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Interpretation for genetic nature of morphological traits and phyto-physio-chemical properties in tomato: An overview

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Abstract
Among the vegetables, tomato is a wealthy genetic heritage. It is the most consumable vegetable due to its nutritional and medicinal values towards animals and human health. The aim of this study is to focus on the overview of primary introduction and cultivation of tomato, the genetic nature of morphological traits and interpretation of phyto-physio-chemicals of tomatoes *viz.*, auxin, gibberellins, cytokinins, abscisic acid (ABA), ethylene (ET), anthocyanin, chlorophyll, carotene, lycopene, ascorbic acid etc., as well as their properties are applied to plant and human health. The plant hormones are available in plants, leaves, flowers and fruits, are responsible for all activities from seed germination to fruit ripening etc. The anthocyanin protects to crop from UV rays as well as protects the human body from major human diseases. Chlorophyll can be used as a drink for human health, changing colour from raw to ripe stages due to degradation of chlorophyll and increased the carotenoids due to start the secretion of a small amount of ethylene in fruits (Klee, 2000). Lycopene is responsible for red colour in tomato fruits, hold sufficient amount of anti-oxidant and reduces the risk of cancers, heart diseases, age-related diseases in human. The aroma and flavours had found in tomato fruit due to the presence of volatile and non-volatile compounds. These cultivars and their chemical properties may be useful for pharmaceutical industries, farmers, breeders and researchers for processing, marketing and variety development on the basis of their morpho-phenological and phyto-physio-chemical properties.

Keywords: Tomato, genetic heritability, pheno-morphology, phyto-hormones, colour pigments

Introduction

This study has covered three major heads as discussed- I. Nomenclature, distribution and agronomy; II. Interpretation for genetic nature; III. Interpretation for pheno-morphological traits and phyto-physio-chemical properties.

1. Nomenclature, Distribution and Agronomy

The generic status of tomato within *Solanaceae,* the *Solanum lycopersicum* a wild ancestor of cultivated tomato which has been generated from a cherry tomato *S. cerasiforme* and used in cultivation surrounding the world (Rick and Holle, 1990) [44]. Earlier, the Linnaeus in 1753 had placed tomatoes in *Solanum,* while in contemporary of Linnaeus, the Miller in 1754 had classified tomatoes in a new genus *Lycopersicon* as well as the majority of later botanists have been followed the Miller and used the genus *Lycopersicon* (Rick *et al*., 1990) [46]. Although, after long period the botanists have been accepted revised nomenclature of Linnaeus on the basis of the information collected from both morphology and molecular sequences, which support its inclusion in the large genus *Solanum* L. (Peralta and Spooner, 2000; Peralta *et al*., 2006) [40, 68]. Facts are in favoured, the cultivars tomato have been generated by wild background and are distributed from America (Peralta *et al*., 2006) [68]. It had been confirmed that the Peru Equador region had considered the centre of origin because the wild tomatoes had grown in the Western South American Andes from Central Equador, through Peru to northern Chile, and in the Galapagos Islands (Peralta and Spooner, 2000) [40]. The nineteenth century plant explorers in India and observed to plant as very common and highly variable as well as grown as a cultivated crop. These cultivated crops justified as first indigenous selections which released as improved cultivars in the middle of the 20th century (Rick *et al*., 1990) [46].

Tomatoes grown in various habitats including arid Pacific coast to the mesic uplands in the high Andes, from near sea level to over 3,300 m.s.m. in elevation.

Besides, the wild tomato populations grow at different altitudes and are adapted to particular microclimatic and soil conditions (Warnock, 1988) [65]. Generally, tomatoes are the herbaceous plants and adopting secondary growth while, in their natural habitats tomatoes probably behave as annuals because frost or drought kill the plants after the first growing season (Solankey *et al*., 2015) [59]. This is a warm-season crop and sensitive to frost at any stage of their growth. The extreme high temperature over 95°F (35 °C) and low temperature below 50°F (10 °C) are responsible for reducing the seed germination, flower formation and fruit set, delay the fruit maturity and restrict red coloration (Solankey *et al*., 2015) [59]. Similarly, the water stress and flooding occur together the plant will suffer to survive and produce soft fruit. For this reason, most outdoor crops are grown in temperate climates in both the Northern and Southern hemisphere. Optimum relative humidity range from 60-85% is suitable for crop in night and day time. The tomato crop is survived in each fertile soil because the plant produces a fibrous root mass which can utilize the subsoil of cultivation pots. The soil pH range is 5.0-7.5 suitable for growing this crop because when pH level drops below 5.5 then magnesium and molybdenum availability also drops and when pH level increases above 6.5 then zinc, manganese and iron become deficient (Astija, 2020) [3]. Tomato plants require a constant supply of moisture during the growing season. Generally, under open field condition, it is requires 214-706 thousand gallons/acre of water in a season for producing high yielding crop. While, in the control condition (greenhouse), this crop is needs 0.3-0.5 gallon of water every day for each plant, this is equivalent to around 1 million gallon/acre per year (Takase *et al*., 2010) [63]. Low water availability in tomato can increase the drought conditions but may promote to inhibit the plant growth, reduce the flowering, increase the flower drop, reduce the fruiting in tomato plants and come several disorders like blossom end rot and other. However, the excess water may lead to root death as well as delayed the flowering and fruit set, and face to several fruit disorders like fruit cracking etc. In whole cropping seasons of tomato 3-6 irrigation is required. A maturity date of tomato had been determined by 60-70 days for determinate and more than 95 days for indeterminate varieties which had grown in northerly latitudes. This crop is sensitive to low light conditions only requires a minimum of 6 hours of direct sunlight to flower. If the intensity of solar radiation is too high then cracking, sunscald, and uneven coloration at maturity may appear. Under greenhouse conditions, the shading of fruit is essential because greenhouses occur across a very wide range of latitudes.

2. Interpretation for genetic nature

Genetic diversity

Tomato had grown globally and conserved a huge diversity of genetic resources (Peralta and Spooner, 2000; Bauchet and Causse 2012) [40, 5]. Nowadays, drastic reduction was found in genetic diversity of tomato, which may be due to its origin, domestication and morpho-physiochemical variability (Scintu *et al*. 2014) [49]. Certainly, the diverse geography and habitats as well as different climates contributed to wild tomato diversity (Warnock, 1988; Singh *et al*., 2014) [65, 57]. Differing numbers of species and conflicting specific classifications have been proposed, based on morphology or crossing studies. Two major cross ability groups had been identified in tomato, first one which included mainly self-compatible species that easily cross with the cultivated tomato but another which had comprised self-incompatible species and they did not cross with the cultivated tomato, easily. A similar research story has been published where a cross did not success when *S. habrochaites* was a female and *S. lycopersicum* was a male, but fertilization done when *S. habrochaites* used as a male. It may be the pollen tubes were arrested and the inter-specific cross was generally sterile due to the incongruity (Singh *et al*., 2015c) [55]. The morphological traits of tomato are determined by their diverse genetic structure, environment, and interaction between genotypes and environment. The genetic diversity represents the number of genetic characteristics and genetic makeup of a population to adapt the changing environments. Tomatoes have conserved rich diversity towards morphological and biochemical resources but among the cultivars (*S. lycopersicum*) a limited diversity had been reported (Bauchet and Causse, 2012) [5].

Genetic variability, heritability and genetic advance

Information on nature of genetic variability along with scale of heritability for any quantitative character during improvement of tomato crop is more important for a breeder (Iqbal *et al*., 2014) [24]. The correlation matrix between heritability and genetic advance helps in determining the influence of environment (Golani *et al*., 2007; Osei *et al*., 2014) [18, 38]. The perception of the genetic expressed the variability existing in populations, and gives the direction of relationship between two or more variables for genetic improvement in yield traits (Golani *et al*., 2007; Reddy *et al*. 2013; Nagariya *et al*., 2015) [18, 43, 34]. The environmental variances are influenced directly with the time of maturity and most of floral characters (Singh *et al*., 2015a) [56]. In some studies, the values of phenotypic coefficient of variation (PCV) were found greater than genotypic coefficient of variation (GCV) and the values of all characters of environmental coefficient of variation (ECV) were lesser than GCV and PCV. While, the most of the characters showed less difference between GCV and PCV values. Lesser difference between GCV and PCV for morphometric traits indicated additive gene action and strong genotypic interaction with less environmental effects (Shashikanth *et al*., 2010) [50]. It was also revealed that two values varied in narrow representing the variability due to genetic make-up of the genotypes and more inconsistency utilised by the environmental factor. Wide difference of ECV from GCV and PCV for morphological and yield traits indicated direct relation by environmental fluctuation, and the selection of desirable traits for highly variable characters would be effective in tomato improvement programme (Shashikanth *et al*., 2010) [50]. The genotypic coefficient of variation along with heritability estimates provided best scope for phenotypic selection and gives the reliable estimate of the amount of genetic advance (Singh *et al*., 2001) [53]. Recently, it had been reported that the highest heritability with high genetic advance for traits exhibited additive gene action and very useful to plant breeders for making effective selection during breeding programs (Singh *et al*., 2001; Reddy *et al*., 2013) [53, 43]. However, the lowest heritability and genetic advance are revealed non-additive (dominant or epistatic) gene action which barriers for tomato improvement through selection (Reddy *et al*., 2013) [43].

Genetic correlation and environmental interactions

The phenotypic traits of tomato were determined by their diverse genetic structure, environment, and interaction between genotypes and environment. These phenotypic inherent can be classified as either qualitative (where variation is controlled by one or few genes) or quantitative (where variation is continuous and controlled by several genes) in tomato according their heritability (Singh *et al*., 2015a) [56]. The correlation matrix between heritability and genetic advance helps in determining the influence of environment (Golani *et al*., 2007; Osei *et al*., 2014) [18, 38]. Correlation coefficient analysis is statistical measure which offers a perception into the genetic variability existing in populations, and gives the direction of relationship between two or more variables for generic improvement in yield traits (Reddy *et al*., 2013; Nagariya *et al*., 2015) [43, 34]. Previously, it has been studied that the positive correlation of yield per plant with stem length, number of fruits, and time of maturity are responsible for increasing the yield capacity (Kumar *et al*., 2013; Nagariya *et al*., 2015) [26, 34] while, the negative correlation of yield per plant with leaf size, fruit size and disease traits have been reported for yield hindrance (Singh *et al*., 2012) [52].

Principal component analysis and multivariate analysis

Principal component analysis (PCA) helps in extracting important variables from huge variables available in a data set and it is more useful when arrangement with higher dimensional data, simply, principal components analysis is using for data reduction from huge data set, and this PCA is also a technique that requires a large sample size (Hair *et al*., 2009; Carli *et al*., 2011) [22, 7]. Principal components analysis can be performed on raw data as a covariance matrix. If raw data is using then the procedure will create the original correlation matrix or covariance matrix as per specified by user. However, if the correlation matrix is using then the variables are standardized and the total variance will equal, the number of variables used because each standardized variable has a variance equal to 1 or the variables will remain in their original metric (Pratta *et al*., 2011; Iqbal *et al*., 2014) [41, 24]. This fact is allowed to identify those sensory attributes which are more influenced by environmental conditions and genetic constitution (Carli *et al*., 2011) [7]. The principal component accounts the variation in morphological and yield traits depending on the environmental fluctuation, time of transplanting, and varying as per tomato varieties and fixed with genetic nature (Hair *et al*., 2009; Pratta *et al*., 2011) [22, 41]. Total yield per plant is depend upon plant growth habit, number of node and internodes, number of flowers, number of fruits, average fruit weight and genetic architecture of plants. Yield is most required character from any crop for fulfilling the need of livelihood as has been discussed in many studies (Carli *et al*., 2011; Iqbal *et al*., 2014; Kumar *et al*., 2017) [7, 24, 27]. Further, a cluster analysis (CA) allowing for the components (PCs) extracted by the 'PCA' as variables was performed by defining a metric (Hair *et al*., 2009) [22]. The pairwise distances between clusters are computed by the constructed dendrogram. The similarities among groups of 'CAs' were quantified through the linkage distances (Hair *et al*., 2009; Iqbal *et al*., 2014) [22, 24]. Earlier, the multivariate analysis (MA) techniques was implemented by Infostat v. 2007, with a professional module taken from the 'R' module statistical package used for estimating linear and generalized linear models (Hair *et al*., 2009) [22]. Multivariate data analysis uses mathematical and statistical techniques to extract information from complex data sets (Kumar *et al*., 2017) [27].

Stability test analysis

The stability test is indicated to the static genetic behaviour of genotypes in diverse environment. Hence, stable phenotypic characters of a genotype have great importance due to changes in the environmental condition from year to year and region to region (Spaldon *et al*., 2017) [62]. Performance of stable genotypes for quantitative characteristics such as stabilizing yield traits and disease characteristics, has depended upon level of genotype x environmental interaction (Kumar *et al*., 2013) [26]. Therefore, the development of a genotype for resistance capacity, high yielding ability and consistency are depending on the genotypes x environmental interactions and phenotypic stability (Kumar *et al*., 2013; Singh *et al*., 2012; Singh *et al.* 2015a) [26, 52, 56]. The phenotypic stability is important for selection of better varieties in a wide range of environments for breeding purposes (Spaldon *et al*., 2017) [62]. According to Banerjee and Kalloo (1987) [4], the phenotypically stable genotypes had great importance due to the contrast environmental condition from year to year and region to region. Although a number of varieties have been recommended for the cultivation, the information on the stability is lacking for the agro-climatic conditions. So, there is necessity to evaluate and screen the potential genotype giving consistent performance over different years and to select the genotypes on the basis of stability parameters for important yield and maturity attributes (Singh *et al*., 2015a) [56]. It has a need of an hour to get the information about morphological characters for improving the yield capacity in different environments to isolate the diverse and stable cultivars of tomato for increasing the yield capacity (Kumar *et al*., 2013) [26].

Heterosis breeding

The heterosis breeding has been utilized as a unique tool for the development of potential hybrids having high yield and quality traits along with resistant capacity against diseases and pests (Singh *et al*., 2014) [57]. The key role of heterosis in plant breeding, is the exploitation of commercial hybrids for seed production. The exploitation of heterosis in F1 generation, is useful for the identification of superior hybrids and selection of those crosses that exhibited high degree of heterosis for economical traits. Earlier, it was studied that the heterosis has involved a genome wide dominant pair and authentic inheritance model for instance locus specific over-dominance reaction (Souza *et al*., 2012) [61]. As well, the heterosis breeding has considered as a functional heterozygosity and better way to observe high yield along with resistance by inter-specific crosses, because the wild species (*S. pimpinellifolium, S. chilense, S. peruvianum, S. habrochaites etc.*) have potential to survive under stress conditions (Singh *et al*., 2014) [57]. Use of wild species is to be increased the homozygosity of recessive deleterious alleles in tomato (Peralta and Spooner, 2000) [40]. In tomato, the breeding for resistance to pathogens and pests are major challenges for tomato breeders. In case of diseases, all the crosses of tomato showed negative heterosis, it was an indication of low disease incidence (Singh *et al*., 2022; Singh *et al*., 2014) [69, 57]. Sometimes, the negative heterosis had exhibited for yield traits and average fruit weight because the male wild accessions were diverse and dominant in genetic phylogeny of tomato (Souza *et al*., 2012) [61]. Usually, high level of heterosis for earliness and yield tratits is an evidence of the importance of non-additive gene effects or dominance gene effects (Souza *et al*., 2012; Solieman *et al*., 2013) [61, 60]. The dominant nature of heterosis is due to dominant gene and inhibitory gene action (Banerjee and Kalloo, 1987; Singh *et al*., 2015a; Singh *et al*., 2015d) [4, 56, 54]. Numerous, tomato hybrids exhibited superiority over the parents and revealed substantial heterosis for desirable traits (Solieman *et al*., 2013; Singh *et al*., 2015d) [60, 54].

3. Interpretation for pheno-morphological traits and phyto-physio-chemical properties

The plant hormones (phyto-hormones) *viz*., auxins, gibberellins (GA), cytokinins (CK), abscisic acid (ABA), ethylene (ET), jasmonic Acid (JA), salicylic acid (SA), brassinosteroids (BR) etc. are responsible as growth regulators and growth inhibitors from seed germination to fruit ripening for different function in plants (Gangwar *et al*., 2014; Zhu *et al*., 2015 Clouse, 2017) [17, 67, 8], as well as these phyto-hormones had also affected to different morphological traits (Table 1). Most of phytohormones had also been played important role for preventing the crops by biotic and abiotic stresses (Rivas-San and Plasencia, 2011; Gangwar *et al*., 2014) [48, 17]. The pheno-morphological trait is indicated to the distinct stages of morphological traits considered for data observation. According to DUS test guidelines, 2009, the data observation of tomato has been elucidated on various stages *viz*., cotyledon stage, seedling stage, vegetative stage, flowering stage, fruiting stage, maturity stage and harvesting stage (Gangwar *et al*., 2014) [17]. Anthocyanin has been detected mainly in outer cell layers such as the epidermis and peripheral mesophyll cells of plant parts (Qiu *et al*., 2016) [42]. The changes in the anthocyanin colour pigments depend on the range of pH because the anthocyanins had degraded at higher pH effect (Rick *et al*., 1994; Andersen 2001) [45, 1]. The cultivated tomato expressed anthocyanins on vegetative tissues, it may be possible due to transfer of anthocyanin-pigments by wild tomato relatives (Rick *et al*., 1994) [45]. Earlier, it has been reported that the anthocyanins are natural pigments which protects to plants from the damage by UV radiations (Table 1), and found in the cell vacuole of flowers, fruits, leaves, stems and some time in roots with different colours, red, purple, or blue (Rick *et al*., 1994; Qiu *et al*., 2016) [45, 42]. According to research, many vegetable crops have been reported for black or purple fruit colour pigments due to the anthocyanin, but in our knowledge, none of the tomatoes produced so-called purple or black due to anthocyanins. It has been studied that the anthocyanins played role of an antioxidant in plants against reactive oxygen and extreme temperatures (Rick *et al*., 1994; Butelli *et al*., 2008; Qiu *et al.* 2016) [45, 6, 42]. The antioxidant ability of anthocyanin has also been recognized for human and animal health which protects to human body by the serious diseases and showed a significant extension of life span (Table 1), and also utilized in the pharmaceutical industries for management of carcinogenesis and mutagenesis etc. (Lazze *et al*., 2004; Butelli *et al.* 2008; Vyas *et al.* 2009) [28, 6, 64]. These anthocyanins can be protected to tomato plants by cold stress with countering reactive oxygen and leading a lower rate of cell death in leaves (Rick *et al*., 1994; Qiu *et al*., 2016) [45, 42]. The importance of pheno-morphological and physio-chemical properties discussed for leaf, flower and fruit characteristics. The tomato flavour is due to a complex mixture of volatile and non-volatile compounds. The aroma of fresh ripe tomato may be due to appropriate concentrations of cis-3-hexenal, cis-3-hexenol, hexanal, 1-penten-3-one, methyl salicylate, 2-isobutylthiazole, and ß-ionone, that has indicated a genetic correlation between colour patterns and aroma of tomato (Davidovich *et al*., 2016) [10]. Distefano *et al.* (2022) [14] noticed that more than 400 volatile organic compounds (VOCs) are responsible for tomato aroma and its flavour sensitivity.

Leaf

The intensity of deep green colour in tomato leaves is due to presence of high concentrations of chlorophyll content (Rick *et al*., 1994; Singh *et al*., 2015b) [45, 58]. They studied that the colour of leaves is a simple indicator of healthiness of plants, deeper green indicates more availability of chlorophyll (Table 1). Chlorophyll appears green colours in tomato leaves because it reflects green-coloured light and absorbs to other colours (Rick *et al.* 1994; Peralta and Spooner, 2000; Singh *et al*., 2015b) [45, 40, 58]. Healthy green colour and vigorousness in leaves or leaflets may also be an indicator for producing high yield in tomato (Singh *et al*., 2015b) [58]. Vigorousness in leaves may be due to nature of plant growth habit. Vigorousness in plants caused a reason for increasing the total stomatal number. Similar scope for high yield and high stomatal density were found in broad leaf area because stomata facilitate photosynthesis in plants and convert sunlight into usable energy (Lopez-Gresa *et al*., 2018) [31]. Another issue in tomato is the presence of pubescence or hairs or trichomes (Figure 1). Theoretically, these dense covering of pubescence protects the living cells surface from direct flow of air, frost and heat in open habitats and also reducing the transpiration rate in plant (Peralta and Spooner, 2000) [40]. 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). A specific aroma or volatile compound in leaf is due to presence of hexenyl butyrate (HB) chemical compound as well as this organic volatile has great potential for protecting the crops from bacterial attacks, other infections and drought (Lopez-Gresa *et al*., 2018) [31].

Flower

Flowers are an attractive gift of nature in a crop with pleasant fragrance and diverse colours. Tomato flowers had classified in yellow and orange colour with green and yellow colour of anther as per DUS test guidelines of tomato, 2009. These colours of flower and anther indicated presence of xanthophylls pigment as discussed in Table 1 (Peralta and Spooner, 2000; Ariizumi *et al*., 2014; deMelo *et al*., 2015) [40, 2, 11]. The abscission layer was present in most of tomato fruits which indicated to strong joint between fruits and peduncles. Dropness of flower buds, fruits and leaves in tomato crop take place due to start the formation of abscisic acid in abscission layer (deMelo *et al*., 2015; Pan *et al*., 2021) [11, 39]. The pectin, sugar, expansin, cyclin, auxin and jasmonate (JA) had caused the cell division and cell expansion in flower, which are responsible for determine the length of stamens and pistils as well as fasciations and stigma exsertion (Figure 2) in tomato flowers (Wasternack *et al*., 2006; Gangwar *et al*., 2014; Pan *et al*., 2021) [66, 17, 39].

Fruit

Presence of green shoulder on tomato fruits before maturity was indicated presence of high availability of chlorophyll content (Figure 3). Presence of green shoulder on tomato fruit may be responsible for late ripening, while, the availability of phenol and ethylene promoted to dark red colour of fruits after maturity or may be chlorophyll convert into high lycopene (D'souza *et al*., 1992; Rick *et al*., 1994; Klee, 2000; Zhu *et al*., 2015) [15, 45, 25, 67]. The morphological and phytochemical traits of tomatoes may be easily altered because these traits also influenced by environmental conditions (Osei *et al*., 2014) [38]. However, the colour of skin and flesh were observed in various colour *viz*., green, yellow, orange, pink and red at the maturity stage (Figure 3). Earlier, tomato fruits had 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 *i.e*., skin and flesh. During ripening of tomato fruit the chlorophyll content has been converted into various pigments of carotenoids (D'souza *et al*., 1992; Fraser *et al*., 1994) [15, 16]. Red and yellow colours of fruit indicates to presence of high level of lycopene and beta-carotene (Table 1) 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) [20, 15, 16, 35]. Earlier, it has been studied that during maturity of fruits the chlorophyll (green colour) lost and increased the carotenoids (red, yellow and orange colour) or induces yellowing of green tissues due to decolouration or degradation in chlorophyll colour pigmentation, because of the secretion of small amount of ethylene in fruits (Goodenough *et al*., 1982; D'souza *et al*., 1992; Fraser *et al*., 1994; Klee, 2000; Zhu *et al*., 2015) [20, 15, 67, 25, 16]. Genetically, colour of skin is controlled by a single recessive gene *y*. The *y*+ (wild type) is dominant and gave results in yellow skin (*y*+*y*=yellow skin). When *y* is expressed in a recessive pairing then the result was red skin (*yy*=red skin). 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, for examples, the red flesh or green flesh and other colours expressed with the bi-colour (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; Goodenough *et al*., 1982) [21, 20]. These pigments affected to colour appearance and nutrition and flavour of fruit (Gormley and Egan, 1978) [21].

Tomato fruits provides high amount of antioxidant biomolecules like lycopene, betacarotene, provitamin-A, carotenoid, ascorbic acid, phenolics, flavonoids and vitamin E which is beneficial for human health (Singh *et al*., 2014) [57]. Lycopene is the major carotenoid in tomato fruit with the nutraceutical properties related to a powerful anti-oxidant, and reducing the risk of cancers, heart diseases, age-related diseases etc. While, paste of ripe tomato fruits is used for increasing glow on human face (Nasir *et al*., 2015) [35]. The presence or absence of skin colour pigments can be recognized by phenotypic characteristics duringvisual observation. The cultivated tomatoes are mainly found in three colours red, yellow and tangerine due to the complex mixtures of carotenoid pigments (Fraser *et al*., 1994) [16]. 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. The red-fruited tomatoes hold several carotenoid pigments and sufficient amount of lycopene (Nasir *et al*., 2015) [35]. The tangerine tomato derives its colour from a closely related orange carotenoid pigment, pro-lycopene (Fraser *et al*., 1994) [16]. Earlier it had reported that the red colour in tomato fruits is due to the degradation of chlorophyll and synthesis of lycopene because of chloroplasts are converted into chromoplasts (Fraser *et al*., 1994) [16].

Aromas and flavours had played an important role in horticultural crops including tomato. The unique flavour of tomato fruit is one of the favourite ingredients of many dishes because fruit flavour is a mixture of feelings of the aroma and taste (Rikanati *et al*., 2016) [47]. The presence of fruit flavours are due to complex mixture of volatile and non-volatile compounds *i.e*., sugars, organic acids, phenolics and >100 volatile compounds, b-ionone, E-2-hexenal, 6-methyl-5-hepten-2-one, and phenyl-acetaldehyde, but less quantity of these compounds and chemicals had responsible for poor flavour of fruits (Di Matteo *et al*., 2010; Rikanati *et al*., 2016; Goncalves *et al*., 2018) [13, 47, 19]. They suggested that the aroma of fresh ripe tomato is also possible due to presence of cis-3-hexenal, cis-3-hexenol, hexanal, 1-penten-3-one, methyl salicylate, 2-isobutylthiazole, and ß-ionone in desired concentrations (Rikanati *et al*., 2016; Goncalves *et al*., 2018) [47, 19]. Sometimes, the flavour and aroma are also depended on the particular varieties, agronomical practices, edaphoclimatic conditions, and postharvest handling as well as the genetic proof had indicated correlation between colour patterns and aroma in fruits of tomato (Rikanati *et al*., 2016; Goncalves *et al*., 2018) [47, 19].

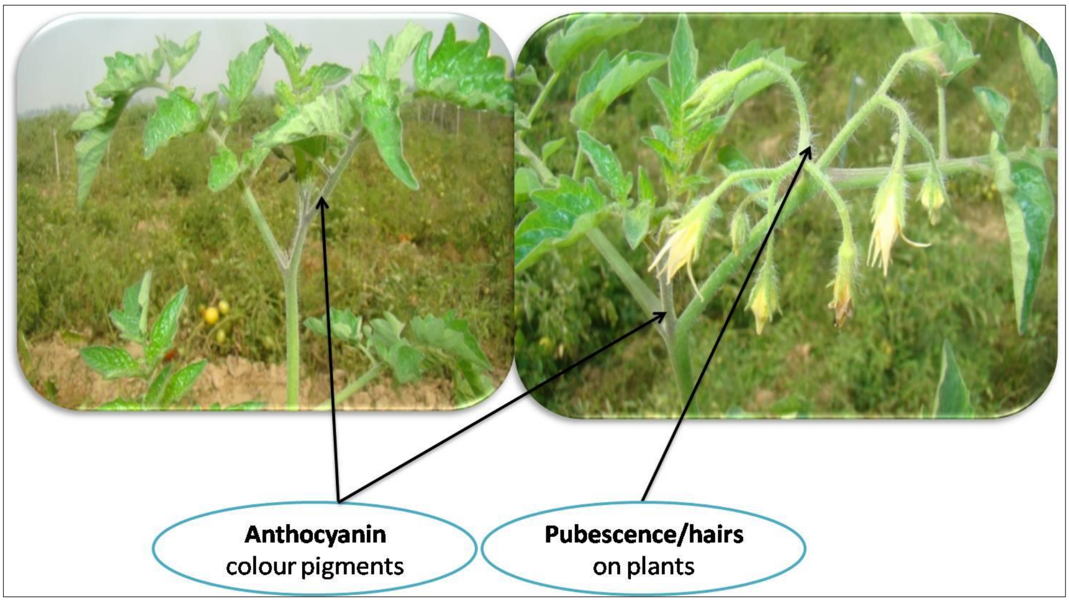


Fig 1: Presence of anthocyanin (colour pigments) and pubescence (hairs) on tomato.

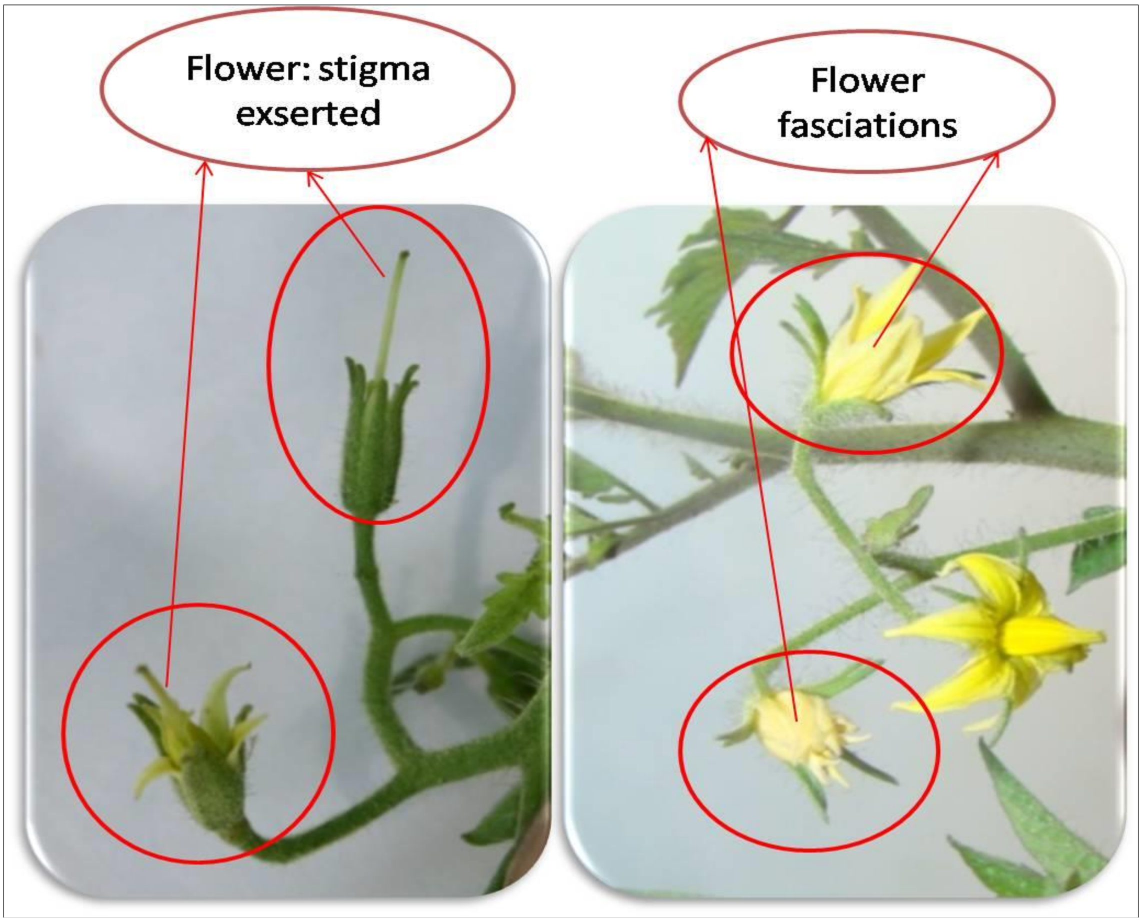


Fig 2: Stigma exertion and fasciations in the flowers of tomato.

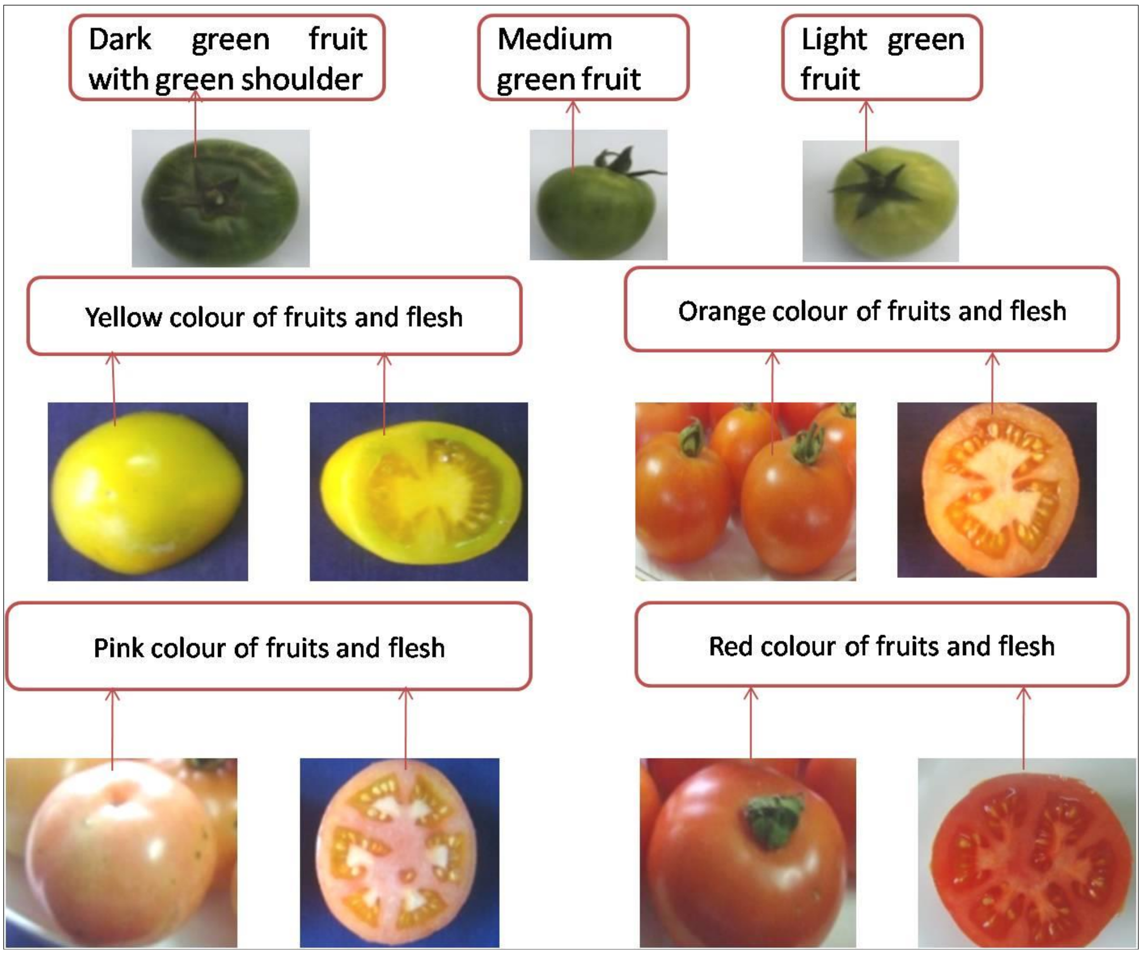
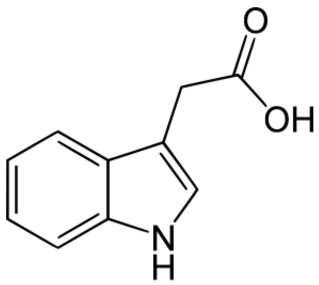
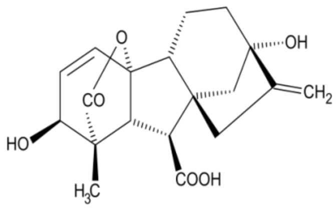
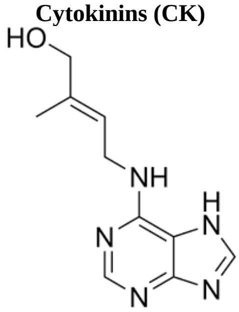
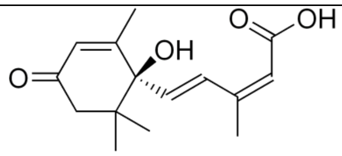
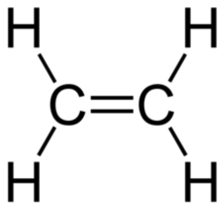
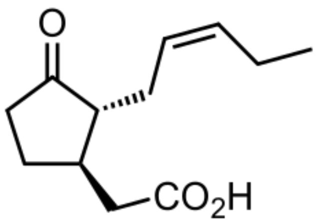
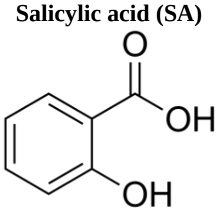
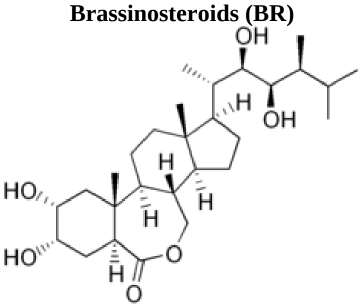
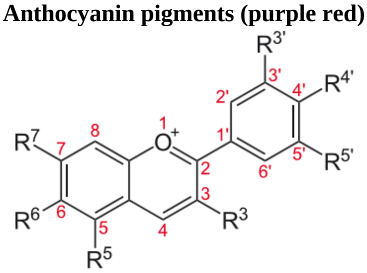
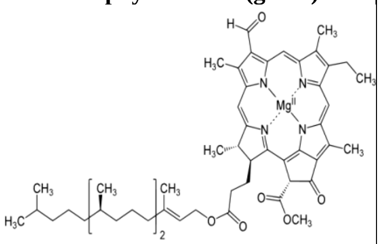


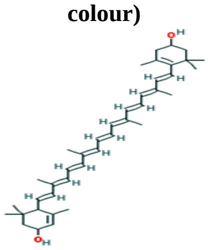
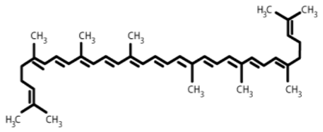
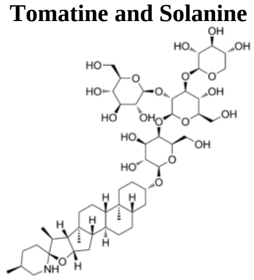
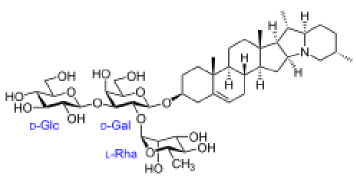
Fig 3: Diverse colours on skin and flesh of tomato fruits.

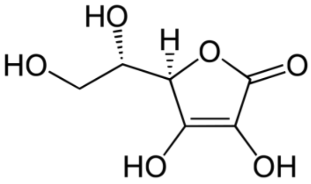
Table 1: Phyto-physio-chemicals compounds in tomato and their properties and economic importance.

Phyto- chemicals and their structures in tomato	Plant parts	Biochemical activities/properties and their value for plant and humanbeing	Source References
Auxins 	Apical meristem cell, leaves stem, root	▪ Auxins were the first growth hormone isolated from the coleoptile tip of oat seedlings. ▪ Plants produce natural auxins such as Indole-3-acetic acid (IAA) and Indole butyric acid (IBA) and synthetic auxins such as Naphthalene acetic acid (NAA) and 2, 4-dichlorophenoxyacetic (2, 4-D). ▪ Natural auxins are found in growing stems and roots from where they promote their action. ▪ Synthetics are involved in tropisms, apical dominance and growth of lateral buds ▪ Helps in cell division, cell elongation of stems and roots and xylem differentiation ▪ Promote flowering, fruit set and increasing the fruit size in tomato. ▪ Prevent dropping of leaves, flowers, and fruits too early. ▪ Induces parthenocarpy (development of fruit without fertilisation) in tomatoes ▪ Useful in stem cuttings and grafting where it initiates rooting	Gangwar *et al*., 2014; Clouse, 2017 [17, 8]
Gibberellins (GA) 	Buds, root, stem, leaves	▪ Gibberellin causes some similar effects in plants as auxin, but it is a very different hormone. ▪ Gibberellins were discovered originally in Japan. A fungus called *Gibberella fujikuroi* infected rice plants and caused them to grow too tall and fall over. ▪ The infectious fungus produced a chemical named 'Gibberellin'. ▪ There are more than 100 gibberellins (GA1, GA2, GA3…..) found acidic in nature. ▪ Gibberellins promote stem elongation between nodes on the stem and reverses dwarfism. ▪ Control fruit set and growth, and seed development in tomato ▪ Delays senescence and fruit ripening in tomato ▪ Induces parthenocarpy ▪ Break the dormancy of seeds and buds; promote growth	Gangwar *et al*., 2014; Clouse, 2017; Li *et al*., 2019a [17, 8, 29]
Cytokinins (CK) 	Buds, root, stem, leaves	▪ Cytokinins play an important role in cytokinesis process. ▪ Plants produce natural cytokinins such as zeatin (corn kernels, coconut milk) and isopentenyladenine, as well as synthetic cytokinins such as kinetin, benzyladenine, diphenylurea and thidiazuron. ▪ Cytokinins are naturally synthesised in the plants where rapid cell division occurs in tomato *e.g.* root apices, shoot buds, young fruits and development fruit. ▪ Movement of cytokinins is basipetal and polar. ▪ It promotes lateral and adventitious shoot growth and used to initiate shoot growth in culture ▪ Helps in overcoming apical dominance induced by auxins ▪ Stimulate the formation of chloroplast in leaves ▪ Promotes nutrient mobilisation and delay leaf senescence ▪ Prevent senescence	Matsuo *et al*., 2012; Gangwar *et al*., 2014; Clouse, 2017 [32, 17, 8]
Abscisic acid (ABA)	Leaves,	▪ It is a growth-inhibiting hormone. ABAs act	Ntatsi *et al*., 2012; Gangwar *et al*., 2014;

	fruits, flowers	as an antagonist to GAs. ▪ It is also called “stress hormone” as it increases the tolerance of plants. ▪ Induces abscission of leaves and fruits ▪ Inhibits seed germination ▪ Induces senescence in leaves ▪ Accelerates dormancy in seeds that is useful for storage purpose ▪ Stimulates closure of stomata to prevent transpiration under water stress	Clouse, 2017 [36, 17, 8]
Ethylene (ET) 	Leaves, fruits, flowers	▪ Ethylene is an unusual plant hormone because it is a gas and a very simple organic compound. ▪ It can move through the air, and a ripening fruit can cause another fruit to ripen or over-ripen. ▪ Ethylene has very limited solubility in water and did not accumulate within the cell. ▪ Ethylene is produced at faster rate in rapidly growing & dividing cells, especially in darkness. ▪ New growth & germinated seedlings produce more ethylene, which leads to inhibit leaf expansion. ▪ In tomato, ethylene is an essential component of flower senescence, organ abscission, adventitious root initiation, and fruit ripening. ▪ Ethylene is also critical for aspects of biotic and abiotic stress responses. ▪ Ethylene affects cell growth, cell shape, stop cell elongation & causing the stem swelling. ▪ Ethylene is true regulator rather than being a requirement for building plant's basic body plan.	Klee, 2002; Gangwar *et al*., 2014; Clouse, 2017 [25, 17, 8]
Jasmonates (JA) 		▪ Jasmonates (JAs) are lipid-based hormones that were originally isolated from jasmine oil. ▪ JAs are especially important in the plant response to attack from herbivores and necrotrophic pathogens. ▪ The most active JA in plants is jasmonic acid. ▪ Jasmonic acid can be further metabolized into methyl jasmonate (MeJA), which is a volatile organic compound. ▪ This unusual property means that MeJA can act as an airborne signal to communicate herbivore attack to other distant leaves within one plant and even as a signal to neighboring plants. ▪ Their role in defense, seed germination, storage of protein in seeds and root growth. ▪ Plants respond to mechanical wounding or herbivore attack with a complex scenario of sequential, antagonistic or synergistic action of different signals leading to defense gene expression. ▪ Tomato plants were used as a model system since the peptide systemin and the lipid-derived jasmonic acid (JA) were recognized as essential signals in wound-induced gene expression.	Wasternack *et al*., 2006; Gangwar *et al*., 2014; Clouse, 2017 [66, 17, 8]
Salicylic acid (SA) 		▪ Salicylic acid (SA) is a hormone with a structure related to phenol. ▪ It was originally isolated from an extract of white willow bark (*Salix alba*). ▪ In a similar manner to JA, SA can also become methylated. ▪ It is useful to make human medicine as precursor of the painkiller aspirin.	Rivas-San and Plasencia, 2011; Gangwar *et al*., 2014; Clouse, 2017; Li *et al*., 2019b [48, 17, 8, 30]

		▪ In plants, SA plays a critical role in the defense against biotrophic pathogens. ▪ Salicylic acid (SA) plays important roles in inducing resistance to biotic stresses (*Tomato yellow leaf curl virus)* and abiotic stresses (drought, high temperatures, heavy metals, and osmotic stress) in tomato.	
Brassinosteroids (BR) 		▪ Brassinolide was the first identified brassinosteroid and was isolated from extracts of rapeseed (Brassica napus) pollen in 1979. ▪ Brassinosteroids are a class of polyhydroxysteroids, the only example of steroid-based hormones in plants. ▪ Brassinosteroids control cell elongation and division, gravitropism, resistance to stress, and xylem differentiation. ▪ They inhibit root growth and leaf abscission. ▪ BRs control almost all aspects of plant growth and development, and also play significant role in plant adaptation to biotic and abiotic stresses. ▪ These findings suggest that brassinosteroids are involved in the development of fruit quality attributes and ethylene-mediated fruit ripening of tomato. ▪ Brassinosteroids influenced the postharvest quality of tomato fruit.	Gangwar *et al*., 2014; Zhu *et al*., 2015; Clouse, 2017 [17, 67, 8]
Anthocyanin pigments (purple red)  Basic chemical structure of anthocyanin (C15H11O+)	Seedlings, leaves, Flowers, stems, fruits	▪ Water soluble and natural pigments derived from anthocyanidins by adding sugars which may appear in red, purple, or blue colour in plants which depending on the pH. Presence of colour plays role for attracting pollinators as well as protects to plant from damage by UV radiation. ▪ Acts as an antioxidant in plants against reactive oxygen species caused by abiotic stresses, such as over exposure to ultraviolet light and extreme low and high temperatures. Use in organic solar cells because of their ability to convert light energy into electrical energy. ▪ Increase the antioxidant capacity of blood and the uric acid levels derived from metabolism of flavonoids (formed by phenylpropanoid metabolism from phenylalanine). Utilizing in the pharmaceutical industries for management of carcinogenesis and mutagenesis etc. ▪ A gene causing anthocyanin production in fruit is Aubergine (Abg). Abg was introgressed into tomato from *Solanum lycopersicoides* dunal accession LA-2408 and has been mapped to chromosome 10 of cultivated tomato.	Rick *et al*., 1994; Andersen, 2001; Lazze *et al*., 2004; Vyas *et al*., 2009; Qiu *et al*., 2016. [45, 1, 28, 64, 42]
Chlophyll content (green)  Basic chemical structure of chlorophyll (compound) (C55H72O5N4Mg)	Leaves, stems, fruits	▪ It is water-soluble and found in the chloroplast of thalakoids of plants. Deep green colours of leaves and plants indicating the presence of high concentrations of chlorophyll content. ▪ It allows better conversion of solar energy into food (carbon dioxide and water into sugar (glucose) and oxygen) and other growth-enhancing substances due to better photosynthetic procedures. Creates the oxygen for using the living organism. ▪ Chlorophyll drink enhances the quality and quantity of human red blood cells (hemoglobin), resulting in improved energy and health with the green extract. If it takes in liquid form, may have detoxifying capabilities that may eliminate toxins and it	Rick *et al*., 1994; Singh *et al*., 2015b [45, 58].

		may be possible for treatment of liver disease and certain types of cancer. Some time its supplement has positive effects on the liver and may prevent by Type 2 diabetes, pneumonia, pancreatitis, herpes and tuberculosis etc.	
Xanthophylls pigments (yellow colour)  Basic chemical structure of xanthophyll (C40H56O2)	Flowers, anthers, fruits	▪ Xanthophylls are yellow pigments produces from the oxygenated carotenoid group. ▪ Carotenoids are fat-soluble compounds that are digested and absorbed with the fats in our diet. ▪ In tomato these carotenoid compounds known by carotenes and xanthophylls. Xanthophylls have lutein, zeaxanthin, neoxanthin, violaxan thin and cryptoxanthin. ▪ The provitamin or β-Carotene is the dietary precursor of vitamin A and plays an important role in human nutrition and its deficiency leads to xerophthalmia and child mortality and have important preventive effects against degenerative eye diseases. It is also act as free redical traps or antioxidants and may play an important role in quenching of toxic radicles.	Peralta and Spooner, 2000; Dharmapuri *et al*., 2002; Ariizumi *et al*., 2014; deMelo *et al*., 2015 [40, 12, 2, 11]
Lycopene content (red and pink)  Basic chemical structure of all-trans-lycopene (C40H56)	Fruits	▪ A polyunsaturated hydrocarbon, insoluble in water and structurally a tetraterpene and assembled by eight isoprene units of carbon and hydrogen. ▪ Prepare by the ripe fruits of tomato. Chemically it is a carotene but absence of vitamin A activity. In fresh ripe tomato its content ranges from 150 to 250mg/kg or 5% to 15%, depending on the nature of the fruit. While, in tomatoes and tomato products it contain predominantly of all-trans-lycopene (35-96% of the total lycopene) and low levels of cis-lycopenes (1-22% of the total lycopene). However, a cup of raw cherry tomatoes provides 3834µg lycopene and a cup of raw, chopped tomatoes provides 4631µg lycopene. ▪ Currently, this is the most powerful antioxidant plays a role in preventing prostate cancer and cardiovascular/heart disease.	European Food Safety Authority (EFSA), 2008; Shi and Maguer, 2000; Nasir *et al*., 2015 [51, 35]
Tomatine and Solanine  Basic chemical structure of all-trans-Tomatine (C50H83NO21)  Basic chemical structure of all-trans-Solanine (C45H73NO15)	Stem, leaves and fruits	▪ Tomatine (also called lycopersicin) is a glycoalkaloid, sometimes confused with the glycoalkaloid solanine. Tomatine is found in the stems and leaves of tomato plants, and in the fruits at much lower concentrations. While, solanine is found in leaves and fruits of all solanaceous vegetables. ▪ Tomatine may play major role in resistance of the tomato plant against fungal, microbial, insect, herbivoral attack, colorado beetle and to snails because it has fungicidal, antimicrobial, and insecticidal properties. It can also stimulate the immune system by participation in a sequence of the respiratory burst by help of hydrogen peroxide. ▪ The symptoms of acute tomatine poisoning in animals are similar to the symptoms of poisoning by solanine, a potato glycoalkaloid. These sympotoms are vomiting, diarrhea, abdominal pain, drowsiness, confusion, weakness, and depression. Generally, tomatine is regarded to cause less toxic effects to mammals than other alkaloids such as solanine.	Hoagland, 2009; Morris and Lee, 1984 [23, 33]
Ascorbic acids (Vitamin C)	Fruits	▪ An antioxidant, water soluble vitamin and found 23mg/100g content in ripe/raw	Clutter and Miller, 1961; Halliwel and Gutteridge, 2007; Nwaichi *et al*., 2015; Di

 Basic chemical structure of ascorbic acids($C_6H_8O_6$)		tomatoes. Presence of more ascorbic acid provides the faster ripening speed of tomatoes. ▪ High level of ascorbic acid improves both biotic and abiotic stress tolerance in plants and enhances postharvest fruit quality. ▪ Need for the growth and repair of tisssues in all parts of body which helps the body make collagen (a protien), used to make skin, cartilage, tendons, ligaments, and blood vessels. It is also needed for healing wounds, and for repairing and mainataining bones and teeth. ▪ Uncontrolled production of oxygen derived free radicals is involved in the onset of many diseases such as cancer, rheumatoid arthritis, and arteriosclerosis as well degenerative processes associated with aging.	Matteo *et al*., 2010 [9, 70, 37, 13]
Vitamins and minerals	Fruits (red, ripe, and raw)	▪ In 100g tomato fruits found vitamin A (42µg), vitamin C (13.7mg), vitamin D (0µg), vitamin E (0.54mg), vitamin K (7.9µg), vitamin B1/thiamine (0.04 mg), vitamin B2/riboflavin (0.02mg), vitamin B3/niacin (0.59mg), vitamin B5/panthothenic acid (0.09mg), vitamin B6/pyridoxine (0.08mg), vitamin B12 (0µg), folate (15µg), choline (6.7mg), calcium (10mg), iron (0.27mg), magnesium (11mg), phosphorus (24 mg), potassium (237mg), sodium (5 mg), zinc (0.17mg), copper (0.06mg), manganese (0.11mg), selenium (0µg), calories (18), water (95%), protein (0.9g), carbohydrates (3.9g), sugar (2.6g), fiber (1.2g), glucose (1.3g), fructose (1.4g), fat (0.2g), saturated (0.03g), monounsaturated (0.03g), polyunsaturated (0.08 g), omega-3 (0g), omega-6 (0.08g), tryptophan (6mg), threonine (27mg), isoleucine (18mg), leucine (25mg), lysine (27mg), methionine (6 mg), cysteine (9mg), tyrosine (14mg), valine (18mg), arginine (21mg), histidine (14mg), alanine (27mg), aspartic acid (135mg), glutamic acid (431mg), glycine (19mg), proline (15mg), serine (26mg), saturated fatty acids (0.028g), monounsaturated fatty acids (0.031g), polyunsaturated fatty acids (0.083g), cholesterol (0 mg). ▪ Tomato contains coumaric acid and chlorogenic acid which protects to body from carcinogens. ▪ Vitamin A, K and calcium in tomato keeps the hair shiny and beneficial for eyes, and skin, and also usefull for repairing bones and bone tissues and teeth. ▪ Vitamin B and potassium in tomatoes are effective in reducing cholesterol level and lowering blood pressure. It can also prevent by heart attacks, strokes etc. While, vitamin C works as an antioxidant and protects by harmfull free redicles in blood.	Source: By Adda Bjarnadottir, MS. Tomatoes 101: Nutrition Facts and Health Benefits (https://authoritynutrition.com/foods/tomatoes); https://www.floridatomatoes.org/news-events/10-reasons-why-you-should-be-eating-more-tomatoes/; Nasir *et al*., 2015 [35]

*Basic chemical structures and formula of phyto-chemicals are received from specific site of google encyclopedia.

Conclusion

Finally, we have reached on a conclusion that the most of tomato cultivars showed distinctiveness for their characters. This is an overview on the huge information available regarding these characteristics in tomato. A high level of diversity in morphological traits indicates that the collection of huge genotypes may be suitable for future association mapping in addition to breeding purposes. In this study, it has confirmed that each trait has its economic and social value *i.e.*, presence of phyto-hormones are responsible for cell division, cell elongation, protect to seed dormancy, fruit ripening, protect by biotic and abiotic stresses etc., as well as presence of the pubescence in tomato protects to plant by insect and speedy winds and presence of anthocyanin protects to plant by UV rays and protect to human by cancerous diseases. Besides the morphological eco-properties, tomato had contained many phyto-physio-chemical compounds. Such type tomato fruits can be utilized in food industry for processing. Presence of aroma and flavours in tomato fruits are due to the complex combination of sugars, organic acids, phenolics and >400 volatile and non-volatile compounds. This study will provide sufficient fictions on tomato and may be helpful for students and researchers. Since, on the basis of best of my knowledge limited literatures have been studied on genetic nature for morphological traits and phyto-physio-chemical properties on single platform.

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