grand mean for 18 traits in 25 tomato genotypes grown in three environments.

Characters	Grand mean	Environmental index		
		E_{-1}	E_{-2}	E_{-3}
Plant height	75.69	-10.92	-2.69	13.61
No.of primary branches	5.38	-0.11	-0.07	0.18
Days to 1st flowering	26.19	5.76	0.83	-6.60
Days to 50% flowering	29.12	5.86	0.63	-6.49
Days to 1st fruit harvest	62.34	-5.90	3.82	2.08
No. of flowers per truss	6.52	0.62	-0.79	0.17
No. of fruits per truss	4.47	0.68	-0.95	0.27
Average fruit weight	24.52	-6.02	-4.53	10.55
Fruit per plant	32.02	-13.96	10.59	3.37
Yield per plant	494.08	-233.64	-83.84	317.49
Yield per hectar	194.66	-91.76	-33.52	125.28
TSS	5.40	0.06	-0.46	0.40
Lycopene	2.40	-0.73	0.04	0.69
β-Carotene	0.86	-0.38	0.20	0.17
Polar diameter	2.79	-0.57	-0.33	0.90
Equatorial diameter	2.81	-0.54	-0.32	0.85
Pericarp thickness	2.58	-0.54	-0.42	0.96
Locule number	2.56	-0.13	-0.09	0.22

summer, designated as E_1 (5th March, 2018, 2018 transplanting), rainy season depicted as E_2 (9th August, 2018 transplanting) and autumn-winter season represented by E_3 (5th October, 2018 transplanting)

Table 2. Stability parameters for growth and reproductive traits in 25 genotypes of tomato. * and ** depict significance at p=0.05 and p=0.01, respectively.

Genotypes	Plant height (cm)			No. of primary branches			Days to 1st flowering (DAT)		
	Pooled Mean	s^2d	b_i	Pooled Mean	s^2d	b_i	Pooled Mean	s^2d	b_i
Arka Alok	72.98	-0.398	0.856**	6.07	-0.011	-0.637	25.33	0573**	1.210**
Arka Meghali	75.12	1.446	0.617**	4.87	0.008	3.240**	28.00	0.752**	0.635**
Arka vikash	50.03	-0.413	0.069**	5.60	0.019*	-0.659	28.78	10.728**	1.171**
BRDT-1	64.96	-0.445	0.643**	5.15	0.008	-1.51	34.22	2.028**	2.387**
BRDT-2	55.82	17.825**	0.711**	4.56	-0.002	1.607**	27.89	5.065**	1.292**
BRDT-3	75.43	-0.033	0.936**	6.50	0.124**	0.392	27.33	1.296**	1.199**
CLN 1621 L	56.77	7.664**	0.674**	5.50	0.468**	3.499	23.89	0.222**	0.536**
CLNB	65.84	0.798	0.650**	4.61	0.072**	0.164	26.22	0.529**	0.610**
EC 520047	74.96	1.45	0.692**	5.19	-0.005	0.729**	23.78	9.657**	0.469
EC 520060	69.78	1.636*	0.825**	4.93	0.015*	1.544*	27.89	0.552**	0.855**
EC 520075	75.40	1.936*	0.581**	6.24	0.012	0.405	27.56	0.333**	0.642**
EC 528372	97.78	-0.298	0.307**	6.36	0.007	0.481	28.89	0.456**	0.834**
EC 528380	92.30	4.087**	1.107**	5.23	0.026**	0.052	28.33	2.523**	0.975**
EC 538455	75.64	8.550**	0.339*	5.08	0.221**	-3.502	27.00	2.767**	1.731**
EC 620421	87.02	35.046**	2.152**	5.14	0.417**	6.867**	28.22	2.144**	1.302**
H-86	68.68	6.433**	0.666**	5.33	0.003	0.509	27.67	7.588**	0.986**
IIHR 2486	82.17	1.463	1.189**	5.10	0.0348**	3.033**	25.44	1.443**	0.873**
IIHR 2606	69.94	82.956**	0.719	5.34	-0.004	1.254**	26.56	1.017**	0.876**
IIHR 2463	87.76	4.356**	0.563**	5.55	0.034**	0.845	26.11	10.349**	0,926
Pusa Rohini	71.62	4.030**	0.482	4.54	0.017*	0.756	26.11	2.124**	1.523**
Sel-18	71.75	9.782**	0.004	5.42	0.250**	-5.368	27.44	0.695**	1.267
Sun Cherry	85.13	1.27	1.263**	4.61	0.183**	3.007	20.44	0.599**	0.501**
Superbug SPS	71.14	0.024	1.651**	6.16	0	2.783**	19.22	5.098**	-0.08
VRT 101A	81.94	266.974**	3.871**	5.44	0.01	5.423**	21.22	0.485**	1.186**
WIR 13708	112.31	15.453**	3.428**	6.20	0.01	0.033	23.43	2.700**	0.822**
Grand mean	75.69	-	-	5.39	-	-	26.20	-	-

Table 2. Continued.

Genotypes	Days to 50% flowering (DAT) Pooled Mean	s^2d	b_i	Days to 1st harvest (DAT) Pooled Mean	s^2d	b_i
Arka Alok	28.67	2.261**	1.470**	58.78	2.133**	0.831**
Arka Meghali	31.89	2.702**	0.739**	60.11	17.029**	1.470*
Arka Vikash	32.22	4.001**	1.263**	59.00	0.061	0.949**
BRDT-1	32.89	35.009**	1.518**	70.44	2.133**	0.831**
BRDT-2	30.78	4.477**	1.291**	64.44	4.950**	1.257**
BRDT-3	29.89	0.091	1.292**	62.11	0.626**	0.902**
CLN 1621 L	26.44	-0.043	0.730**	54.89	-0.153	0.996**
CLNB	29.67	2.225**	0.903**	53.11	4.430**	0.760*
EC 520047	26.56	8.658**	0.597	59.78	11.395**	0.617
EC 520060	31.33	1.585**	1.148**	66.78	0.849**	1.115**
EC 520075	30.89	0.871**	0.908**	61.33	1.502**	1.272**
EC 528372	32.33	0.660**	1.125**	62.44	-0.015	1.044**
EC 528380	31.22	0.361**	1.046**	64.56	3.232**	1.210**
EC 538455	30.22	2.392**	1.712**	71.22	24.681**	1.565*
EC 620421	31.11	-0.042	1.213**	75.56	13.730**	1.423**
H-86	30.00	3.548**	0.872**	68.00	2.811**	0.807**
IIHR 2486	28.11	1.237**	0.984**	63.22	3.123**	1.040**
IIHR 2606	28.78	0.434**	1.006**	69.00	0.061	0.949**
IIHR 2463	29.00	9.557**	0.833*	61.78	4.430**	0.760*
Pusa Rohini	28.44	3.769**	1.505**	65.67	30.030**	0.381
Sel-18	30.22	0.134	1.139**	65.78	21.522**	0.475
Sun Cherry	23.89	2.187**	0.525**	53.33	0.061	0.949**
Superbug SPS	22.00	4.001**	0.047	48.22	0.3	0.925**
VRT 101 A	25.67	2.104**	0.84**	53.22	3.232**	1.210**
WIR13708	26.00	0.350**	0.291**	65.78	4.950**	1.257**
Grand mean	29.13	-	-	62.34	-	-

at the Vegetable Research Farm of Bihar Agricultural University, Sabour,Bhagalpur located at 25˚ 15′ 40″ N latitude and 80˚ 2 ′42″ E longitude in the middle Gangetic plains of Bihar, having an altitude of 46 m above mean sea level. The genotypes were grown in Randomized Block Design replicated thrice in each season, planted at a spacing of 50 cm × 50 cm. The crop was maintained following good agricultural practices for raising tomato as per Chattopadhyay et al. (2007).

Fifteen agronomic and three quality traits were recorded from five randomly selected plants per replication. The agronomic traits included plant height, number of primary branches per plant, days to first flowering, days to 50% flowering, days to first fruit harvesting, number of flowers/truss, number of fruits/truss, polar diameter (i.e., fruit length), equatorial diameter (i.e., fruit diameter), pericarp thickness, locule number/fruit, average fruit weight, number of fruits/plant, fruit yield/plant and total yield. The quality traits recorded were total soluble solids (TSS), lycopene and beta-carotene content.

Stability analysis was carried out as per the model suggested by Eberhart and Russell (1966).

RESULTS AND DISCUSSION

The mathematical model of stability by Eberhart and Russell (1966) partitioned the genotype × environment interaction of individual genotype into two parts viz., slope of the regression line and deviation from it. A genotype having regression coefficient of unity (b_i =1) and least deviation from regression line (S_d^2=0) was considered to be stable. However, the variety should also possess desirable mean value. Any genotype having b_i =1 is considered suited for all conditions and called average responsive; b_i>1 is considered highly responsive, i. e., suitable for favorable environment, whereas those having b_i

Table 3. Stability parameters for fruit morphological traits in 25 genotypes of tomato. * and ** depict significance at p=0.05 and p =0.01, respectively.

Genotypes	Average fruit weight (g) Pooled Mean	s^2d	b_i	Polar diameter (cm) Pooled Mean	s^2d	b_i	Equatorial diameter (cm) Pooled Mean	s^2d	b_i
Arka Alok	54.92	25.313**	1.737**	4.36	0.00092	1.37002**	4.11	0.111**	1.463**
Arka Meghali	37.15	7.792**	3.532**	3.04	0.06681**	1.89492**	2.89	0.164**	2.021**
Arka Vikash	47.76	255.971**	1.076	3.90	0.02607**	1.18970**	4.18	0.143**	1.495**
BRDT-1	53.88	6.258**	3.207**	4.13	0.25314**	2.24792**	4.30	0.617**	2.295**
BRDT-2	39.15	3.228**	1.626**	3.28	0.74345**	1.53471**	3.60	1.662**	1.75
BRDT-3	30.49	-0.103	1.231**	2.78	0.04916**	0.60696**	2.96	0.049**	0.706**
CLN 1621 L	22.28	1.702**	0.203	2.99	0.01628**	1.23833**	3.27	0.213**	1.028*
CLNB	20.12	3.157**	0.559**	3.21	0.18553**	1.02314**	2.96	0.132**	1.181**
EC 520047	13.55	81.066**	0.484	2.16	0.00553**	1.06552**	2.26	0.064**	0.870**
EC 520060	9.43	-0.118	0.227**	2.56	0.68237**	0.35308	255	0.756**	0.278
EC 520075	13.66	51.827**	0.327	2.37	0.00749**	0.69801**	2.34	0.087**	0.482
EC 528372	5.94	2.190**	0.188	1.67	0.11745**	0.39833	1.65	0.117**	0.701*
EC 528380	8.11	17.353**	0.277	1.40	0.13594**	0.10095	1.15	0.027**	0.165
EC 538455	11.15	2.962**	0.114	2.27	0.27164**	0.98139**	2.32	0.271**	1.415*
EC 620421	16.55	61.264**	0.307	2.88	1.06924**	0.46034	2.49	0.480**	1.008
H-86	52.17	86.290**	4.154**	4.22	0.09117**	1.29655**	4.91	0.143**	1.558**
IIHR 2486	9.95	50.901**	0.141	1.77	0.01089****	0.63008**	1.97	0.042**	0.465*
IIHR 2606	15.63	34.766**	0.619	2.46	0.21108**	0.65641	2.31	0.178**	0.697
IIHR 2463	13.60	27.206**	0.612	1.87	0.00017	0.98013	2.09	0.252**	0.108
Pusa Rohini	35.10	0.702**	2.437**	3.84	0.02025**	0.9749	3.75	0.108**	0.974**
Sel-18	24.18	15.543**	0.419	3.19	0.01140**	1.1556	3.23	0.174**	0.654
Sun Cherry	10.59	0.158	0.108	1.78	0.06033**	0.54598	1.92	0.017**	0.490**
Superbug SPS	25.87	84.550**	0.093	3.21	1.61797**	1.72655	2.61	0.402**	1.09
VRT 101 A	32.85	55.320**	1.211*	2.78	0.00118	0.94679**	2.58	0.035**	0.614**
WIR 13708	8.99	4.122**	0.123	1.82	0.05696**	0.90916**	2.05	0.091**	0.907**
Grand mean	24.52	-	-	2.80	-	-	2.82	-	-

Table 3. Continued.

Genotypes	Pericarp thickness (mm) Pooled Mean	s^2d	b_i	Locule number Pooled Mean	s^2d	b_i
Arka Alok	4.41	0.042	1.296**	3.14	0.007**	2.079**
Arka Meghali	2.67	0.007**	1.790**	2.90	0.006**	7.613**
Arka vikash	4.01	0.388**	1.682**	3.68	0.025**	5.464**
BRDT-1	3.57	0.046**	3.005**	3.34	0	2.235**
BRDT-2	2.96	0.529**	2.075**	3.18	0	1.207**
BRDT-3	2.94	0.049**	0.956**	3.15	0.05	1.898**
CLN 1621 L	3.10	0.135**	1.903**	2.38	0.021	1.170**
CLNB	3.13	0.092**	1.092**	2.39	0.029	0.068
EC 520047	2.02	0.005**	0.492**	2.17	0.078	-0.159
EC 520060	1.49	0.265**	0.265	2.00	-0.001	0
EC 520075	2.01	0.434**	0.684	2.00	-0.001	0
EC 528372	1.43	0.117**	0.47	2.00	0.118**	0
EC 528380	1.07	0.030**	0.147	2.00	-0.001	0
EC 538455	1.94	0.272**	1.290**	2.18	0.272**	0.808
EC 620421	2.98	0.098**	0.122	2.60	0.020**	0.979
H-86	4.83	0.043**	1.131**	3.67	0.274**	2.262
IIHR 2486	1.36	0.057**	0.251	2.27	0.278**	-1.425
IIHR 2606	1.85	0.138**	0.276	2.73	-0.001	-1.153
IIHR 2463	1.90	0.010**	0.517**	2.44	0.002	-0.154
Pusa Rohini	3.95	0.321**	1.449**	3.43	0.412**	1.866

Table 3. Continued.

Genotypes	Pericarb thickness (mm) Pooled Mean	s^2d	b_i	Locule number Pooled Mean	s^2d	b_i
Sel-18	2.94	0.212**	0.872**	2.09	0.004**	0.312
Sun Cherry	1.73	0.015**	0.411**	2.00	-0.001	0
Superbug SPS	2.46	0.557**	1.753**	2.00	-0.001	0
VRT 101A	2.15	0.129**	0.770**	2.49	0.066**	-0.07
WIR 13708	1.83	0.248**	0.356	2.00	-0.001	0
Grand mean	2.59	-	-	2.57	-	-

< 1 is referred to as low responsive, i. e., suitable for unfavorable situations.

In the current study, for plant height, no genotypes were found stable. Sel-18 and IIHR 2606 could be designated as average responsive. For primary branches genotypes EC 520075, EC 528372 and WIR 13708 possessed desirable mean values, average regression and low deviation from regression and thus could be called stable over all the environments.

For days to first flowring, 50% flowering and first harvest, no genotypes were found stable for all the environments. However, the genotypes that exhibited $b_i = 1$ and could be termed average responsive were EC 520047, IIHR 2463 and Superbug SPS for first flowering, EC 520047 and Superbug SPS for 50% flowering and EC 520047, Pusa Rohini and Sel-18 for first harvest.

BRDT-1 and IIHR 2463 were found to be stable

Table 4. Stability parameters for yield and its attributing traits in 25 genotypes of tomato * and ** depict significance at p=0.05 and p=0.01, respectively.

Genotypes	No. of flower/truss Pooled Mean	s^2d	b_i	No. of fruits/truss Pooled Mean	s^2d	b_i	No.of fruits/plant Pooled Mean	s^2d	b_i
Arka Alok	5.48	-0.01	0.86**	4.36	0.10**	1.22**	11.504	17.713**	0.224
Arka Meghali	5.69	0.08**	0.62**	3.7	0.44**	0.26	16.701	1.833**	-0.008
Arka Vikash	6.06	0.49**	1.44**	4.86	0.28**	1.42**	10.467	35.335**	-0.172
BRDT-1	5.74	-0.01	-0.27	3.94	0.44**	1.30*	12.089	19.504**	0.016
BRDT-2	5.2	-0.01	0.38**	3.59	-0.01	1.95**	9.587	9.598**	0.136
BRDT-3	5.5	0.02	0.88**	3.4	0	1.46**	8.313	-0.232	0.281**
CLN 1621 L	6.96	0	1.34**	4.06	0	0.24**	28.769	14.674**	0.576**
CLNB	5.97	-0.01	0.52**	4.07	0.03*	0.38*	31.704	0.965**	0.289**
EC 520047	7.06	0.02	0.83**	4.25	0.04**	0.17	76.606	4948.036**	4.828
EC 520060	9.47	0.07**	2.57**	6.25	0.02*	1.88**	46.048	0.689	-0.276
EC 520075	6.99	0.04**	2.48**	5.31	0.02**	2.09**	45.533	824.842**	3.486**
EC 528372	6.42	0.09**	0.3	4.4	0.05**	0.88**	61.135	-0.164	1.123**
EC 528380	8.1	5.03**	2.12	6.54	7.06**	0.96	41.473	378.195**	1.488
EC 538455	7.63	0.71**	2.12*	4.62	0.54**	0.81	39.243	-0.01	1.734**
EC 620421	7.2	0.12**	0.41	4.16	0.04**	0.99**	29.491	20.018**	1.007**
H-86	6.82	0.10**	1.47**	3.87	0.03*	1.75**	9.446	7.037**	-0.068
IIHR 2486	5.49	0.02	1.24**	4.64	0.02*	0.34*	50.013	81.750**	2.751**
IIHR 2606	6.56	0.01	1.68**	3.91	0.05**	1.34**	18.158	151.714**	0.203
IIHR 2463	6.39	0.01	-0.34	4.44	0.01	0.02	42.879	1053.227**	2.939
Pusa Rohini	5.38	0.05**	0.72**	4.15	0.19**	1.27**	10.135	14.262**	0.392
Sl-18	6.36	0.91**	-0.24	4.41	0.22**	0.84*	20.907	118.998**	-0.14
Sun Cherry	7.58	1.33**	1.57	5.23	0.47**	1.61**	56.269	1935.673**	0.819
Superbug SPS	6.95	0.02	0.41*	4.33	0.48**	0.41	29.01	623.920**	0.225
VRT 101A	5.79	0.06**	1.42**	4.49	-0.02*	0.74**	21.242	78.639**	-0.025
WIR 13708	6.39	0.12**	0.47	4.97	0.003**	0.71**	37.98	602.827**	1.122
Grand mean	6.53	-	-	4.47	-	-	32.02	-	-

Table 4. Continued.

Genotypes	Fruit yield per plant			Total yield (q/ha)		
	Pooled Mean	s^2d	b_i	Pooled Mean	s^2d	b_i
Arka Alok	657.576	166.308	1.488**	258.863	26.382	1.489**
Arka Meghali	545.431	593.951**	1.432**	214.76	94.129**	1.435**
Arka Vikash	469.107	15863.098**	0.964**	185.1	2504.425**	0.963**
BRDT-1	683.616	48151.096**	1.953**	269.191	7380.815**	1.955**
BRDT-2	398.081	2625.888**	0.919**	156.731	402.842**	0.920**
BRDT-3	306.292	-75.272	1.317**	120.638	864.698**	1.318**
CLN 1621 L	625.598	9401.533**	0.614*	246.551	1360.027**	0.612**
CLNB	638.406	1050.511**	0.708**	251.316	178.443**	0.709**
EC 520047	631.647	55027.927**	0.398	248.445	8378.647**	0.398
EC 520060	408.005	451.693**	0.303**	159.501	45.815**	0.316**
EC 520075	430.282	118646.913**	0.778	171.907	17104.337**	0.746
EC 528372	341.237	-75.204	0.513**	134.371	707.745**	0.514**
EC 528380	272.614	-12.566	0.240**	106.826	8.302	0.243**
EC 538455	414.485	-75.05	0.535**	162.848	5701.513**	0.535
EC 620421	423.121	86.239	0.771**	166.606	14.523	0.773**
H-86	520.701	12952.771**	1.691**	204.979	1962.021**	1.693**
IIHR 2486	369.946	26.64	1.056**	146.031	0.671	1.054**
IIHR 2606	296.269	20723.815**	0.826*	116.718	3186.192**	0.828*
IIHR 2463	409.08	60751.624**	0.61	160.76	9308.935**	0.609
Pusa Rohini	400.4	-66.551	1.424**	157.668	-11.489	1.425**
Sel-18	505.867	19907.095**	0.877*	198.419	2946.645**	0.888*
Sun Cherry	605.398	8225.990**	1.402**	240.056	1015.372**	1.398**
Superbug SPS	680.941	15899.034**	1.601**	269.286	2212.839**	1.598**
VRT 101A	716.072	4139.297**	1.608**	282.034	640.841**	1.610**
WIR 13708	601.891	36193.448**	0.973*	236.9	5553.191**	0.974*
Grand mean	494.08	-	-	194.66	-	-

for number of flowers/truss which showed non-significant deviation from regression slope and regression coefficient near to unity, while the genotypes EC 528372, EC 528380, EC 620421, Sel-18, Sun Cherry and WIR 13708 showed b_i=1 i.e, average responsive genotypes.

For number of fruits per truss the genotypes IIHR 2463 was found to be stable because $b_i = 1$ and $Sd^2 = 0$ were recorded. Besides, the genotypes Arka Meghali, EC 520047, EC 528380, EC 538455 and Superbug SPS exhibited $b_i = 1$ i.e. average responsive genotypes .

For average fruit weight, Sun Cherry was stable but possessed low mean value than the grand mean value and thus poor responsive. Apart from these, the genotypes having $b_i = 1$were Arka Vikash, CLN 1621 L, EC 520047, EC 520075, EC 528372, EC 528380, EC 538455, EC 620421, IIHR 2486, IIHR 2606, IIHR 2463, Sel-18, Superbug SPS and WIR 13708 and said to be average responsive genotypes.

For polar diameter IIHR 2463 was found stable ($Sd^2 = 0.00$ and $b_i = 0.98$). EC 520060, EC 528372, EC 528380, EC 620421, IIHR 2606, Pusa Rohini, Sel-18, Sun Cherry and Superbug SPS exhibited b_i=1 i.e, average responsive genotypes. No genotype was stable for equatorial diameter and pericarp thickness. However, BRDT-2, EC 520060, EC 520075, EC 528380, EC 620421, IIHR 2606, IIHR 2463, Sel-18 and Superbug SPS were found average responsive for equatorial diameter, whereas EC 520060, EC 520075, EC 528372, EC 528380, EC 620421, IIHR 2486, IIHR 2606 and WIR 13708 were average responsive for pericarp thickness.

A number of genotypes were observed to be stable for locule number per fruit, viz., CLNB, EC 520047, EC 520060, EC 520075, EC 528380, IIHR 2606, IIHR 2463, Sun Cherry, Superbug SPS and WIR 13708, whereas EC 528372, EC 538455, EC 620421, H-86, IIHR 2486, Pusa Rohini, Sel-18 and VRT 101 A, were said to be average responsive genotypes.

Table 5. Stability parameters for quality traits in 25 genotypes of tomato * and ** depict significance at p= 0.05 and p= 0.01, respectively.

	Total soluble solids (°Brix)			Lycopene (mg/100g)			Beta-carotene (mg/100 g)		
Genotypes	Pooled Mean	s^2d	b_i	Pooled Mean	s^2d	b_i	Pooled Mean	s^2d	b_i
Arka Alok	4.56	1.891**	1.488	2.30	0.12**	1.21**	0.80	0.01**	1.49**
Arka Meghali	3.94	0.216**	0.519	1.57	0.02**	0.91**	0.54	0.02**	1.43**
Arka Vikash	4.51	2.210**	0.284	2.14	0.12**	1.02**	0.72	0.005**	0.96**
BRDT-1	3.78	0.286**	0.501	3.02	1.12**	0.45	1.05	0.17**	1.95
BRDT-2	4.13	3.165**	0.588	2.44	0.52**	1.02	0.82	0.09**	0.92
BRDT-3	4.29	0.049**	0.341	0.23	0.05**	0.22	0.36	0.05**	1.32
CLN 1621 L	5.09	2.599**	0.528	3.53	0.87**	1.81	1.22	0.03**	0.61**
CLNB	4.72	0.372**	0.544	2.95	0.15**	0.97*	1.00	0.03**	0.71
EC 520047	7.32	0.387**	2.813**	1.61	0.09**	0.89**	0.56	0.004**	0.40**
EC 520060	7.37	5.461**	0.434	2.91	0.01**	0.94**	1.03	0.01**	0.30**
EC 520075	6.57	0.135**	0.379	3.58	0.06**	2.01**	1.23	0.07**	0.78*
EC 528372	7.04	0.117**	1.951**	1.58	0.12**	0.91**	0.51	0.12**	0.51
EC 528380	6.34	2.470**	3.711	1.49	0.06**	0.18	0.50	0.002**	0.24
EC 538455	5.31	0.271**	2.731**	2.55	0.27**	0.17	0.85	0.27**	0.53
EC 620421	5.19	0.266**	1.384	3.00	1.38**	2.66*	1.48	0.05**	0.77**
H-86	4.52	1.567**	0.890	1.88	0.22**	0.66	0.63	0.03**	1.69
IIHR 2486	6.09	1.587**	-0.473	2.29	0.01**	0.92**	0.79	0.004**	1.06**
IIHR 2606	5.68	1.673**	1.941	2.54	0.001	0.38**	0.86	0.003**	0.83*
IIHR 2463	6.28	0.002	0.137	2.27	0.004**	0.26**	0.77	0.01**	0.61*
Pusa Rohini	4.56	0.621**	0.516	2.87	0.12**	1.30**	0.99	0.01**	1.42**
Sel-18	5.12	1.161**	0.453	3.21	0.05**	1.20**	1.09	0.02**	0.88*
Sun Cherry	5.86	0.776**	2.077	3.28	0.05**	2.02**	1.26	0.02**	1.40**
Superbug SPS	5.08	0.233**	0.120	2.16	0.09**	0.83**	0.84	0.01**	1.60**
VRT 101 A	4.89	0.066**	1.021**	1.52	0.0002	0.26**	0.52	0.001**	1.61*
WIR 13708	5.87	0.568**	1.128	2.56	0.07**	0.95**	1.10	0.02**	0.97**
Grand mean	5.41	-	-	2.40	-	-	0.86	-	-

For fruit number per plant, fruit yield per plant and total yield, no genotypes were found stable. However, b_i=1 depicting average responsiveness was exhibited by Arka Alok, Arka Meghali, Arka Vikash, BRDT-1, BRDT-2, EC 520047, EC 520060, EC 528380, H-86, IIHR 2606, IIHR 2463, Pusa Rohini, Sel-18, Sun Cherry, Superbug SPS, VRT 101 A and WIR 13708 for fruit number per plant, EC 520047, EC 520075 and IIHR 2463 for fruit yield per plant and EC 520047, EC 520075, EC 538455 and IIHR 2463 for total yield.

For total soluble solids, IIHR 2463 was found stable, while Arka Alok, Arka Meghali, Arka Vikash, BRDT-1, BRDT-2, BRDT-3, CLN 1621 L, CLNB, EC 520060, EC 520075, EC 528380, EC 620421, H-86, IIHR 2486, IIHR 2606, Pusa Rohini, Sel-18, Sun Cherry, Superbug SPS and WIR 13708, were observed to be average responsive genotypes.

For lycopene and beta-carotene content, no genotype was found stable. However the genotypes which showed b_i=1 were BRDT-1, BRDT-2, BRDT-3, CLN 1621 L, EC 528380, EC 538455 and H-86 and found to be average responsive for lycopene, while BRDT- 1, BRDT-2, BRDT-3, CLNB, EC 528372, EC 528380, EC 538455 and H-86 were noticed to be average responsive for beta-carotene.

Several researchers previously reported different genotypes to be stable for different traits in previous studies. Mulge and Aravindakumar (2003), Kumar et al. (2019) had previously reported Arka Meghali to be stable for plant height and number of primary branches, while Megha to be earlier and stable for days to 50% flowering. Thapliyal (2008) had identified that genotypes VR-20 and Ajeet-11 were stable for the mean fruit weight. The studies of Spaldon et al. (2017) showed that the genotype Rupali was stable for number of locules per plant. Previous researchers

Tiwari and Lal (2014) found Pant T-5 and ARTH-3 were the genotypes suitable for fruit yield per plant, while Ortiz and lzquierdo (1994) identified a hybrid Narita was found stable for marketable yield. The studies of Al-Aysh (2014) revealed that landrace 20303 was high yielder, stable and adapted for favorable environments. On the other hand Savale and Patel (2017) observed the genotypes AVTO-4 and the hybrids AVTO-6 × GT-2 were found stable for yield perplant. Alsadon and Wahab-Allah (2007) identified two tomato parental lines, Strain B and Pakmore VF and three hybrids, viz., Strain B × Pakmor VF, Strain B × Tnshet Star and Pakmore VF × Tnshet Star, as high yielding and stable for different studied traits. Genotype AVTO-5 for TSS was found stable in the studies of Savale and Patel (2017), while Aruna, Pant T-7 and Pant-10 were identified by Thapliyal (2008) suitable for wide range of environments. Kumar et al. (2019) reported eight cross combinations in tomato that were stable and adapted over different seasons.

However, in this experiment none of the genotypes were found stable for all traits. In fact, for some of the traits, not even a single stable genotype was identified. The temperature being a limiting factor in tomato cultivation played a major role that hampered the performance of the genotypes, particularly, in the summer season when all the traits could not be expressed properly.

The environmental index was found to be highest in the autumn-winter sason in most of the traits which indicates that autumn-winter was the best time for tomato cultivation whereas the environmental index was lowest for most of the traits in summer season, which shows that genotypes perform poorly in the summer season. The favorable temperature for tomato cultivation ranged between 18˚C and 29˚C (Hassen 1991). There was severe hamper in growth above a temperature of 35˚C and fruit set severely decreased when day temperature reached 32˚C and night temperature 21˚C (Rashwan 2016). In summer, such temperature regimes were attained in the growing conditions, thereby the crop was under heat stress leading to poor performance of the summer crop. In rainy season heavy rains washed out the pollen from the flower and also hampered anther dehiscence which resulted in lesser fruit set and thus fruit yield.

CONCLUSION

Autumn-winter season was identified as most favorable season for tomato cultivation, while summer season was the least preferred in the middle Gangetic plains of Bihar owing to the very high temperature during summer season. None of the genotypes was identified as stable for all traits. Not even all traits recorded stable genotypes. Superbug SPS and VRT 101 A could be identified for earliness over all seasons; for yield , CLNB for summer season, EC 520047 for rainy season and BRDT-1 for autumn-winter season were the best performers. Among the quality traits, for TSS, EC 520047 and EC 520060 were most promising, for lycopene CLN 1621 L and EC 520075 and for beta carotene EC 620421 and EC 5200075 were the most promising genotypes identified over the three seasons.

ACKNOWLEDGEMENT

The authors acknowledge Indian institute of Vegetable Research, Varanasi, Indian Institute of Horticultural Research, Bengaluru and Bidhan Chandra Krishi Viswavidyalaya, Mohanpur for providing initial seed and Bihar Agricultural University, Sabour for providing seeds and facility for conducting the research work.

REFERENCES

Al-Aysh FM (2014) Genotype-environment interaction and phe notypic stability for fruit yield and its productive components of tomato. J Recent Adv Agric 2 (5) : 219—226.

Alsadon AA, Wahab-Allah MA (2007) Yield stability for tomato cultivars and their hybrids under arid conditions. In 27 International Horticultural Congress-IHC2006 : II Int Symp Pl Genetic Resour Hort 760 : 249—258.

Anonymous (2017) Horticultural Statistics at a Glance, National Horticultural Board, Bangalore.

Beecher GR (1998) Nutrient content of tomatoes and tomato products. Proc Soc Exp Biol Med 218 : 98—100.

Chattopadhyay A, Dutta S, Bhattacharya I, Karmakar K, Hazra P (2007) Technology for vegetable crop production. Published by All India Coordinated Project on Vegetable Crops, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal , India,

pp 226.
Crossa J (2012) From genotype × environment interaction to gene × environment interaction. Curr Genom 13 (3) : 225—244.
Eberhart SA, Russell WA (1966) Stability parameters for comparing varieties. Crop Sci 6 (1) : 36—40.
Frusciante L, Carli P, Ercolano MR, Pernice R, Di Matteo A, Fogliano V, Pellegrini N (2007) Antioxidant nutritional quality of tomato. Mol Nutr Food Res 51 (5) : 609—617.
Giovannucci E (2002) A review of epidemiologic studies of tomatoes, lycopene and prostate cancer. Exp Biol Med 227 : 852—859.
Hassen AA (1991) The productive of vegetable crops. Arabic house for publications, Cairo, ARE (in Arabic).
Kumar R, Singh SK, Srivastava K (2019) Stability analysis in tomato inbreds and their F_1s for yield and quality traits. Agric Res 8 (2) : 141—147.
Mulge R, Aravindakumar JS (2003) Stability analysis for growth and earliness in tomato. Ind J Hort 60 (4) :353—356.
Ortiz R, Crossa J, Vargas M, Izquierdo J (2006) Studying the effect of environmental variables on the genotype × environment interaction of tomato. Euphytica 153 (1-2) : 119—134.
Ortiz R, Izquierdo J (1994) Yield stability differences among tomato genotypes grown in Latin America and the Carib bean. Hort Sci 29 (10) : 1175—1177.
Rashwan AM (2016) Comparative study in fifteen genotypes of tomato for heat tolerance under upper egypt conditions. J Am Sci 12 (6) : 68—76.
Savale SV, Patel AI (2017) Stability analysis for yield and quality attributes in tomato (*Solanum lycopersicum* L.). J Pharmacogn phytochem 6 (6) : 637—642.
Singh BD (2015) Plant breeding : Principles and methods. Kalyani Publishers, New Delhi.
Spaldon S, Samnotra RK, Dolkar R, Choudhary D (2017) Stability analysis and genotype × environment interaction of quality traits in tomato. Int J Curr Microbiol Appl Sci 6 (2) : 1506—1515.
Swarup V (2006) Vegetable science and technology in India. Kalyani Publishers, India.
Thamburaj S, Singh NA (2003) Text book on vegetable, tuber crops and spices. Published by ICAR, India.
Thapliyal A (2008) Stability analysis for growth, yield and quality characters in tomato (*Solanum lycopersicum* L.) (Doctoral dissertation, GB Pant University of Agriculture and Technology, Pantnagar 263145 (Uttarakhand).
Tiwari AK, Lal G (2014) Genotype × environment interaction and stability analysis in tomato. Ind J Hill Farming 27 (2) : 16—18.