RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 58 Special Issue: 969-978 (November 2024)

Phenotypic Trait Analysis of Tomato (*Solanum lysopersicum*) Genotypes in Qatar and Indian Agro-climatic Conditions

Muvin Khan[1], Amar Prakash Garg[2]

10.18805/IJARe.A-6318

ABSTRACT

Background: The study included four genotypes of tomato (EC620378, EC620380, EC620383, EC620534) which were cultivated to find out their similarities and differences based on phenotypic traits when they were grown under different soil zones of Doha (Qatar) and Meerut (India) to find out that which of the genotypes can be cultivated better in Qatar and India.

Methods: The experiment was laid out in Randomized Complete Block Design (RBCD) with two replications. Statistical analysis for variation in quantitative characteristics among genotypes was done by collecting data in 15 qualitative and quantitative traits. Data showed great variation for almost all the traits. The principal component analysis involved plant height and days to marketable maturity as the most discriminating trait that accounted for greater variability in genotypes in both zones, and they should be considered in tomato improvement programs. The correlation analysis showed that fruit yield per plant was positively and significantly correlated with number of fruits per plant and fruit width. Present findings suggest that the identified superior genotypes may be utilized by different farms to further improve their breeding and cultivation strategies.

Result: In Indian soil zone, genotype EC620534 performed extremely well in terms of maximum yield per plant. Similarly, in Qatar soil zone, EC620534 and EC620380 performed well. The phenotypic coefficient of variation (PCV) was higher than its corresponding genotypic counterpart (GCV) for all characters studied showing environmental influence. High broad-sense heritability were recorded for days to marketable maturity, fruit shape index and fruit weight in both agro-climatic zones, they were associated with low genetic advance indicating non-additive gene action and environmental influence, hence, heterosis breeding is recommended.

Key words: Genotype and yield, Indian soil, Phenotypic Traits, Qatar soil, Tomato.

INTRODUCTION

Tomato (*Solanum lycopersicon* L.) is one of the most produced and consumed vegetable crop globally and ranks second in the world in importance only next to potato and ranked first in preserved and processed vegetable market (Solieman *et al*., 2013). Tomato crop has wider adaptability, high yielding potential and multipurpose uses in fresh as well as processed food industries. Tomatoes have high nutritional values and diverse methods of preparation and consumption, making in an indispensable part of the food basket of Indian and Qatari households. Tomatoes are an excellent source of minerals, vitamins (Akinfasoy *et al*., 2011), possessing cancer preventing antioxidants such as lycopene and beta- carotene and other heart diseases preventive biomolecules (Kaur *et al*., 2013).

India is the largest producer of tomato in the world with total production of 20.70 million tonnes from 796.87 thousand hectares of land (FAOSTAT, 2022), which is 8% higher than the normal production. Total annual export of tomato from India was 1,20,000 metric tons in 2023-24, mainly to Pakistan, Bangladesh and Bhutan. In Qatar, the crop has been designated as a critical commodity under the Qatar National Food Security Strategy Program (QNFSS) 2018-23. Tomatoes have historically witnessed high demand in Qatar. The per capita consumption of tomatoes has also seen a steady increase over the years, from 17.7 kg/year in 2017 to 33.3 kg/year in 2021 (QDB, 2023). The local demand for tomato is expected to grow at a sustained rate in the future, with consumption to reach 155,455 tonnes by 2027. The increase in demand is expected to benefit local producers who will play an important role in meeting self-sufficiency benchmarks by catering to the needs of large proportion for domestic consumption of tomatoes.

In order to have a sustainable tomato agriculture industry, locally produced tomatoes must be able to compete with imported both in quality and price. Diversity in soil characteristics and climatic conditions between tomato production regions in India and Qatar has resulted

[1]School of Biological Engineering and Life Sciences, Shobhit Institute of Engineering and Technology, (NAAC accredited Grade "A", Deemed to- be-University), Meerut-250 110, Uttar Pradesh, India. [2]Swami Vivekanand Subharti University, Subhartipuram, Meerut-250 005, Uttar Pradesh, India.

Corresponding Author: Amar Prakash Garg, Swami Vivekanand Subharti University, Subhartipuram, Meerut-250 005, Uttar Pradesh, India. Email: amarprakashgarg@yahoo.com
Orcid id: https://orcid.org/0000-0003-0613-9495

How to cite this article: Khan, M. and Amar, P.G.. (2024). Phenotypic Trait Analysis of Tomato (*Solanum lysopersicum*) Genotypes in Qatar and Indian Agro-climatic Conditions. Indian Journal of Agricultural Research. 58 (Special issue): 969-978. doi: 10.18805/IJARe.A-6318.

Submitted: 09-10-2024 **Accepted:** 09-10-2024 **Online:** 09-11-2024

in specialized management and cultural practices. Environmental variability and differing commercial production practices used by growers have made tomato breeding more difficult, because of differential responses between genotype and environments, generally influence fruit yield and quality characteristics.

The production and productivity not only depends on cultural practices and area of cultivation but on high yielding genotypes too which may have differential adaptability to the growing area (Asiya *et al*., 2017). Tomato has a great variability at the level of genetics and genomics (Foolad, 2007). Systematic study and assessment of germplasm is crucial for existing and anticipated agronomic and genetic advancement of the crop (Anuradha *et al*., 2018). Hence, evaluation of tomato genotypes is essential to see the performance of genotypes for their adaptability and agronomic performance like growth and yield traits to identify the potential genotype. Genetic improvement of any crop is largely dependent on the magnitude of several genetic parameters like phenotypic and genotypic variances (Sharma, 1988), phenotypic and genotypic coefficient of variation (PCV and GCV), broad sense heritability and genetic gain; on which the breeding methods are formulated for its further improvement. Analysis on genetic variability reveals its presence and is of utmost importance as it provides the basis for effective selection. The extent of variability is measured by genotypic coefficient of variance (GCV) and phenotypic coefficient of variance (PCV) which provides information about the relative amount of variation in different characters. Hence, to obtain a comprehensive idea, it is necessary to undertake an assessment of quantitative traits. Heritability estimates in conjunction with the predicted genetic gain is more reliable (Johnson *et al*., 1955).

Considering the above facts, present study is designed as an attempt to characterize selected tomato genotypes in different agro-climatic zones and soil conditions of India and Qatar to analyze the genetic pattern of morphological character of tomato. The main objective is to identify the high yielding variety of tomato in Qatar agro-climatic zone and to quantify yield potential of tomato genotypes for future utilization.

MATERIALS AND METHODS

Experimental site and field operations

The experiments were carried out in research field of Shobhit Institute of Engineering and Technology, Deemed to be University, Meerut, India where the climate is characterized by monsoon influenced humid subtropical climate with hot summers and cooler winters. Summers are extremely hot and duration is from April-June. The monsoon season starts from late June and ends in middle of September. During monsoon, humidity remains high with cloud cover and low temperature (www.meerut.nic.in, 2022). Winter season is dry and mild from November to the middle of March. In Qatar, experiment was conducted in Al Thumama, Doha which is characterized by an arid and semi-arid climate. Rainfall is highly unpredictable in space and time with annual precipitation generally less than 50 mm. Temperatures are generally high, reaching 50°C at times in summer-the main problem is prolonged hot periods (over 35°C) through the summer, when the relative humidity is also often high. Duration of the experiment was from September 2022 to March 2023. Four tomato genotypes (EC620378, EC620380, EC620383, EC620534) obtained from the NBPGR, New Delhi, India were used for the study. They were evaluated in a randomized complete block design (RCBD) with two replicates. The field was prepared and divided into two blocks. The seeds were sown on a raised nursery bed and were transplanted after three weeks in main field at a spacing of 60×45 cm following randomized block design (RBD) with two replications. Necessary fertilization and irrigation practices were adopted to raise a healthy crop. The observations were recorded on five randomly selected plants per replication for each genotype on fifteen characters *viz.,* days to 50% flowering, number of fruits per cluster, number of fruits per plant, average fruit weight (g), fruit yield per plant (kg), fruit shape index, number of locules per fruit, pericarp thickness (mm), plant height (cm), harvest duration (days), internodal distance (cm), days to marketable maturity, total soluble solids (°Brix), ascorbic acid content (mg/100 g). The quality parameters were analyzed as per the methods of A.O.A.C. (1984). Mean across three replications were calculated for each trait and the mean performance was assessed. The recorded data were statistically analyzed at 5% level of significance following the standard process as described by Panse and Sukhatme (1967).

Statistical analysis

The experimental data was analyzed by taking the mean value of the genotypes of tomato for all 15 traits from all replicates. Then, it was subjected to the following statistical analyses: Analysis of variance (ANOVA) for the design of experiment (Panse and Sukhatme, 1967), Coefficient of variation, Heritability and genetic advance (Burton and deVane, 1953), Genetic advance in per cent of mean (Johnson *et al*., 1955), Principal component analysis and Correlation coefficient (Searle, 1961), Direct and indirect path co-efficient (Lynch and Walsh, 1998) by using Scilab (Campbell *et al*., 2010) to show the highest discriminating trait and level of relationship, respectively, among the tomato genotypes.

RESULTS AND DISCUSSION

Morphological variability

The results obtained from the present investigation on growth parameters exhibited significant difference by the genotypes in both climatic zones of Meerut (India and Doha (Qatar) (Table 1). The mean performance of different genotypes for different phenotypic traits are tabulated in Table 1.

In Indian agro-climatic conditions, the maximum plant height was recorded in genotype EC620534 and the lowest in EC620380. Plant height of remaining genotypes was below one meter. The maximum number of fruits per cluster was observed in EC620534 and minimum in EC620380. Significant differences were observed among the entries with respect to days to 50% flowering. The value ranged from 30.36 to 34.31 days. It was lowest in EC620534 and highest in EC 620380. However, in Qatar agro-climatic conditions, the variation among phenotypic traits was observed. The maximum plant height was recorded in genotype EC620534 and the lowest in EC 620380. Plant height of remaining genotypes was below one meter. The maximum number of fruits per cluster was observed in EC-620534 and minimum in EC 620380. Significant differences were observed among the entries with respect to days to 50% flowering, the lowest in EC620380 and highest in EC 620534, respectively. A wide variation was found among the germplasm genotypes for the number of fruits per plant, which significantly varied from 9.5 to 15.67 among the genotypes. Eshteshabul *et al*. (2010) also concluded that the mean number of fruits per plant range between 4.46 and 38.30 which is closely similar to our findings in this study. In Indian conditions, EC 620380 showed the lowest number of fruits per plant and EC620534 the highest number of fruits per plant, whereas, in Qatar conditions, EC620380 being the lowest and EC620378 highest. The average fruit weight ranged from 36.67 g to 77.81 g. The minimum fruit weight was recorded by the genotype EC620378 and maximum by EC620534 in both climatic conditions. Our findings accord with several other authors (Sushma *et al*., 2021; Mounika *et al*., 2020; Kumar and Rana, 2018; Turhan *et al*. 2011 and Abrar *et al*., 2011). The minimum numbers of fruits per cluster were recorded by the genotype EC620380 and maximum by the genotype EC620534 in both agro-climatic conditions. Besides EC620534, the genotype EC 6205383 showed a good number of fruits per cluster. The minimum number of locules was registered with genotype EC 620380, while maximum with genotype EC620534, in both Indian and Qatar agro-climatic conditions. Similar results were shown by other researchers (Kumar and Rana, 2018; Nalla et al., 2016; Ahmed *et al*., 2007 and Sankari, 2000). The line EC 620534 was shown to be better general combiner for number of branches per plant, number of fruits per truss and total number of fruits per plant (Vilas *et al*., 2015). The wide variation in growth parameters of all the genotype might be due to their genetic makeup, which indirectly governs the morphology of the plant that has a direct impact on the formation of floral buds since all the genotype were grown under the same climatic condition.

The fruit yield per plant of tomato evaluated varied significantly among the genotypes, ranging from 0.47 to 1.21 Kg. In both growing conditions, the minimum fruit yield per plant was recorded with genotype EC 620380, while maximum with genotype EC620534. Other genotype

Table 1: Mean performance of tomato genotypes for different phenotypic traits.

Genotypes	Days to 50% flowering	Number of fruits per cluster	Number of fruits per plant	Average fruit weight (g)	Fruit shape index	Number of locules per fruit	Pericarp thickness (mm)	Plant height (cm)	Harvest duration (days)	Internodal distance (cm)	Days to marketable maturit	Total soluble solids (°B)	Ascorbic acid content (mg/100 g)	Fruit yield per plant (kg)
In Indian agro-climatic zone														
EC 620378	32.2	3.7	16.24	36.67	1.19	2.7	5.97	42.1	30.67	8.63	73.67	3.77	29.73	0.57
EC 620383	30.81	4.35	22.09	47.23	0.81	2.86	5.53	95.29	32.33	8.85	66.33	3.82	19.35	1.02
EC 620380	34.31	3.11	8.21	57.51	0.91	3.2	5.82	58.41	18.33	12.56	74.67	3.09	30.82	0.47
EC 620534	30.36	4.6	17	67.56	0.9	3.5	5.1	110.72	31.33	9.07	70.67	3.75	16.49	1.17
In Qatar agro-climatic zone														
EC 620378	31.33	4.2	15.67	43.65	1.09	3.54	6.2	74.01	30.67	10.64	70.33	3.59	27.51	0.65
EC 620383	31.65	3.69	13.6	77.81	1.2	2.3	6.64	73.74	30	6.56	68.67	3.48	16.53	1.05
EC 620380	30.34	3.77	9.5	50.2	0.95	3.62	6.7	61.56	20.33	8.31	71.33	2.84	27.46	0.5
EC 620534	31.74	5.16	13	65.87	1.2	3.8	5.13	108.4	25.67	10.87	73	3.8	18.56	1.21

exhibiting promising fruit yield was EC620383. Similar results were obtained by other workers (Anuradha *et al*., 2021; Das *et al*., 2012; Mehta and Asati, 2008). Also, genotype EC620383 showed to be earliest to marketable maturity while the most delayed one being EC620534. Significant difference among genotypes for the total soluble solid content of fruit at the marketable stage was noticed. TSS of fruit ranged from 2.77 to 3.90 (°Brix). The highest TSS content of fruit was recorded with the genotype EC 620378 (India) and EC620534 (Qatar). These results are in conformity with the finding of Swaroop and Suryanarayana (2005) and Ahmed *et al*. (2007). The ascorbic acid content of fruit at marketable stage ranged from 16.60 to 27.58, the highest being EC620380 in both agroclimatic conditions. However, the content was found to be low in Qatar conditions which may be due to the humidity percentage. Similar type of results is reported by other researchers (Sushma *et al*., 2021, Anuradha *et al*., 2021; Kumar and Rana, 2008; Shashikanth *et al*., 2010; Manna and Paul, 2012).

Genetic variability

All the studied agro-metrical characters showed significant differences (P<0.05) among genotypes (Table 2), indicating that the tomato genotypes were genetically divergent. Thus, there is a huge scope for selection of promising lines with different agro-metrical traits from the present gene pool.

Wide range of variability among genotypes might be due to diverse sources of the materials, as well as environmental influence affecting the phenotypes. The coefficient of variation (%CV) compares the relative amount of variability between plant traits in a particular crop (Sharma, 1988). The value of coefficient of variation (CV%) ranges from 0.61 to 20.61 in Indian zone, while, 0.26 to 6.64 in Qatar zone (Table 3). In Indian zone, the highest being recorded plant height followed by fruit shape index and number of locules per fruit. Similarly, in Qatar zone, highest being recorded by yield per plant followed by fruit shape index and number of locules per fruit. These results imply that the plant height, number of locules per plant and fruit shape index, in that order, had higher amounts of exploitable genetic variability among the studied tomato characteristic traits. It implies that there is greater potential for favorable advance in selecting these attributes compared to others. Further, the lowest CV% was recorded for fruit weight and days to marketable maturity for both zones, which exhibits low exploitable genetic variability and, thus, has less potential for favorable advance in selecting when compared to other traits.

The estimated values of phenotypic variance (PV), Genotypic variance (GV), genotypic (GCV) and phenotypic (PCV) coefficient of variation, broad sense heritability (h2bs) and genetic advance mean (GAM%) of genotypes for yield and yield attributing traits of tomato are presented in Table 3. In general, the phenotypic coefficient of variation (PCV %) was higher than its genotypic counterpart (GCV %) for all the characters studied (Table 3). The higher PCV and GCV for all traits showed that there were environmental

Table 2: Analysis of variance for yield and its contributing traits in tomato.

Source of variation	DF	DoF	FPC	FPP	FW	FSI	LPF	PT	PH	HD	ID	DMM	TSS	A A	FYP
In Indian agro-climatic zone															
Replication	2	1.6356	0.0214	0.0462	0.1088	0.0135	0.003	0.0502	250.0621	0.3333	0.0622	1.0833	0.0632	0.0444	0.0013
Treatment	3	9.4721	1.3557	98.8718	530.1058	0.0788	0.3827	0.4377	3034.277	130.3333	10.4323	42	0.36	157.3226	0.3477
Error	6	1.0168	0.0292	0.0095	0.0555	0.0025	0.0127	0.0043	239.9051	0.3333	0.0944	0.4167	0.0092	0.0504	0.0009
In Qatar agro-climatic zone															
Replication	2	0.0079	0.0155	0.1108	0.0484	0.027	0.0207	0.0377	0.0117	0.5833	0.1027	0.5833	0.0732	0.1067	0.0038
Treatment	3	1.231	1.3631	19.7257	713.2193	0.0423	1.4091	1.5809	1220.544	68.2222	12.6007	9.8889	0.5114	100.8587	0.3331
Error	6	0.0124	0.0101	0.0571	0.0242	0.0026	0.0165	0.0124	0.0352	0.4722	0.0061	0.1389	0.0116	0.1106	0.0032

influences on the phenotypic expression of all the genotypes. Among all the traits, yield per plant showed highest, plant height and fruit weight showed the moderate and days to marketable maturity showed lowest PCV and GCV values respectively. So the selection on the phenotypic value can be effective for the improvement. Similar conclusions were drawn earlier by researchers (Mohamed *et al.,* 2012; Kaushik *et al.,* 2011; Das and Sharma, 2011). The low difference between phenotypic and genotypic coefficient of variations indicated a slight environmental influence on the expression of this character. High PCV and GCV indicate the existence of a greater scope of selection for the trait being considered, which depends on the amount of variability present (Khan *et al*., 2009). Thus, a greater potential is expected in selecting for the yield per plant, plant height and fruit weight among the studied tomato genotypes. Strikingly, in Qatar agro-climatic zone, a greater difference between PCV and GCV estimates for yield per plant and fruit shape index indicates a greater degree of environmental control for these traits. The environmental coefficient of variation (ECV%) is also high in both these traits in Qatar zone.

Heritability estimates

The heritability along with GA gives an insight into the array of genetic control for phenotypic expression and phenotypic reliability in predicting its breeding value and higher index indicates less environment influence in observed variation. Burton (1952) suggested that the genetic coefficient of variation together with heritability estimates gave a better picture of the extent of heritable variation. Broad sense

Table 3: Mean square and genetic parameters for some quantitative traits in tomato genotypes in both agro-climatic zones.

Traits	G Mean	F ratio	PV	GV	EV	CV (%)	PCV (%)	GCV (%)	ECV (%)	h2 (%)	GAM (%)
Indian Agro-climatic zone											
DoF	31.92	9.32	3.84	2.82	1.02	3.16	6.14	5.26	3.16	73.49	9.29
FPC	3.94	46.42	0.47	0.44	0.03	4.34	17.43	16.88	4.34	93.80	33.68
FPP	15.89	10419.6	32.96	32.95	0.01	0.61	36.14	36.14	0.61	99.97	74.43
FW	52.24	9543.30	176.74	176.6	0.06	0.45	25.45	25.44	0.45	99.97	52.40
FSI	0.95	31.33	0.03	0.03	0.00	5.26	17.55	16.74	5.25	91.00	32.89
LPF	3.07	30.15	0.14	0.12	0.01	3.68	12.03	11.46	3.68	90.67	22.48
PT	5.60	100.81	0.15	0.14	0.00	1.18	6.88	6.78	1.17	97.08	13.77
PH	76.63	12.65	1171.3	931.4	239.9	20.21	44.66	39.83	20.21	79.52	73.16
HD	28.17	391.00	43.67	43.33	0.33	2.05	23.46	23.37	2.05	99.24	47.96
ID	9.78	110.54	3.54	3.45	0.09	3.14	19.25	18.99	3.14	97.33	38.59
DMM	71.33	100.80	14.28	13.86	0.42	0.90	5.30	5.22	0.90	97.08	10.59
TSS	3.61	39.15	0.13	0.12	0.01	2.66	9.85	9.48	2.66	92.71	18.80
A A	24.10	3118.56	52.47	52.42	0.05	0.93	30.06	30.05	0.93	99.90	61.87
FYP	0.81	392.41	0.12	0.12	0.00	3.69	42.36	42.19	3.72	99.24	86.59
Qatar Agro-climatic zone											
DoF	31.27	99.63	0.42	0.41	0.01	0.36	2.07	2.04	0.36	97.05	4.14
FPC	4.21	134.40	0.46	0.45	0.01	2.39	16.15	15.97	2.39	97.80	32.53
FPP	12.94	345.41	6.61	6.56	0.06	1.85	19.87	19.78	1.85	99.14	40.58
FW	59.38	29444.4	237.76	237.7	0.02	0.26	25.97	25.97	0.26	99.99	53.49
FSI	1.11	16.08	0.02	0.01	0.00	4.63	11.36	10.37	4.60	83.41	19.51
LPF	3.32	85.27	0.48	0.46	0.02	3.88	20.92	20.55	3.87	96.56	41.60
PT	6.17	127.29	0.54	0.52	0.01	1.81	11.86	11.72	1.81	97.68	23.86
PH	79.43	34683.2	406.87	406.8	0.04	0.24	25.40	25.40	0.24	99.99	52.31
HD	26.67	144.47	23.06	22.58	0.47	2.58	18.01	17.82	2.58	97.95	36.33
ID	9.09	2057.26	4.20	4.20	0.01	0.86	22.55	22.53	0.86	99.85	46.38
DMM	70.83	71.20	3.39	3.25	0.14	0.53	2.60	2.55	0.53	95.90	5.13
TSS	3.43	44.16	0.18	0.17	0.01	3.14	12.32	11.91	3.14	93.50	23.73
A A	22.51	911.63	33.69	33.58	0.11	1.48	25.78	25.74	1.48	99.67	52.94
FYP	0.85	103.47	0.11	0.11	0.00	6.64	39.39	38.82	6.62	97.16	78.83

DoF= Days to 50% flowering; FPC= Number of fruits per cluster; FPP= Number of fruits per plant; FW= Fruit weight (g); FSI= Fruit shape index; LPF= Number of locules per fruit; PT= Pericarp thickness (mm); PH= Plant Height (cm); HD= Harvest duration (days); ID= Internodal distance (cm); DMM= Days to marketable maturity; AA= Ascorbic acid (mg/100 g); TSS (°Brix)= Total soluble solid; FYP= Fruit yield per plant (kg).

heritability (h2bs) and genetic advance mean (GAM%) estimates were interpreted as low, medium and high as per the classification of Johnson *et al*. (1955). In Indian zone, broad sense heritability ranged from 99.97% for fruits per cluster and fruits per plant to 73.49% for days to 50% flowering, whereas in Qatar zone, the value ranged from 99.99% for fruit weight and plant height to 83% for fruit shape index. This indicates presence of considerable genetic variation and thus, these traits may be given special emphasis during tomato improvement programs. In this analysis, although high h2bs estimates were recorded for most of the traits in both agro-climatic zones, they were associated with low genetic advance (Table 3) indicating non-additive gene action and environmental influence, especially in days to marketable maturity, days to 50% flowering and fruit shape index (in Qatar zone).

The findings of present investigation reveal that high heritability accompanied by estimates of GAM% for most of the traits measured, that indicates the selection of genotype based on phenotypic levels would be useful for the improvement of these traits. High heritability with low GA and GA% of various yield-contributing traits has been reported by other researchers in tomato. Mehta and Asati (2008) reported that the highest GCV and PCV with high heritability and genetic advance for plant height. Meena and Bahadur (2014b) also obtained high heritability for plant height which also supports our findings. These findings were in agreement with Dar and Sharma (2011) and Golani *et al* (2007). Mohanty (2002) also found that days to 50% flowering has low heritability and low GA%, which is in support of the present results. Meitei *et al.* (2014). reported high heritability and high GA% in fruit cluster per plant, number of fruit per plant, fruit weight which are similar to our experiment results. Pujari *et al.* (1995) obtained high heritability, high GA% with low genetic gain for fruit yield per plant. Similar resutls were also found by other researchers as well (Ghosh *et al*., 1995; Vinod *et al*., 2003). Therefore traits with high heritability with low GA can be improved by hybridization followed by progeny selection.

Principal component analysis

In the present findings, all the selected traits are considered for principal component analysis, by which two main components were found that explained 98% of total variance in both zones (Table 4). In the Indian zone, the first component (PC1) described 92.56% of the total variation and was positively and highly associated with days to marketable maturity, plant height and fruit weight, whereas, negatively associated with yield per plant, fruit shape index and fruits per cluster*and* therefore, could be called as a vegetative component. The second component axis (PC2) explained 6.1% of the total variability and was positively associated with days to marketable maturity, whereas, for plant height, it was found to be highly negative. The results for the qatar zone followed a similar trend. The PC1 accounted for 96.75% of the total variation and was also positively and highly associated with days to marketable maturity, plant height and fruit weight, whereas, negatively

Table 4: Eigen vectors and total percentage variation for the principal component axes of tomato genotypes evaluated in both agro-climatic zones.

Indian Agro-climatic zone			Qatar Agro-climatic zone		
Groups	PC_1	PC_2	Groups	PC_1	PC_2
DoF	0.6829	0.3557	DoF	0.5735	-0.1157
FPC	-1.4591	-0.1133	FPC	-1.4233	0.05241
FPP	-0.5665	-0.1269	FPP	-0.7794	0.002951
FW	2.1047	-0.0483	FW	2.5613	0.6468
FSI	-1.6796	-0.1065	FSI	-1.6488	0.07494
LPF	-1.5232	-0.1029	LPF	-1.4846	0.02446
PT	-1.3237	-0.03437	PT	-1.2703	0.02332
PH	3.7505	-1.2826	PH	3.9865	0.1084
HD	0.366	0.06494	HD	0.2293	-0.01939
ID	-1.0076	0.0208	ID	-1.0612	-0.04749
DMM	3.6868	0.9736	DMM	3.4935	-0.4495
TSS	-1.48	-0.08987	TSS	-1.4794	0.06418
AA	0.1437	0.6286	AA	-0.02733	-0.4546
FYP	-1.6949	-0.1387	FYP	-1.6696	0.08925
% of variance	92.5607	6.1553	% of Variance	96.7534	1.6856
Cumulative (%)	92.5607	98.716	Cumulative (%)	96.7534	98.439

DoF= Days to 50% flowering; FPC= Number of fruits per cluster; FPP= Number of fruits per plant; FW= Fruit weight (g); FSI= Fruit shape index; LPF= Number of locules per fruit; PT= Pericarp thickness (mm); PH= Plant Height (cm); HD= Harvest duration (days); ID= Internodal distance (cm); DMM= Days to marketable maturity; AA = Ascorbic acid (mg/100 g); TSS (°Brix)= Total soluble solid; FYP= Fruit yield per plant (kg).

associated with yield per plant, fruit shape index and fruits per cluster. The PC2 explained 1.68% of the total variation and was positively related to plant height and fruit weight, whereas, days to marketable maturity and yield per plant was negative. The genetic diversity studies about tomato quantitative traits based on the multivariate analysis using PCA involved days to marketable maturity, plant height, fruit weight as the most discriminating traits

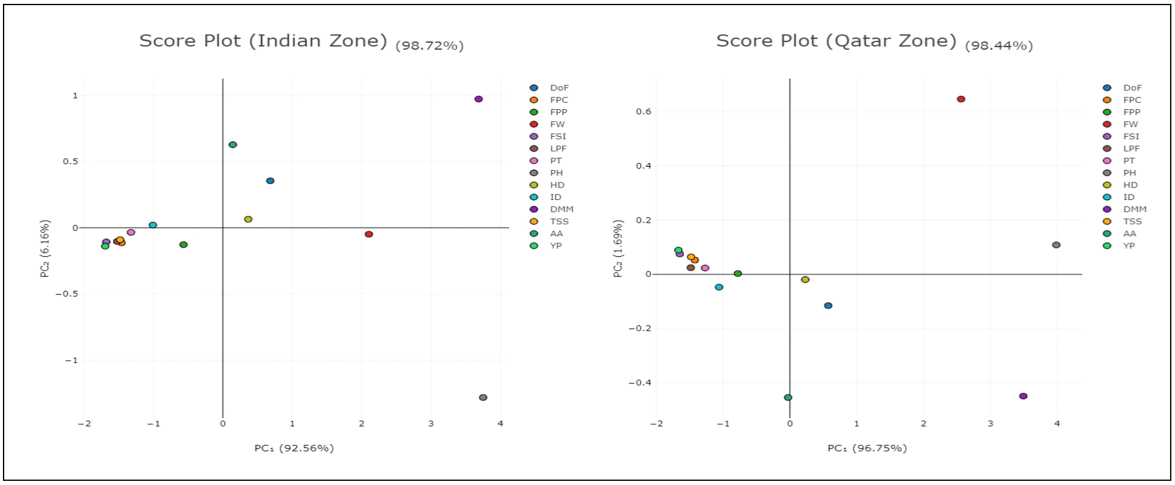


Fig 1: Score plots pf principal components (PC1and PC2) in both zones.

Table 5: Correlation coefficients between different phenotypic traits of tomato genotypes in Qatar.

	PH	DoF	FPC	FPP	FW	A A	TSS	FYP
PH	1	-0.1782	0.3001	-0.2427	-0.1271	0.0549	0.3443	0.0598
DoF		1	-0.2192	0.0216	0.3266	-0.2395	0.2122	-0.264
FPC			1	0.3727	-0.0564	0.1355	0.0366	0.0127
FPP				1	0.0885	0.0601	-0.1827	0.5324*
FW					1	-0.0735	-0.4697*	0.3936
A A						1	0.3484	0.2262
TSS							1	-0.4098
FYP								1

DoF= Days to 50% flowering; FPC= Number of fruits per cluster; FPP= Number of fruits per plant; FW= Fruit weight (g); FSI= Fruit shape index; LPF= Number of locules per fruit; PT= Pericarp thickness (mm); PH= Plant height (cm); HD= Harvest duration (days); ID= Internodal distance (cm); DMM= Days to marketable maturity; AA= Ascorbic acid (mg/100 g); TSS (°Brix)= Total soluble solid; FYP= Fruit yield per plant (kg).

Table 6: Path coefficient analysis for direct effect of phenotypic traits on yield of tomato (FYP) Qatar agro-climatic zone.

	PH	DoF	FPC	FPP	FW	A A	TSS
PH	1.2223	-0.2178	0.3668	-0.2966	-0.1554	0.0671	0.4209
DoF	0.0502	-0.2816	0.0617	-0.0061	-0.092	0.0675	-0.0598
FPC	-0.0046	0.0033	-0.0152	-0.0057	0.0009	-0.0021	-0.0006
FPP	-0.2345	0.0209	0.3602	0.9664	0.0855	0.0581	-0.1766
FW	0.2502	-0.6428	0.111	-0.1741	-1.968	0.1446	0.9243
A A	0.0539	-0.2351	0.133	0.059	-0.0721	0.9816	0.342
TSS	0.0146	0.009	0.0016	-0.0078	-0.0199	0.0148	0.0425
FYP	0.0598	-0.264	0.0127	0.5324	0.3936	0.2262	-0.4098

DoF= Days to 50% flowering; FPC= Number of fruits per cluster; FPP= Number of fruits per plant; FW= Fruit weight (g); FSI= Fruit shape index; LPF= Number of locules per fruit; PT= Pericarp thickness (mm); PH= Plant height (cm); HD= Harvest duration (days); ID= Internodal distance (cm); DMM= Days to marketable maturity; AA= Ascorbic acid (mg/100 g); TSS (°Brix)= Total soluble solid; FYP= Fruit yield per plant (kg).

in both zones explaining greater variability in tomato (Fig 1).

Correlation and path coefficient analysis

Correlation studies and path coefficient analysis were carried out for phenotypic traits of genotypes in Qatar climatic zone (Table 5,6). Number of fruits per plant and fruit width had significant positive correlation with fruit yield per plant. Number of fruits per cluster and ascorbic acid had significantly positive association with number of primary branches per plant and days to 50% flowering. Number of fruits per plant had negative correlation with acidity. Fruit weight had negative correlation with TSS. Ascorbic acid had negative association with TSS. Similar type of results was tabulated by several other researchers (Kumar *et al*., 2006; Dhankhar and Dhankar, 2006; Singh *et al*, 2007; Singh, 2009; Kumar and Dudi, 2011).

The path coefficient studies (Table 3) revealed that plant height (PH), number of fruits per plant (FPP) and ascorbic acid (AA) had high positive direct effects on fruit yield per plant (FYP). High negative direct effects on fruit yield per plant had been observed for days to 50% flowering (DoF), fruits per cluster (FPC) and fruit weight (FW). The results are in accordance with the conclusions of other workers (Asati *et al*., 2008; Kumar and Thakur, 2007).

The above information revealed that highly significant positive correlation with highest positive direct effect was observed in days to 50% flowering, days to marketable maturity and fruits per plant which can be considered as selection criteria for improvement in tomato production in Qatar.

CONCLUSION

Considering the scale of demand, majority of the farms operating in Qatar produce tomatoes. An increased cultivated land area under tomatoes indicates higher relative preference for their production, both in open field and greenhouses. Primary research revealed an increasing affinity of Qatari population towards locally produced fresh and organic produce. This shift in preferences has also led to high demand (and consequently, high production) of locally produced tomatoes, especially those grown under greenhouses. Evaluation of phenotypic performance of genotypes before release of varieties in market is shown to be scientifically valid by many authors. In the present study, the results showed a significant difference among the material assessed for all the traits. Considering the mean performance of qualitative traits such as fruit yield, ascorbic acid content and TSS, genotypes EC620534 and EC620380 performed remarkably well under Qatar agro-climatic conditions. Hence, it is suggested these genotypes are suitable for cultivation in India and Qatar and should be characterized using molecular markers such as SSR, RFLP *etc*. to investigate environmental influence on yield. The trait which expressed high heritability and low genetic gain (days to marketable maturity, fruit shape index and fruit width) showed non additive gene interaction, hence heterosis breeding is recommended for these traits. The variation of days to marketable maturity, plant height, fruit weight were high in the principal axes. The correlation analysis showed that fruit yield per plant was positively and significantly correlated with number of fruits per plant and fruit width. So, by improving these traits yield can be significantly increased. These observation suggests that these traits are major traits explaining most of the variations in tomato and further contributing to total yield in the tomato genotypes.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the authorities of Shobhit Institute of Engineering and Technology, Deemed to-be-University, Meerut for providing the facilities for field trial.

Conflict of interest

The authors declare that they have no conflict of interests.

REFERENCES

Abrar, H.S., Shams, U.M., Noor, U.A., Safdar, H.S. (2011). Evaluation of two nutrient solutions for growing tomatoes in a noncirculating hydroponics system. J. Agri. 27(4): 558- 567.

Ahmad, F., Obedullah, K., Sarwar, S., Hussain, A. and Ahmad, S. (2007). Evaluation of tomato cultivars at high altitude. Sharad J Agri. 1984. 23: 312-14.

Akinfasoye, J., Dotun, A., Ogunniyan, J.and Ajayi, E.O. (2011). Phenotypic relationship among agronomic characters of commercial tomato (*Lycopersicum esculentum*) hybrids. American-Eurasian J. Agronomy. 4(1): 17-22.

Anuradha, B., Saidaiah, P., Ravinder Reddy, K., Harikishan Sudini, Geetha, A.(2021). Mean performance of 40 genotypes in tomato (*Solanum lycopersicum* L.). International Journal of Chemical Studies. 9(1): 279-283.

Anuradha, B., Saidaiah, P., Sudini, H., Geetha, A. and Ravinder Reddy, K. (2018). Correlation and path coefficient analysis in tomato (*Solanum lycopersicum* L.). Journal of Pharmacognosy and Phytochemistry. 7(5): 2748-2751.

AOAC, (1984) Methods of Analysis of Association of Official Analytical Chemist, Washington D.C., U.S.A.

Asati, B.S., Rai, N. and Singh, A.K. (2008). Genetic parameters study for yield and quality traits in tomato. The Asian Journal of Horticulture. 3(2): 222-225.

Asiya, K.R., Amarananjundeswara, H., Aravinda, J.S., Doddabasappa B., Veere Gowda, R. (2017). Performance of garlic (*Allium sativum* L.) genotypes for growth and yield traits under Eastern Dry Zone of Karnataka. J. Phar. Phyt. 12(1): 213-216.

Burton, G.W. (1952). Qualitative Inheritance in Grasses. Proceedings of the 6th International Grassland Congress, Pennsylvania State College. 17-23 August. Pennsylvania State College, Pennsylvania, USA. 1: 277-283.

Burton, W.G. and deVane, E.W. (1953). Estimating heritability in tall fescue (*Festuca arundinace*) from replicated clonal material. Proejtunniens. 9(22): 12-15.

Campbell, S.L., Chancelier, J.P., Nikoukhah, R., Campbell, S.L., Chancelier, J.P. and Nikoukhah, R., (2010). Modeling and Simulation in SCILAB. Springer New York. pp. 73-106.

Das, R.A., Sharma, J.P. (2011). Genetic variability studies of yield and quality traits in tomato (*Solanum lycopersicon* L.). International Journal of Plant Breeding and Genetics. 5: 168-174.

Das, R.A., Sharma, J.P. (2012). Nabi, A., Chopra, S., Germplasm, evaluation for yield and fruit quality traits in tomato (*Solanum lycopersicon* L.). Afr. J Agri. Res. 7(46): 6143-6149.

Dhankhar, S.K. and Dhankar, S.S. (2006). Variability, heritability, correlation and path coefficient studies in tomato. Haryana Journal of Hortcultural Science. 35(1 and 2): 179-181.

Eshteshabul, M., Hakim, M.A., Amanullah, A.S.M., Ahsanullah, A.S.M. (2010). An Assessment of physiochemical properties of some tomato genotypes and varieties grown at Rangnur. Ban. Res. Pub. J. 4(3): 135-243.

FAOSTAT (2022) Online Database (available at http://faostat.fao.org/ accessed January 2023).

Foolad, M.R. (2007). Genome mapping and molecular breeding of tomato. International Journal of Plant Genomics. 28: 64358.

Ghosh, P.K., Symal, M.M., Rai, N., Joshi, A.K. (1995). Improvement of hybrid tomatoes. Advanced Plant Science. 2: 207-2013.

Golani, I., Mehta, D., Purohit, V., Pandya, H., Kanazariya, M. (2007). Genetic variability, correlation and path coefficient studies intomato. Indian Journal of Agricultural Research. 41(2): 146-149.

Jabborova, D., Mamarasulov, B., Davranov, K., Enakiev, Y., Bisht, N., Singh, S., Stoyanov, S. and Garg, A.P. (2024). Diversity and plant growth properties of rhizospheric bacteria associated with medicinal plants. Indian Journal of Microbiology. 64: 409-417. https://doi.org/10.1007/s12088-024-01275-w.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. (1955). Estimation of genetic and environmental variability in soybean. Agronomy Journal. 47: 314-318.

Kaur, C., Walia, S., Nagal, S., Walia, S., Singh, J., Singh, B.B., Saha, S., Singh, B., Kalia, P. and Jaggi, S. (2013). Functional quality and antioxidant composition of selected tomato (*Solanum lycopersicon* L) cultivars grown in Northern India. LWT-Food Science and Technology. 50 (1): 139-145.

Kaushik, S.K., Tomar, D.S., Dixit, A.K. (2011). Genetics of fruit yield and its contributing characters in tomato (*Solanum lycopersicon*) Journal of Agricultural Biotechnology and Sustainable Development. 3: 209-213.

Khan, A.S.M.M.R., Kabir, M.Y. and Alam, M.M. (2009). Variability, correlation, path analysis of yield and yield components of pointed gourd. Journal Agricultural Rural Development. 7(1-2): 93-98.

Kumar, M. and Rana, M.K., (2018). Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for yield and yield attributing characters in semi arid zone of Haryana (Hisar). Journal of Pharmacognosy and Phytochemistry. 7(1): 1605-1608.

Kumar, M. and Dudi, B.S. (2011). Study of correlation for yield and quality characters in tomato (*Lycopersicon esculentum* Mill.). Electronic Journal of Plant Breeding. 2(3): 453-460.

Kumar, R., Kumar, N., Singh, J. and Rai, G.K. (2006). Studies on yield and quality traits in tomato. Vegetable Science. 33(2): 126-132.

Kumar, R. and Thakur, M.C. (2007). Genetic variability, heritability, genetic advance, correlation coefficient and path analysis in tomato. Haryana Journal of Horticultural Science. 36(3 and 4): 370-373.

Lynch, M., Walsh, B. (1998). Genetics and Analysis of Quantitative Traits. Sinauer Associates Inc. Sunderland, Massachusetts. 823-831.

Manna, M., Paul, A. (2012). Studies on genetic variability and character association of fruit quality parameters in tomato. Hort. Flora Res. Spectrum. 1(2): 110-116.

Meena, O.P., Bahadur, V. (2014). Assesment of genetic variability, heritability and genetic advance among tomato (*Solanum lycopersicum* L.) germplasm. Agricultural Science Digest. 27:185-192.

Meitei, K.M., Bora, G., Singh, S.J., Sinha, A.K. (2014). Morphology based genetic variability analysis and identification of important characters for tomato (*Solanum lycopersicum* L.) crop improvement. Journal of the American Society for Horticultural Science. 86: 114-119.

Mehta, N., Asati, B.S. (2008). Genetic relationship of growth and development traits with fruit yield in tomato (*Lycopersicon esculentum* Mill.). Karnataka J Agri. Sci. 21(1): 92-96.

Mohamed, S., Ali, E., Mohamed, T. (2012). Study of heritability and genetic variability among different plant and fruit characters of tomato (*Solanum lycopersicon* L.). International Journal of Scientific and Technology Research. 1: 55-58.

Mohanty, B.K. (2002). Studies on variability, heritability, interrelationship and path analysis in tomato. Annals of Agricultural Research. 23: 65-69.

Mounika, B., Goud, C.R., Holajjer, P., Saidaiah, P. and Nayak, M.H., (2020). Growth and resistance response of tomato genotypes to root-knot nematode, Meloidogyne incognita. Indian Journal of Plant Protection. 48(3): 210-216.

Nalla, M.K., Pandav, A.K., Aslam, T.A.R.I.Q.U.E. and Rana, M.K., (2016). Studies on variability, heritability and genetic advance in tomato (*Solanum lycopersicon* L.). Advances in Life Sciences. 5(4): 1536-1539.

Panse, V.G., Sukhamte, P.V. (1967). Statistical Methods for Agricultural Workers, ICAR.

Pujari, C.V., Wagh, R.S., Kale, R.N. (1995). Genetic variability and heritability in tomato. Maharastra Journal of Agricultural University. 20: 15-17.

Sankari, A., (2000). Ph.D. Thesis, Tamilnadu Agricultural University, Coimbatore, India.

Searle (1961). Genotypic and environmental variance and covariance in an upland cotton crops of interspecific origin. Agronomy Journal. 50: 633-636.

Sharma, J.R. (1988). Statistical and Biometrical Techniques in Plant Breeding. New Age International Limited Publishers, New Delhi, India. 432 p.

Shashikant, B.N., Hosamani, R.M., Patil, B.C. (2010). Genetic variability in tomato (*Solanum lycopersicum* L.). Karnataka J. Agri. Sci. 23(3): 536-537.

Singh, A.K. (2009). Genetic variability, heritability and genetic advance studies in tomato under cold arid region of Ladakh. Indian Journal of Horticulture. 66(3): 400-403.

Singh, J., Rai, M., Kumar, R., Prasanna, H.C., Verma, A., Rai, G.K. and Singh, A.K. (2007). Genotypic variation and hierarchical clustering of tomato (*Solanum lycopersicum*) based on morphological and biochemical traits, Vegetable Science. 34(1): 40-45.

Solieman, T.H.I., El-Gabry, M.A.H. and Abido, A.I., (2013). Heterosis, potence ratio and correlation of some important characters in tomato (*Solanum lycopersicum* L.). Scientia Horticulturae. 150: 25-30.

Sushma, K., Saidaiah, P., Sudini, H., Geetha, A. and Ravinder, K., (2021). Per SE performance of tomato (*Solanum lycopersicum* L.) germplasm for yield and yield attributes. The Pharma Innovation Journal. 10(5): 854-858.

Swaroop, K., Suryanarayana, M.A. (2005). Evaluation of tomato varieties and lines for growth, yield, quality and bacterial wilt resistance under the coastal tropical condition of the Andaman Islands. Trop. Agri. 82: 294-299.

Qatar Development Bank (QDB) Report (qdb.qa/en/Documents/QDB_Agriculture%20Report.pdf, accessed on March 2023)

Turhan A, Ozmen N, Serbeci MS, Seniz V. (2011). Effects of grafting on different rootstocks on tomato fruit yield and quality. Hort. Sci. 38(4): 142-149.

Vilas, C.A., Rana, M.K., Dhankar, S.K., Kumar, V. and Yadav, N., (2015). Studies on combining ability analysis for yield and yield related traits in tomato (*Solanum lycopersicum* L.). Enzyme Eng. 4: 133.

Vinod, K.R., Nandan, K.R., Srivastava, S.K., Sharma, R., Kumar, A. (2013). Genetic parameters and correlation study for yield and quality traits in tomato (*Solanum lycopersicum* L.). Plant Archives. 13: 463-467.