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RESEARCH ARTICLE

# Characterization, Diversity Analysis and Stability Testing of Extant Tomato Cultivars for Pheno-morphological Traits

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Tomato (*Solanum lycopersicum* L.), is cultivated globally. Its cultivation faces several problems such as shrinking genetic diversity, morphological variability and stability. Therefore, a study was conducted to characterize, classify, assess the diversity and test stability in 100 extant cultivars of tomato for 35 pheno-morphological traits. Data were recorded on the basis of distinctiveness, uniformity and stability test guidelines of tomato. All the cultivars exhibited distinct and uniform characters. The 100 cultivars of tomato were grouped into five major clusters based on their characteristics in the coefficient range of 0.48-1.00. In the stability test analysis, interaction of cultivars and environment was significant for various morphological characteristics. These traits were stability in most of the cultivars across different environments. The characterized pheno-morphological traits in study would be helpful for creating a database on tomato.

**Key Words : DUS testing, Genetic diversity, Morphological traits, Stability analysis, Tomato**

## Introduction

Tomato (*Solanum lycopersicum* L.), is cultivated globally as annual and a well-studied crop for variety development (Peralta and Spooner, 2000). It belongs from large and diverse family of *Solanaceae*, which have more than three thousand species (Bauchet and Causse, 2012). Today, a drastic reduction found in genetic diversity of tomato by which these crop has faced several jams over the years, it may be due to its origin, domestication, and morpho-physio-chemical variability etc. (Peralta and Spooner, 2000; Scintu *et al.*, 2014; Athinodorou *et al.*, 2021).

Tomato fruits have rich source of antioxidant biomolecules *viz.*, lycopene, betacarotene, provitamin-A, carotenoid, ascorbic acid, phenolics, flavonoids and vitamin E. Lycopene is the major carotenoid in tomato fruit with the nutraceutical properties related to a powerful anti-oxidant which can reduce the risk of cancers, heart diseases, age-related diseases and increase the glow on human face (Giovannucci, 1999; Shi and LeMaguer, 2000; Nasir *et al.*, 2015). Besides lycopene a class of pigment anthocyanins is also available in tomato which protects to human body by serious diseases and showed a significant extension of life span (Rick *et al.*, 1994; Andersen, 2001; Lazze *et al.*, 2004; Butelli *et al.*, 2008). The skin colour pigments of cultivated tomato are mainly found in three types, red, yellow and tangerine due to the complex mixtures of carotenoid pigments (Fraser *et al.*, 1994). The red-fruited tomatoes hold several carotenoid pigments and sufficient amount of lycopene (Shi and LeMaguer, 2000; Nasir *et al.*, 2015). The yellow tomatoes have low total content of carotenoid pigments and small quantities of lycopene but this is most important natural source, directly or indirectly of vitamin A. While, the tangerine colour of tomato closely related to orange carotenoid pigment as pro-lycopene (Fraser *et al.*, 1994; Shi and LeMaguer, 2000). Earlier it has been reported that the red colour in tomato fruits is due to the degradation of chlorophyll and synthesis of lycopene because that time chloroplasts are converted into chromoplasts (Fraser *et al.*, 1994; Shi and LeMaguer, 2000; Camelo and Gomez, 2004). Fruit shape and size along with quality traits like pericarp thickness, number of locules, firmness of fruit and total soluble solid are major issues for public interest (Osei *et al.*, 2014).

Besides the multiuse of tomato fruits, the leaves, stems and flowers also have high economic value in ecosystem (Osei *et al.*, 2014). There was a strong positive relationship between plant growth and fruit yield. Stem growth rate of plants are also a reason of

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total stomatal number. Similar scope for high yield and high stomatal density were found in broad leaf area because stomata facilitate photosynthesis procedure in plants (Li *et al.,* 2014). A myth about leaves and stems of many nightshade plants are poisonous containing toxic alkaloid and solanine but tomato is not one of them (http://www.thekitchn.com/fresh-tip-use-tomato-leaves-to-123288). In this self-pollinated crop flowers are appearing on apical meristem with size of 1-2 cm in yellow colour (https://en.wikipedia.org/wiki/Tomato).

The morphological traits of cultivated tomatoes are easily altered by environmental conditions (Osei *et al.*, 2014; Mahbubar *et al.*, 2020) because morphological description and classification is a traditional approach to elucidate the economic importance of tomato. Due to their widespread use in many centuries, the conserved tomato cultivars save diversity of the species thereby comprising a precious genetic material for selection and breeding. Breeders are devoted in utilizing the tomato cultivars from different locations in order to develop improved varieties with high nutritional value and stable yield potential. The stability test has indicated the inert nature of phenotypic and genetic characters of tomato under different climates (Spaldon *et al.*, 2017). The quantitative traits of stable genotypes depended upon level of genotype × environmental interaction (Kumar *et al.,* 2013). The environmental interactions between genotypes and stability in morphological traits are important in selection of better varieties along with yield capacity for improvement of varieties in different environments (Singh *et al.*, 2015a; Spaldon *et al.,* 2017; Athinodorou *et al*., 2021). Since, on the basis of best of my knowledge limited literatures published with huge morphological traits in tomato on a single platform. This study will provide sufficient fictions on tomato and may be helpful for students and researchers. Therefore, the objective of this study was to classify the extant cultivars of tomato on the basis of distinct pheno-morphological traits for analysing the distinctiveness, uniformity and stability and to identify the divers and stable cultivars for developing new varieties of tomato.

## Materials and Methods

### *Plant materials and transplanting*

A total of hundred extant cultivars of tomato developed through different pedigree (Table 1**)** and obtained from many research institutes, SAUs (State Agricultural Universities) and CUs (Central Universities) across the India, and maintained at the vegetable research experimental field of DUS testing, ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, U.P., India. For observation of pheno-morphological characteristics a total 150 tomato plants of each cultivar were transplanted in three replications (50 plants in each) in randomized block design during main cropping season September to March of 2013, 2014, 2015 and 2016. The spacing was maintained at 60 cm × 60 cm (line to line and plant to plant). All cultural practices and crop protection management were applied for surviving healthy crops.

### *Data observation*

Data was recorded from each replication (avoiding the border rows) at quantified growth stages of crop when the specified characters had on full expression (PPV&FRA, 2009). For the measurement of colour characteristics, the latest Royal Horticultural Society (RHS) colour chart was used. Observations of seedling, plants, leaves, flowers and fruits were recorded from the stages of cotyledon completely unfolded to harvest maturity of fruits. The data was recorded of 35 botany based characters as discussed in descriptor of distinctiveness, uniformity and stability (DUS) guidelines of tomato (PPV&FRA, 2009). Growth stages recorded on specific characteristic codes, e.g., 'code 10' on cotyledons completely unfolded (seedling: anthocyanin colouration of hypocotyl), 'code 20' on active vegetative growth before flowering (leaf: intensity of green colour), 'code 30' on appearance of first flower flush (stem characteristics), 'code 40' on 50% flowering (leaf and flower characteristics), 'code 50' on first harvest stage (number of inflorescence on main stem), 'code 60' on fruit fully developed before colour break (fruit colour and intensity before maturity), 'code 70' on harvest maturity (fruit characteristics) from different types of assessment group (Table 1-3) as prescribed in DUS guidelines of tomato (PPV&FRA, 2009).

**Leaf area index (leaf size):** Leaf area index was calculated by dividing leaf length from leaf width (Singh *et al*., 2015b). Leaf area index was measured by scales <1cm=small, 1-2cm=medium and >2cm=large. These scales were indicated to leaf length (<25cm=short, 25-30cm=medium,>30cm=long) and leaf width (<15cm=narrow, 15-20cm=medium, >20cm=broad).

**Leaflet area index (leaflet size):** Leaflet area index was calculated by dividing leaflet length from leaflet width (Singh *et al.*, 2015b). Leaflet area index was measured by scales <1cm=small, 1-2cm=medium and

**Table 1. Details of 100 extant cultivars of tomato**

| Name of extant cultivars | Pedigree of extant cultivars | Origin centre where from seed received |
|---|---|---|
| Ageta-32 | Selction | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| ALT-4-19 | Pure line selection | Anand Agricultural University (AAU), Anand, Gujarat, India |
| Anand Tomato-3 (AT-3) | Mahabaleshwar-2 × Sel.-7 | Anand Agricultural University (AAU), Anand, Gujarat, India |
| Anand Tomato-4 (AT-4) | Pure line selection | Anand Agricultural University (AAU), Anand, Gujarat, India |
| Angha (LE-415) | Pure line selection | Kerala Agricultural University (KAU), Vellanikkara, Thrissur, Kerala, India |
| Angoorlata (Kalyanpur) | Selection from local germplasm | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Arka Abha | Selection from IIHR 663-12-3-SB-SB (VC-8-1-2-1) from AVRDC, Taiwan | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Ahuti (Sel 11) | Selection from IIHR 143-3-7-SB-1 (Ottawa 60 from Canada) | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Alok | Selection from IIHR 719-1-6 (CL-114-5-1-0) from AVRDC, Taiwan | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Ashish (IHR674SBSB) | Improvement over UC83 B from California | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Meghali | Arka Vikash x IIHR-554 | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Saurabh (Sel-4) | Selection from V-685 (Canadian line) | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Arka Vikash (Sel-22) | Selection from American introduction (Tip Top) | ICAR-Indian Institute of Horticultural Research (IIHR), Hessaraghatta lake post, Bangalore, Karnataka, India |
| Azad T-2 (KS-2) | HB-5 × Kuber | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Azad T-3 | Pure line selection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Azad T-4 | Pure line selection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Azad T-5 (KS-17) | Pure line selection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Azad T-6 (KS-118) | Pure line selection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Azad T-8 | Pure line selection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Best of All | Introduction from American line | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Bhagyashree | Selection from local germplasm | Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India |
| BT-11 | Pure line selection | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| BT-136 | Pure line selection | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| CO-3 (Marutham) | Induced mutant from CO-1 | Tamil Nadu Agricultural University (TNAU), Coimbatore, India |
| Colambia | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| CTS-06 | Selction | Sher-e-Kashmir University of Agricultural Sciences and Technology (SKUAS&T), Jammu, India |
| DARL-68 | EC-386032 × BL-342 | Defence Agricultural Research Laboratory (DARL), Pithoragarh, Uttarakhand, India |
| DCT-1 | Selction | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| DCT-2 | Selction | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Dhanshree | 407 DPDBK × LA-124 | Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra, India |
| Dhrubya | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| DMT-1 | Selction | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |

| Name of extant cultivars | Pedigree of extant cultivars | Origin centre where from seed received |
|---|---|---|
| Feb-2 | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| Flora Dade | Open pollinated and heirloom variety | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| Gujarat Tomato-1 (GT-1) | Angoorlata x Punjab Chhuhara | Junagadh Agricultural University (JAU), Junagadh, Gujarat, India |
| Gujarat Tomato (GT-2) | Angoorlata × Punjab Chhuhara | Anand Agricultural University (AAU), Anand, Gujarat, India |
| Hisar Anmol (H-24) | Hisar Arun × *L.hirsutumf.glabratum* | Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, India |
| Hisar Arun (Sel-7) | Pusa Early Dwarf × K-1 | Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, India |
| Hisar Lalit (NT-8) | HS-101 × Resistant Banglore | Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, India |
| JT-3 | Pure line selection | Junagadh Agricultural University (JAU), Junagadh, Gujarat, India |
| Kalyanpur T-1 | Selection from local collection | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Kalyanpur T-3 | Type 1 × KS-2 (through pedigree method) | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Kashi Adarsh | Pedigree & marker assisted selection from Indam 2013 × Vaibhav | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Aman | Backcross pedigree of Sel-7 x *L. Hirsutam f. Glabratum* B6013 | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Amrit | Backcross pedigree of Sel-7 × *L. Hirsutam f. Glabratum* B6013 | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Anupam | Sel-7 × *L. Hirsutum f. Glabratum* B6013 | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Chayan | Selection from RILs of H-86 × H-88-78-2 | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Hemant (IIVR Sel-1) | Sel-18 × Flora Dade | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Sharad (IIVR Sel-2) | MTH-6 x Kalyani Eunish | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashi Vishesh | Selection using *S. habrochaites f. glaboratum* (B-6013) as donar parent (back cross) | ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi, Uttar Pradesh, India |
| Kashmiria | Introduction from exotic collection | ICAR-ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| KS-16 | 5414 × Type 1 (through pedigree method) | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| KS-7 | Punjab Chuhara × 7019 (Selection through pedigree method) | Chandra Shekhar Azad University of Agriculture and Technology (CSAU&T), Kanpur, Uttar Pradesh, India |
| Manileima (Sel-2) | Pure line selection | ICAR-Research Complex for North Eastern Hill Region (ICAR RC NEH), Umiam, Meghalaya, India |
| Marglobe | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| Mukthi (LE-79-5) | Selection from LE79 (CL32D-0-1-19GS) | Kerala Agricultural University (KAU), Vellanikkara, Thrissur, Kerala, India |
| NDT-1 | Selection | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-2 | Developed from EC 119201 | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-3 | Resistant Bangalore × Kalyanpur Kuber | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-4 | Pusa Ruby × Kalyanpur Kuber | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-5 | Selection from EC 130041 | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-7 | Selection | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |

| Name of extant cultivars | Pedigree of extant cultivars | Origin centre where from seed received |
|---|---|---|
| NDT-8 | Selection | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDT-9 | Pusa Ruby × Kalyanpur Kuber | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| NDTVR-73 | Selection | Narendra Dev University of Agriculture and Technology (NDUA&T), Faizabad, Uttar Pradesh, India |
| Pant T-3 | Pure line selection | Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Uttarakhand, India |
| Pant T-5 | Pure line selection | Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Uttarakhand, India |
| Patharkuchi | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| PNR-7 | Sel-12 × NMR-1 | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Prestige | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| PT-11 | Selection | Govind Ballabh Pant University of Agriculture and Technology (GBPUA&T), Pantnagar, Uttarakhand, India |
| Punjab Varkha Bahar-1 | Pedigree selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Punjab Varkha Bahar-2 | Pedigree selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Punjab Chhuhara | Introduction from Israel and Shimla Gold | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Punjab Keshari | Punjab Tropic × EC 55055 | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Punjab Ratta | Pedigree selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Punjab Upma | Pedigree selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Pusa Gaurav | Glamour × Watch | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Pusa Ruby | Selection from Sioux × Improved Meruthi | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Pusa Upma | Pedigree selection | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Pusa-120 | Selection from introduction | ICAR-Indian Agricultural Research Institute (IARI), Hill Side Road, Pusa, New Delhi, India |
| Roma | Introduction from exotic collection | ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| Sel-12 | Selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Sel-18 | Selection | Punjab Agricultural University (PAU), Ludhiana, Punjab, India |
| Sioux | Introduction from exotic collection | ICAR-ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa campus, New Delhi, India |
| Solan Lalima | Pure line selection | Dr.Yashwant Singh Parmar University of Horticulture and Forestry (DYSPUH&F), Solan, Himachal Pradesh, India |
| Solan Vajra | Pure line selection | Dr.Yashwant Singh Parmar University of Horticulture and Forestry (DYSPUH&F), Solan, Himachal Pradesh, India |
| Swarna Deepti | Pedigree selection | ICAR-Horticulture and Agro-forestry Research Programme (HARP), Ranchi, Jharkhand, India |
| Swarna Gola | Pure line selection | ICAR-Horticulture and Agro-forestry Research Programme (HARP), Ranchi, Jharkhand, India |
| Swarna Lalima | Pure line selection | ICAR-Horticulture and Agro-forestry Research Programme (HARP), Ranchi, Jharkhand, India |
| Swarna Naveen | Pure line selection | ICAR-Horticulture and Agro-forestry Research Programme (HARP), Ranchi, Jharkhand, India |
| Utkal Upahar (BT-120) | Selection | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Utkal Deepti (BT-2) | Selection | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Utkal Kumari (BT-10) | Sel-22 × BT-2 | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Utkal Pragyan (BT116-3-2) | Sel- 4 × BT- 1 | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Utkal Raja (BT-20-2-1) | Azad Kirti × BWR- 5 | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |

| Name of extant cultivars | Pedigree of extant cultivars | Origin centre where from seed received |
|---|---|---|
| Utkal Urvashi (BT-12) | Punjab Chhuhara × LE-79 | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Utkal Pallavi (BT-1) | Punjab Chhuhara X AC- 142 | Orissa University of Agriculture and Technology (OUA&T), Bhubaneswar, Odisha, India |
| Vaibhaw | Pure line selection | University of Agricultural Sciences (UAS), Bangalore, Karnataka, India |
| VL Tamatar-4 | Introduction and selection from AVRDC line CL 5915-206 (EC 461691) | ICAR-Vivekanand Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora-263601 (Uttarakhand), India |

**Table 2. Analysis of variance for stability analysis in 36 extant cultivars of tomato under different environments for 10 morphological traits (SLI, LL, LW, TF, AFW, FL, FD, FTP, FLN, TFM)**

| Source of Variation | DF | SLI | LL | LW | TF | AFW | FL | FD | FTP | FLN | TFM |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | 35 | 273.60** | 112.40** | 63.05** | 81.28** | 1828.74** | 4.15** | 3.36** | 0.88** | 3.36** | 212.98** |
| Environment | 3 | 249.31** | 10.90** | 10.13** | 316.48** | 94.16** | 1.00** | 1.13** | 242.32** | 1.60** | 622.27** |
| Var. × Envion. | 105 | 0.39** | 0.01* | 0.01* | 0.04* | 0.21** | 0.02* | 0.05* | 0.20** | 0.00** | 0.06* |
| Env + Var × Env | 108 | 7.30** | 0.32** | 0.29** | 8.83** | 2.82** | 0.03* | 0.03** | 6.93** | 0.05** | 17.35** |
| Env (Linear) | 1 | 747.93** | 32.70** | 30.40** | 949.43** | 282.48** | 3.01** | 3.39** | 726.97** | 4.79** | 1866.82** |
| Env × Var (Lin) | 35 | 1.16** | 0.04* | 0.03* | 0.11* | 0.62** | 0.01* | 0.02* | 0.61** | 0.01** | 0.19** |
| Pooled Deviation | 72 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Pooled Error | 280 | 5.87 | 2.02 | 10.91 | 5.94 | 2.17 | 0.07 | 0.08 | 0.04 | 0.03 | 11.96 |

*,**Significance Levels at P=<0.05, P=<0.01; **DF**= Degree of freedom; **SLI**=Stem: Length of internode between 1st and 4th inflorescence (cm); **LL**=Leaf length (cm); **LW**=Leaf width (cm); **TF**=Time of flowering (50% of the plants with at least one open flower from seed sowing) (days); **AFW**=Average Fruit Weight (g); **FL**=Fruit length (cm); **FD**=Fruit diameter (cm); **FTP**=Fruit thickness of the pericarp (cm); **FLN**- Fruit locule number; **TFM**= Time of fruit maturity (from seed sowing) (days).

>2cm=large. These scales were indicated to leaflet length (<5cm=short, 5-10cm=medium, >10cm=long) and leaflet width (<4cm=narrow, 4-6cm=medium, >6cm=broad).

**Fruit size:** Fruit size was determined on the basis of average weight of 10 fruits as given in DUS descriptor e.g., <100g=very small, 100-200g=small, 201-700g=medium, large=701-1000g, very large=>1000g.

### *Genetic diversity*

For analyzing the genetic diversity a dendrogram was constructed by using 100 extant cultivars of tomato (Table 1) based on 32 morphological characters (Figure 1). Cluster analysis constructed on the basis of Euclidian distance coefficient and unweighted pair-group method of arithmetic means (UPGMA) by using the SAHN program in numerical taxonomy and multivariate analysis system (NTSYS-PC software) version 2.11s (Rohlf, 2005).

### *Stability test analysis*

To analyse the data over four environments the stability model was used for isolation of the stable genotypes from ten yield related morphological traits *viz.*, Stem length of internode between 1st and 4th inflorescence (SLI), Leaf length (LL), Leaf width (LW), Time of flowering at 50% of the plants with at least one open flower from seed sowing (TF), Average Fruit Weight (AFW), Fruit length (FL), Fruit diameter (FD), Fruit thickness of the pericarp (FTP), Fruit locule number (FLN), Time of fruit maturity from seed sowing (TFM). Among the 100 extant cultivars of tomato only 36 were selected for the stability test on the basis of better yield related morphological traits. The data was analysed on genotypes × environmental interaction model proposed by Eberhart and Russell (1966).

## Results

### *Pheno-morphological characterization*

#### *Seedling, stem and leaves*

Observation of pheno-morphological characteristics of seedling, stems and leaves of 100 extant cultivars of tomato were presented in Supplementary Table 1. A total 96 extant cultivars of tomato were initiated anthocyanin colouration of hypocotyls on their seedlings. However, after transplanting and vigorous growth of plants the anthocyanin colouration was displayed on upper third portion of stem in 79 cultivars with different intensity like, weak (29), medium (40) and strong (10) (Supplementary Table 1). Although, in present study the determinate and indeterminate nature of plant growth habit of tomato were observed in 49 and 51 cultivars, respectively. Whereas, in another finding all the extant cultivars were present the pubescence (hairs or trichomes) on their stem (Supplementary Figure 1) excluding 'Hisar

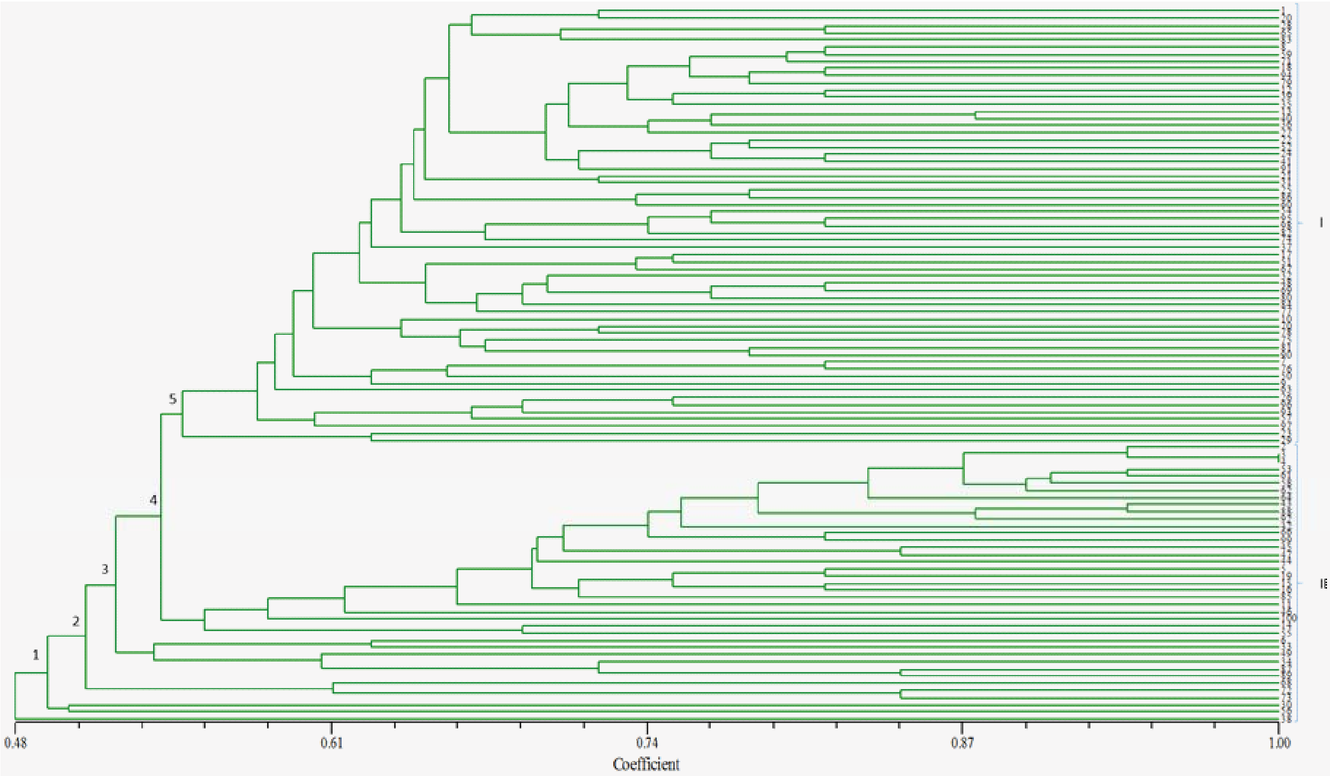


**Fig. 1. Unweighted Pair Group Method with Arithmetic mean (UPGMA) dendrogram (with Euclidean distance coefficient) of generated by 100 extant cultivars of tomato based on 32 pheno-morphological characters [1-100 extant cultivar's order as mentioned in Table 1]**

Anmol' (Supplementary Table 1). Intensity of green colour in tomato leaves was recorded in three categories light, medium and dark of 16, 62 and 22 extant cultivars, respectively (Supplementary Table 1). In present study it was observed that 22, 74 and 4 tomato cultivars were displayed short, medium and large in leaf and leaflet size (Supplementary Figure 2). Similarly, leaf structure of 100 cultivars categorized into open (22), intermediate (71) and closed (7). While, leaflet serration was classified in 5 (absent or potato type), 79 (less serrated) and 16 (highly serrated) cultivars. However, the attitude of leaf and leaflet in relation to main stem or axis were observed semi-erect, horizontal and drooping in 68, 9 and 23 cultivars of tomato, respectively (Supplementary Table 1).

*Flowers*

In present study, type of inflorescence was classified into three categories of uniparous (19 cultivars), intermediate (47 cultivars) and multiparous (34 cultivars). Flower fascinations were absent in 66 extant cultivars while it was present in 34 extant cultivars (Supplementary Table 2). Out of 100 extant cultivars, 91 were adopted non-exerted nature of stigma and remaining 9 cultivars were found stigma exerted in their flowers. Correspondingly, stigma nature was classified into three categories unilobe, bilobe and multilobe for 13, 34 and 53 extant cultivars, respectively (Supplementary Table 2; Supplementary Figure 3). In this study, presence of pubescence on style of flowers was present in all cultivars excluding two cultivars 'Dhanshree' and 'Mukti'. Whereas, abscission layer in peduncle was presented in all cultivars (Supplementary Table 2). It was also observed that the colour of flowers exhibited yellow (97 cultivars) and orange (3 cultivars), while colour of anthers of flowers were green (14 cultivars) and yellow (86 cultivars), respectively. During observation it was also recorded that the time of flowering (50% of the plant) was recorded as early, medium and late in 17, 76 and 7 cultivars, respectively (Supplementary Table 2).

*Fruits*

In current study, the intensity of green colour of fruits skin before maturity was monitored in 100 extant

**Table 3. Stability test analysis in 36 extant cultivars of tomato under different environments for 10 morphological traits (SLI, LL, LW, TF, AFW, FL, FD, FTP, FLN, TFM)**

| Genotypes | SLI | | | LL | | | LW | | | TF | | | AFW | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | b | S²di | m | b | S²di | m | b | S²di | m | b | S²di | m | b | S²di |
| Ageta-32 | 44.92 | 1.29 | -1.96 | 17.38 | 0.67 | -0.67 | 14.17 | 0.70 | -3.64 | 71.71 | 1.01 | -1.98 | 55.36 | 0.72 | -0.72 |
| Arka Ahuti | 29.95 | 0.85 | -1.96 | 30.33 | 1.17 | -0.67 | 20.32 | 1.03 | -3.64 | 70.70 | 1.00 | -1.98 | 73.46 | 0.97 | -0.72 |
| Arka Alok | 48.03 | 1.38 | -1.96 | 25.66 | 0.98 | -0.67 | 22.49 | 1.13 | -3.64 | 72.38 | 1.02 | -1.98 | 97.78 | 1.29 | -0.72 |
| Arka Vikash | 33.56 | 0.96 | -1.96 | 23.58 | 0.91 | -0.67 | 16.83 | 0.84 | -3.64 | 70.70 | 1.00 | -1.98 | 66.76 | 0.87 | -0.72 |
| Azad T-2 (KS-2) | 29.30 | 0.85 | -1.96 | 19.43 | 0.78 | -0.67 | 14.84 | 0.76 | -3.64 | 72.05 | 1.02 | -1.98 | 65.68 | 0.86 | -0.72 |
| Azad T-3 | 36.18 | 1.04 | -1.96 | 19.39 | 0.78 | -0.67 | 16.73 | 0.84 | -3.64 | 72.36 | 1.02 | -1.98 | 63.58 | 0.83 | -0.72 |
| Azad T-6 (KS-118) | 26.99 | 0.77 | -1.96 | 22.01 | 0.82 | -0.67 | 17.93 | 0.91 | -3.64 | 72.03 | 1.02 | -1.98 | 54.50 | 0.72 | -0.72 |
| Bhagyashree | 17.68 | 0.51 | -1.96 | 23.55 | 0.91 | -0.67 | 19.43 | 0.96 | -3.64 | 74.38 | 1.05 | -1.98 | 58.34 | 0.76 | -0.72 |
| Colambia | 31.32 | 0.90 | -1.96 | 21.59 | 0.82 | -0.67 | 17.79 | 0.91 | -3.64 | 71.04 | 1.00 | -1.98 | 104.65 | 1.38 | -0.72 |
| DARL-66 | 56.21 | 1.61 | -1.96 | 23.38 | 0.89 | -0.67 | 17.23 | 0.87 | -3.64 | 70.69 | 1.00 | -1.98 | 56.53 | 0.74 | -0.72 |
| Dhanshree | 33.64 | 0.96 | -1.96 | 30.86 | 1.22 | -0.67 | 25.98 | 1.33 | -3.64 | 74.38 | 1.05 | -1.98 | 77.41 | 1.02 | -0.72 |
| Floradade | 27.54 | 0.79 | -1.96 | 24.63 | 0.97 | -0.67 | 19.88 | 0.99 | -3.64 | 71.71 | 1.01 | -1.98 | 116.06 | 1.52 | -0.72 |
| Hisar Arun (Sel-7) | 34.33 | 0.99 | -1.96 | 23.24 | 0.90 | -0.67 | 18.79 | 0.96 | -3.64 | 72.03 | 1.02 | -1.98 | 76.65 | 1.00 | -0.72 |
| Kalyanpur T-1 | 50.92 | 1.46 | -1.96 | 27.61 | 1.06 | -0.67 | 17.07 | 0.84 | -3.64 | 70.69 | 1.00 | -1.98 | 81.83 | 1.07 | -0.72 |
| Kashi Adarsh | 31.58 | 0.90 | -1.96 | 28.18 | 1.11 | -0.67 | 21.59 | 1.09 | -3.64 | 72.36 | 1.02 | -1.98 | 67.58 | 0.88 | -0.72 |
| Kashi Amrit | 51.38 | 1.47 | -1.96 | 27.11 | 1.06 | -0.67 | 18.39 | 0.91 | -3.64 | 72.03 | 1.02 | -1.98 | 62.73 | 0.82 | -0.72 |
| Kashi Hemant | 25.28 | 0.73 | -1.96 | 23.26 | 0.92 | -0.67 | 17.73 | 0.88 | -3.64 | 71.71 | 1.01 | -1.98 | 54.67 | 0.72 | -0.72 |
| Kashi Sharad | 34.43 | 0.98 | -1.96 | 28.34 | 1.11 | -0.67 | 17.63 | 0.88 | -3.64 | 82.75 | 1.17 | -1.98 | 107.50 | 1.41 | -0.72 |
| Kashi Vishesh | 35.31 | 1.01 | -1.96 | 24.62 | 0.96 | -0.67 | 20.73 | 1.00 | -3.64 | 73.04 | 1.03 | -1.98 | 76.48 | 1.00 | -0.72 |
| Manileima (Sel-2) | 35.48 | 1.02 | -1.96 | 27.64 | 1.06 | -0.67 | 18.19 | 0.91 | -3.64 | 71.71 | 1.01 | -1.98 | 98.28 | 1.29 | -0.72 |
| Marglobe | 35.19 | 1.01 | -1.96 | 27.94 | 1.09 | -0.67 | 18.78 | 0.94 | -3.64 | 71.37 | 1.01 | -1.98 | 114.71 | 1.51 | -0.72 |
| NDTVR-73 | 32.93 | 0.95 | -1.96 | 23.64 | 0.90 | -0.67 | 26.68 | 1.34 | -3.64 | 60.64 | 0.86 | -1.98 | 56.36 | 0.74 | -0.72 |
| Pant T-5 | 33.38 | 0.96 | -1.96 | 22.24 | 0.82 | -0.67 | 18.90 | 0.93 | -3.64 | 72.36 | 1.02 | -1.98 | 121.76 | 1.59 | -0.72 |
| Prestige | 33.48 | 0.96 | -1.96 | 22.84 | 0.85 | -0.67 | 16.19 | 0.82 | -3.64 | 72.03 | 1.02 | -1.98 | 54.33 | 0.72 | -0.72 |
| Punjab Chhuhara | 24.73 | 0.71 | -1.96 | 37.14 | 1.40 | -0.67 | 30.58 | 1.53 | -3.64 | 74.72 | 1.05 | -1.98 | 64.90 | 0.85 | -0.72 |
| Punjab Keshari | 31.91 | 0.92 | -1.96 | 29.13 | 1.14 | -0.67 | 21.16 | 1.05 | -3.64 | 73.05 | 1.03 | -1.98 | 64.58 | 0.85 | -0.72 |
| Punjab Upma | 35.72 | 1.03 | -1.96 | 22.39 | 0.87 | -0.67 | 18.62 | 0.94 | -3.64 | 60.98 | 0.86 | -1.98 | 65.42 | 0.86 | -0.72 |
| Punjab Varkha Bahar-1 | 31.62 | 0.91 | -1.96 | 28.13 | 1.08 | -0.67 | 21.98 | 1.13 | -3.64 | 72.36 | 1.02 | -1.98 | 85.38 | 1.13 | -0.72 |
| Punjab Varkha Bahar-2 | 33.58 | 0.96 | -1.96 | 28.61 | 1.11 | -0.67 | 24.61 | 1.24 | -3.64 | 71.71 | 1.01 | -1.98 | 116.73 | 1.53 | -0.72 |
| Pusa Gaurav | 34.66 | 1.00 | -1.96 | 27.51 | 1.06 | -0.67 | 20.40 | 1.02 | -3.64 | 72.03 | 1.02 | -1.98 | 78.15 | 1.03 | -0.72 |
| Pusa-120 | 23.67 | 0.68 | -1.96 | 21.00 | 0.83 | -0.67 | 14.58 | 0.76 | -3.64 | 60.30 | 0.85 | -1.98 | 53.33 | 0.70 | -0.72 |
| Sel-12 | 49.36 | 1.42 | -1.96 | 20.19 | 0.78 | -0.67 | 17.73 | 0.88 | -3.64 | 57.96 | 0.82 | -1.98 | 46.79 | 0.62 | -0.72 |
| Solan Vajra | 32.83 | 0.94 | -1.96 | 39.98 | 1.53 | -0.67 | 26.74 | 1.33 | -3.64 | 72.38 | 1.02 | -1.98 | 93.92 | 1.23 | -0.72 |
| Swarna Naveen | 42.61 | 1.22 | -1.96 | 37.58 | 1.45 | -0.67 | 22.10 | 1.15 | -3.64 | 70.70 | 1.00 | -1.98 | 85.54 | 1.13 | -0.72 |
| Utkal Pragyan (BT-116-3-2) | 33.85 | 0.98 | -1.96 | 18.96 | 0.73 | -0.67 | 14.91 | 0.76 | -3.64 | 73.05 | 1.03 | -1.98 | 52.50 | 0.69 | -0.72 |
| Vaibhav | 31.25 | 0.90 | -1.96 | 33.68 | 1.29 | -0.67 | 28.31 | 1.42 | -3.64 | 67.69 | 0.95 | -1.98 | 69.19 | 0.92 | -0.72 |
| PM±SE | 34.85 ±0.01 | 1.0 ±0.003 | | 25.91 ±0.01 | 1.0 ±0.015 | | 19.89 ±0.01 | 1.0 ±0.015 | | 70.94 ±0.01 | 1.0 ±0.002 | | 76.09 ±0.01 | 1.0 ±0.004 | |

**m**= mean; **b**= regression coefficient; **$S^2$di**= deviation from regression; **SLI**=Stem: Length of internode between 1st and 4th inflorescence (cm); **LL**=Leaf length (cm); **LW**=Leaf width (cm); **TF**=Time of flowering (50% of the plants with at least one open flower from seed sowing) (days); **AFW**=Average Fruit Weight (g); **PM±SE**= Pooled mean± standard error

cultivars. These cultivars were exposed in light (52), medium (38) and dark (10) green colour. However, green shoulder on tomato fruits before maturity was present in 11 extant cultivars (Supplementary Table 3, Supplementary Figure 4). In case of fruit size of tomato was measured by average weight of 10 fruits which was categorized in very small <100g (0), small 100-200g (1), medium 201-700g (53), large 701-1000g (32) and very large >1000g (14) fruit size. Whereas, fruit shape in longitudinal section (Supplementary Table 3, Supplementary Figure 4) was examined in flattened (5), slightly flattened (30), circular (38), rectangular (3),

**Table 3 (Contd.). Cont. Stability analysis in 36 extant cultivars of tomato under different environments for 10 morphological traits (SLI, LL, LW, TF, AFW, FL, FD, FTP, FLN, TFM)**

| Genotypes | FL | | | FD | | | FTP | | | FLN | | | TFM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | b | $S^2di$ | m | b | $S^2di$ | m | b | $S^2di$ | m | b | $S^2di$ | m | b | $S^2di$ |
| Ageta-32 | 4.58 | 0.77 | -0.02 | 4.59 | 0.96 | -0.03 | 1.63 | 0.90 | -0.01 | 3.08 | 1.05 | -0.01 | 119.83 | 1.00 | -3.99 |
| Arka Ahuti | 7.33 | 1.54 | -0.02 | 4.36 | 0.96 | -0.03 | 1.63 | 0.84 | -0.01 | 2.05 | 0.61 | -0.01 | 118.82 | 0.99 | -3.99 |
| Arka Alok | 4.52 | 0.77 | -0.02 | 5.90 | 0.99 | -0.03 | 1.95 | 1.20 | -0.01 | 5.13 | 1.66 | -0.01 | 124.54 | 1.04 | -3.99 |
| Arka Vikash | 3.65 | 0.77 | -0.02 | 5.23 | 0.96 | -0.03 | 1.75 | 1.07 | -0.01 | 4.10 | 1.22 | -0.01 | 119.49 | 1.00 | -3.99 |
| Azad T-2 (KS-2) | 3.75 | 0.77 | -0.02 | 3.53 | 0.67 | -0.03 | 1.26 | 0.69 | -0.01 | 3.08 | 1.05 | -0.01 | 105.65 | 0.88 | -3.99 |
| Azad T-3 | 5.54 | 1.33 | -0.02 | 4.49 | 0.96 | -0.03 | 1.68 | 0.86 | -0.01 | 2.05 | 0.61 | -0.01 | 122.53 | 1.02 | -3.99 |
| Azad T-6 (KS-118) | 4.38 | 0.77 | -0.02 | 4.56 | 0.96 | -0.03 | 1.60 | 0.90 | -0.01 | 3.08 | 1.05 | -0.01 | 116.45 | 0.97 | -3.99 |
| Bhagyashree | 4.18 | 0.77 | -0.02 | 4.63 | 0.96 | -0.03 | 1.57 | 0.93 | -0.01 | 3.08 | 1.05 | -0.01 | 121.50 | 1.01 | -3.99 |
| Colambia | 6.14 | 1.33 | -0.02 | 6.31 | 1.17 | -0.03 | 3.19 | 1.00 | -0.01 | 4.10 | 1.22 | -0.01 | 119.82 | 1.00 | -3.99 |
| DARL-66 | 4.65 | 0.77 | -0.02 | 4.73 | 0.96 | -0.03 | 1.65 | 0.94 | -0.01 | 2.05 | 0.61 | -0.01 | 120.84 | 1.01 | -3.99 |
| Dhanshree | 4.68 | 0.77 | -0.02 | 5.59 | 0.96 | -0.03 | 1.84 | 1.14 | -0.01 | 3.08 | 1.05 | -0.01 | 119.83 | 1.00 | -3.99 |
| Floradade | 6.64 | 1.33 | -0.02 | 7.42 | 1.49 | -0.03 | 2.48 | 1.50 | -0.01 | 5.13 | 1.66 | -0.01 | 117.13 | 0.98 | -3.99 |
| Hisar Arun (Sel-7) | 4.66 | 0.96 | -0.02 | 5.73 | 0.99 | -0.03 | 1.92 | 1.17 | -0.01 | 5.13 | 1.66 | -0.01 | 116.78 | 0.97 | -3.99 |
| Kalyanpur T-1 | 4.45 | 0.77 | -0.02 | 5.49 | 0.96 | -0.03 | 2.68 | 0.90 | -0.01 | 3.08 | 1.05 | -0.01 | 119.15 | 0.99 | -3.99 |
| Kashi Adarsh | 4.22 | 0.77 | -0.02 | 4.79 | 0.96 | -0.03 | 1.59 | 0.97 | -0.01 | 3.08 | 1.05 | -0.01 | 122.85 | 1.02 | -3.99 |
| Kashi Amrit | 4.45 | 0.77 | -0.02 | 4.89 | 0.96 | -0.03 | 1.68 | 0.98 | -0.01 | 4.10 | 1.22 | -0.01 | 108.35 | 0.90 | -3.99 |
| Kashi Hemant | 4.38 | 0.77 | -0.02 | 4.49 | 0.96 | -0.03 | 1.51 | 0.91 | -0.01 | 3.08 | 1.05 | -0.01 | 117.80 | 0.98 | -3.99 |
| Kashi Sharad | 5.71 | 1.33 | -0.02 | 5.93 | 0.99 | -0.03 | 1.96 | 1.20 | -0.01 | 4.10 | 1.22 | -0.01 | 121.53 | 1.01 | -3.99 |
| Kashi Vishesh | 4.45 | 0.77 | -0.02 | 5.43 | 0.96 | -0.03 | 1.83 | 1.10 | -0.01 | 3.08 | 1.05 | -0.01 | 139.74 | 1.16 | -3.99 |
| Manileima (Sel-2) | 6.28 | 1.33 | -0.02 | 5.49 | 0.96 | -0.03 | 1.99 | 1.07 | -0.01 | 2.39 | 0.76 | -0.01 | 122.87 | 1.03 | -3.99 |
| Marglobe | 6.48 | 1.33 | -0.02 | 8.12 | 1.49 | -0.03 | 3.65 | 1.40 | -0.01 | 4.10 | 1.22 | -0.01 | 118.13 | 0.98 | -3.99 |
| NDTVR-73 | 3.85 | 0.77 | -0.02 | 4.43 | 0.96 | -0.03 | 1.59 | 0.87 | -0.01 | 2.73 | 0.90 | -0.01 | 116.12 | 0.96 | -3.99 |
| Pant T-5 | 6.01 | 1.33 | -0.02 | 5.49 | 0.96 | -0.03 | 1.87 | 1.11 | -0.01 | 2.05 | 0.61 | -0.01 | 117.80 | 0.98 | -3.99 |
| Prestige | 4.15 | 0.77 | -0.02 | 4.33 | 0.96 | -0.03 | 1.56 | 0.84 | -0.01 | 3.08 | 1.05 | -0.01 | 121.53 | 1.01 | -3.99 |
| Punjab Chhuhara | 7.02 | 1.40 | -0.02 | 4.46 | 0.96 | -0.03 | 1.63 | 0.87 | -0.01 | 3.08 | 1.05 | -0.01 | 119.15 | 0.99 | -3.99 |
| Punjab Keshari | 6.41 | 1.33 | -0.02 | 4.23 | 0.96 | -0.03 | 1.53 | 0.82 | -0.01 | 2.05 | 0.61 | -0.01 | 139.40 | 1.16 | -3.99 |
| Punjab Upma | 5.94 | 1.33 | -0.02 | 5.23 | 0.96 | -0.03 | 1.85 | 1.04 | -0.01 | 3.08 | 1.05 | -0.01 | 116.79 | 0.98 | -3.99 |
| Punjab Varkha Bahar-1 | 4.52 | 0.77 | -0.02 | 5.39 | 0.96 | -0.03 | 1.94 | 1.06 | -0.01 | 3.08 | 1.05 | -0.01 | 139.40 | 1.16 | -3.99 |
| Punjab Varkha Bahar-2 | 4.82 | 0.77 | -0.02 | 5.23 | 0.96 | -0.03 | 1.88 | 1.03 | -0.01 | 4.10 | 1.22 | -0.01 | 116.45 | 0.97 | -3.99 |
| Pusa Gaurav | 6.41 | 1.33 | -0.02 | 4.56 | 0.96 | -0.03 | 1.78 | 0.85 | -0.01 | 2.05 | 0.61 | -0.01 | 120.15 | 1.00 | -3.99 |
| Pusa-120 | 4.35 | 0.77 | -0.02 | 4.86 | 0.96 | -0.03 | 1.84 | 0.93 | -0.01 | 3.08 | 1.05 | -0.01 | 123.19 | 1.03 | -3.99 |
| Sel-12 | 4.55 | 0.77 | -0.02 | 4.46 | 0.96 | -0.03 | 1.60 | 0.87 | -0.01 | 2.05 | 0.61 | -0.01 | 105.65 | 0.88 | -3.99 |
| Solan Vajra | 4.89 | 0.96 | -0.02 | 5.97 | 0.99 | -0.03 | 2.20 | 1.16 | -0.01 | 2.05 | 0.61 | -0.01 | 116.45 | 0.97 | -3.99 |
| Swarna Naveen | 5.13 | 1.14 | -0.02 | 6.25 | 1.20 | -0.03 | 2.10 | 1.26 | -0.01 | 3.08 | 1.05 | -0.01 | 117.80 | 0.98 | -3.99 |
| Utkal Pragyan (BT-116-3-2) | 5.81 | 1.33 | -0.02 | 4.36 | 0.96 | -0.03 | 1.57 | 0.85 | -0.01 | 2.05 | 0.61 | -0.01 | 122.53 | 1.02 | -3.99 |
| Vaibhav | 3.65 | 0.77 | -0.02 | 4.43 | 0.96 | -0.03 | 1.83 | 0.81 | -0.01 | 2.39 | 0.76 | -0.01 | 122.18 | 1.02 | -3.99 |
| PM±SE | 5.07 ±0.01 | 1.0 ±0.050 | | 5.15 ±0.01 | 1.0 ±0.038 | | 1.88 ±0.01 | 1.0 ±0.006 | | 3.11 ±0.01 | 1.0 ±0.045 | | 120.23 ±0.01 | 1.0 ±0.001 | |

**m**= mean; **b**= regression coefficient; **$S^2$di**= deviation from regression; **FL**=Fruit length (cm); **FD**=Fruit diameter (cm); **FTP**=Fruit thickness of the pericarp (cm); **FLN**= Fruit locule number; **TFM**= Time of fruit maturity (from seed sowing) (days); **PM±SE**= Pooledmean± standard error.

cylindrical (0), heart shaped (3), obovoid (13), ovoid (5) and pear shaped (3). Similarly, fruit shape in cross section was noticed as round and not round in 56 and 44 cultivars, respectively. Ribbing at peduncle end was absent in 21 cultivars. While, ribbing at peduncle end was present in 79 cultivars which were categorized into different intensity of weak (37 cultivars), medium (33 cultivars) and strong (9 cultivars). However, fruit depression at peduncle end was present in 30, 50, and 18 cultivars with the intensity of shallow, medium and deep but 2 cultivars were absent the depression at peduncle end. Among the 100 cultivars size of scar around peduncle and size of blossom scar of all cultivar's fruits were categorized in small (52 and 64), medium (45 and 34) and large (3 and 2). While, shape of blossom end at fruit was observed in different shape like indented, indented to flat, flat, flat to indented and pointed for 18, 39, 30, 10 and 3 cultivars, respectively. In this study colour of skin and flesh were recorded in yellow (3 and 3), orange (11 and 9), pink (9 and 44) and red (77 and 44) colour (Supplementary Table 3; Supplementary Figure 4). Whereas, the fruit firmness was measured as soft, medium and firms in 17, 72, and 11 cultivar's fruit. While, the time of fruit maturity from date of seed sowing was recorded as early (110 days), medium (110-130 days) and late (>130 days) in 8, 81 and 11 extant cultivars, respectively.

### *Genetic diversity*

In the present finding, a dendrogram was developed with five major clusters (clusters '1', '2', '3', '4' and '5') by using 100 cultivars of tomato and 32 morphological traits (Figure 1). These five clusters were classified into two groups 'I' and 'II' including 62 (cluster '5') and 38 (clusters '1', '2', '3' and '4') extant cultivars in the coefficient range of 0.48%–1.00%. Two cultivars 'Agata-32' and 'Best of All' were close in group 'I'. Similarly, the cultivars 'Anand Tomato-3' and 'Anand Tomato-4' were found very close in group 'II'. A cultivar 'Hisar Arun' was isolated individually in cluster '1' of group 'II'.

#### *Stability test analysis*

The estimates of genotypes, environment and G × E variances were highly significant for all the characters (Table 2). The estimates of mean (m), deviation from regression ($s^2di$) and regression coefficient (b) for morphological traits (SLI, LL, LW, TF, AFW, FL, FD, FTP, FLN, TFM) were calculated for stability test in 36 cultivars of tomato (Table 3). Out of 36 a total 29, 26, 27, 35, 25, 22, 32, 26, 27 and 33 cultivars were showed less than or equal to '1' (b<1 or b=1) for the characters SLI, LL, LW, TF, AFW, FL, FD, FTP, FLN and TFM, respectively (Table 3). Whereas, 22 and 32 cultivars were showed less than '1' regression coefficient (b<1). It was also observed that all the cultivars were occupied less than '1' or close to '0' deviation from regression ($s^2di<1$ or $s^2di=0$) for the characters LL, AFW, FL, FD, FTP and FLN.

## Discussion

According to literatures many vegetable crops have been reported for black or purple fruit colour pigments due to the anthocyanins but tomato is in queue for producing purple or black colours in farmer's field. In present study, the anthocyanin coloration was present at the stages of seedlings and vigorous growth in most of cultivars (Supplementary Figure 1). In some other studies the cultivated tomato expressed the anthocyanins in vegetative tissues, it may be possible due to transfer of anthocyanin-pigments by wild tomato relatives (Rick *et al.*, 1994; Andersen, 2001). Earlier, it has been reported that the anthocyanins are natural pigments which protects the plants from damage by UV radiations and found in the cell vacuole of flowers, fruits, leaves, stems and some time in roots with different colours red, purple and blue (Rick *et al.*, 1994; Qiu *et al.*, 2016). Anthocyanin has been detected mainly in outer cell layers such as the epidermis and peripheral mesophyll cells of plant parts (Qiu *et al.*, 2016). The changes in anthocyanin colour pigments depend on the range of pH because these anthocyanins have degraded at higher pH effect (Rick *et al.*, 1994; Andersen, 2001; Qiu *et al.*, 2016). The anthocyanins known for its antioxidant properties against reactive oxygen and extreme temperatures and is reported to protect tomato plants by cold stress with countering reactive oxygen and leading a lower rate of cell death in leaves (Rick *et al.*, 1994; Andersen, 2001; Qiu *et al.*, 2016). Plant growth type in tomato are classified into two categories, determinate or bush type and indeterminate or vining type (Supplementary Figure 1). Vigorousness in plants caused by more plant height and spreading of branches and may be deserved for producing high yield in crop (Singh *et al.*, 2014, 2015a, 2015b). It was also found that all the cultivars had pubescence (hairs or trichomes) on their stem (Supplementary Figure 1). Theoretically these dense covering of pubescence protects the living cell surface from insects, direct flow of air, frost and heat in open habitats and also reducing the transpiration rate in plant (Peralta and Spooner, 2000). In agreement of this finding only 'H-24' cultivar was reported as pubescenceless and also discussed in DUS descriptor of tomato (2009). In present study, the intensity of green colour leaves in tomato were categorized as light, medim and dark green colour and indicated the presence of chlorophyll content (Rick *et al.*, 1994; Peralta and Spooner, 2000; Singh *et al.*, 2015b). Correspondingly, other characters of leaves or leaflets *e.g.*, attitude, serration, structure, morphology and size (Supplementary Figure 2) are also responsible for the photosynthetic processes and also helpful in food accumulations (Peralta and Spooner, 2000; Jones, 2000; Singh *et al.,* 2015b). It may be light or deform green colour of leaves due to nitrogen or iron or sulphur deficiency but in the present observation it was determined by the genetic characters of tomato cultivars. Healthy green colour and vigorousness in leaves or leaflets may also support for producing high yield in tomato (Rick *et al.*, 1994; Jones, 2000; Singh *et al.,* 2015b).

Flowers play very important role to obtain an expected high yield in any crops. Only presence of flower will not be responsible for producing high yield, while, the nature and structure of stigma and the morphology, size, number and earliness of flowers and fruits (Supplementary Figure 3) are also important. In present finding, many characters of flowers *viz.*, type of inflorescence (uniparous, intermediate or biparous and multiparous), fasciations (absent and present), stigma exertion (exerted and non-exerted) and nature of stigma (unilobe, bilobe and multilobe) had direct relation by significant and potential yield capacity (Rashid *et al.*, 2016). In present study, the pubescence on style of flowers and abscission layer was present in most of cultivars. Presence of pubescence is known to help in reducing the transpiration rate and protects by insects (Peralta and Spooner, 2000). While, presence of abscission layer indicated to strong joint between fruits and peduncles. Some time, formation of abscisic acid (ABA) take place in abscission layer and may be caused bud dormancy or dropness of fruits and leaves (deMelo *et al.*, 2015; Rashid *et al.*, 2016). It was also found that the colour of flowers and anthers was yellow in many cultivars but few cultivars were displayed orange flowers and green anthers. Earlier it has been studied that the yellow colour of flowers in tomato is due to xanthophyll pigments (Peralta and Spooner, 2000; Ariizumi *et al.*, 2014; deMelo *et al.*, 2015). In this study the time of flowering (50% of the plant) was recorded medium in many cultivars. Early flowering is responsible for early fruiting and may be beneficial for breeders and farmers (Moya *et al.*, 1995; Rashid *et al.,* 2016).

Fruit attributes (fruit colour, size, shapes, yield, qualities and time of maturity) are demanding issue for any crop and has been need of breeders, researchers, and farmers. In results of this study it was observed that the few tomato cultivars had dark green colour intensity on their fruit's skin and shoulder (Supplementary Figure 4). Earlier it has been studied that the green colour of fruits indicated presence of chlorophyll content (Rick *et al.*, 1994; Mahbubar *et al.*, 2020; Goodenough *et al.*, 1982; D'souza *et al.,* 1992) but the presence of green shoulder is due to high availability of chlorophyll content along with high phenol and ethylene (D'souza *et al.*, 1992; Rick *et al.*, 1994). The green colour of tomato fruits convert into deep red colour after ripening due to presence of phenol and ethylene, either it may also be due to chlorophyll convert into lycopene (D'souza *et al.*, 1992; Rick *et al.*, 1994). In case of fruit size most of the cultivars were found medium fruit size but none was in very small size. Very small fruit size is found only in cherry tomato and wild species because most of tomato cultivars having small to very large size (Singh *et al.*, 2015a). Whereas, fruit shape in longitudinal section was categorized as flattened, slightly flattened, circular, rectangular, cylindrical, heart shaped, obovoid, ovoid and pear shaped as prescribed in DUS guideline of tomato, 2009 (Supplementary Figure 4). Size and shape of tomato fruits are deciding to the demand of consumers (Sheldrake, 1989; Singh *et al.,* 2015a). Similarly, some morphological characters *e.g.,* ribbing at peduncle, depression at peduncle end, size of scar around peduncle end, size of blossom scar and shape of blossom end at fruit (indented, indented to flat, flat, flat to indented and pointed) were noticed among the cultivars. Presence or absence of these characters in tomato fruits has decided to better and poor fruit shape and demands of growers and consumers (Sheldrake, 1989). In results of this study, the colour of fruit's skin and flesh were recorded in yellow, orange, pink and red in many cultivars at the maturity stage (Figure 4). Earlier, tomato fruits has been found in a range of colours like red, yellow, white, pink, green, purple, brown and black but these colours are influenced only for two traits skin and flesh. It may be due to origin of various pigments of carotenoids at the ripening stages of fruits. (D'souza *et al.*, 1992; Fraser *et al.*, 1994). Red and yellow colours of fruit indicates to presence of high level of lycopene and beta-carotene while, the pink and orange colour may be indicated to low lycopene and beta-carotene in tomato fruits (Goodenough *et al.*, 1982; D'souza *et al.*, 1992; Fraser *et al.*, 1994; Nasir *et al.*, 2015). Earlier, it has been studied that during maturity of fruits the chlorophyll (green colour) was reduced and increased the carotenoids (red, yellow and orange colour) or induces yellowing of green tissues due to decolouration and degradation in chlorophyll pigments by the secretion of small amount of ethylene in fruits (Goodenough *et al.*, 1982; D'souza *et al.*, 1992; Fraser *et al.*, 1994). In another study, when the colour of skin is genetically controlled by a single recessive gene 'y' then the 'y'+ (wild type) is dominant and gave results in yellow skin ('y'+'y' = yellow skin), and when the 'y' is expressed in a recessive pairing then the result was red skin ('yy' = red skin) (Gorini and Testoni, 1990). Sometimes, the flesh or pericarp of tomato is the interior tissue of the fruit. Various genes for control of flesh colour can be expressed at the same time. Likewise, the red flesh or green flesh and other colours expressed with the bicolour (red + green flesh) trait at the same time because it has different alleles which produced slight variations to the expression of the gene (Gormley and Egan, 1978; Gorini and Testoni, 1990; Goodenough *et al.*, 1982). These pigments not only affect fruit appearance but they also influenced nutrition and flavour (Gormley and Egan, 1978; Gorini and Testoni, 1990). Another finding was the fruit firmness measured as soft, medium and firms in many cultivars which is determine to quality and post-harvest capacity of fruits (Gormley and Egan, 1978; Goodenough *et al.*, 1982). It was also observed that many cultivars noticed for their fruit maturity as early, medium and late. Early or medium days of maturity and ripening of fruits may be good for quality as well as commercialization of seeds by farmers, entrepreneurs and companies. Time of maturity of tomato decides to the attitude of market and also helpful in breeding program for a breeder (Sheldrake, 1989; Gorini and Testoni, 1990; Henareh *et al.*, 2015).

The genetic diversity represents the number of genetic characteristics and genetic makeup of populations to adapt the changing climate. Tomatoes have conserved rich diversity towards quantity and quality resources but among the cultivars (*S. lycopersicum*) a limited diversity has been reported (Bauchet and Causse, 2012). The cluster dendrogram is a way of presenting the distance and closeness between genotypes. In present finding, five clusters in two major groups were developed which was located in a dendrogram made by hundred extant cultivars (Figure 1). These two groups were indicated genetically difference because of using different pedigree and showed different morphological characters (Table 1). It was also noticed that most of the cultivars were very close with each other and came in same group but some cultivars were diverse to each other and went with different group. It may be due to these same group cultivars developed from similar research centres and showed similar morphology (Table 1 and supplementary Table 1-3). Earlier, it has been studied that tomato has many simple and complex traits and low genetic variation (Scintu *et al.*, 2014; Athinodorou *et al*., 2021). Another finding was that the cultivar 'Hisar Arun' clustered individually in a group, it may be possible due to involving wild parentage and covering genetically different morphology (Singh *et al.*, 2015a, 2015b). The differences and closeness indicated to genetic relationship between the extant cultivars which may be utilized during hybridization (Bauchet and Causse, 2012; Singh *et al.*, 2014).

Stability test is a way to confirm the stability rate of varieties for growing in difficult circumstances. In present study, those characters of the cultivars were showed less than '1' (b<1) or equal to '1' (b=1) regression coefficient either they sowed less than '1' (s2di<1) or close to '0' (s2di=0) deviation from regression, that cultivars can stable for cultivation in each environment. In support of this finding several workers has been reported that the results of less or equal to '1' regression coefficient (b=<1 and b=1) and close to '0' deviation from regression ($s^2$di=0) indicated most stable and adaptive genotypes of tomato which can be utilized for cultivation in any climatic zone (Eberhart and Russell, 1966; Singh *et al.*, 2012; Kumar *et al.*, 2013; Singh *et al.*, 2015a; Spaldon *et al.*, 2017; Athinodorou *et al*., 2021).

## Conclusions

From present study, it was concluded that hundred extant cultivars of tomato were represented quite a good diversity for morphological and mopho-physio-chemical properties. For example, the presence of pubescence in tomato protects to plant by insect and speedy winds; presence of anthocyanin protects to plant by UV rays and protect to human by cancerous diseases; intensity of green colour and vigorousness of plant morphology helps in photosynthetic processes; fruit size, shape and firmness determines to the quality and demands of consumers; early flowering and fruiting will be beneficial for producers to achieve the market demand; red, orange, yellow and pink colour of ripen tomato fruit was due to conversion of chlorophyll into carotenoids pigments in presence of ethylene etc. Moreover, the characterization of these cultivars on the basis of their various morphological traits would be helpful for generating a data base on tomato and also will be time saver and helpful for students, industrialists and breeders to know about behaviour of tomato varieties from a single platform. The evaluation of the genetic diversity and closeness between the tomato cultivars could be utilized in conservation, evolution and improvement of crop. Consequently, the stable cultivars of tomato can be grown in any climatic zone and could be utilized in varietal improvement programme for desired characteristics. Furthermore, these categorized cultivars can be protected and registered under PPV&FRA, New Delhi on the basis of DUS testing and may be protected by IPR issues.

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*Supplementary Table or Figure mentioned in the article are available in the online version.

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