EVALUATION OF TOMATO (*Solanum lycopersicum* L.) GENOTYPES FOR YIELD UNDER WATER STRESS CONDITIONS

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"EVALUATION OF TOMATO (*Solanum lycopersicum* L.) GENOTYPES FOR YIELD UNDER WATER STRESS CONDITIONS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"EVALUATION OF TOMATO (*Solanum lycopersicum* L.) GENOTYPES FOR YIELD UNDER WATER STRESS CONDITIONS"** is a record of research work done independently by Ms. Namitha Elizabeth under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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We, the undersigned members of the advisory committee of Ms. Namitha Elizabeth, a candidate for the degree of **Master of Science in Agriculture** with major in Plant Breeding and Genetics, agree that the thesis entitled **"Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for yield under water stress conditions"** may be submitted by Ms. Namitha Elizabeth, in partial fulfillment of the requirement for the degree.

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LIST OF ABBREVIATIONS

%	-	per cent
&	-	and
ANOVA	-	Analysis of Variance
DAS	-	Days After Sowing
DAT	-	Days After Transplanting
CD (0.05)	-	Critical Difference at 5 % level
cm	-	centimeter
m	-	meter
g	-	gram
hr	-	hour
µmol	-	micromoles
d.f	-	degrees of freedom
et al.	-	and co-workers/co-authors
Fig.	-	Figure
GCV	-	Genotypic Coefficient of Variation
PCV	-	Phenotypic Coefficient of Variation
ECV	-	Environmental Coefficient of Variation
GAM	-	Genetic Advance as percentage of Mean
H^2	-	Heritability
V_G	-	Genotypic Variance
V_P	-	Phenotypic Variance
V_E	-	Environmental Variance
i.e.	-	that is
KAU	-	Kerala Agricultural University
SE	-	Standard Error
viz.	-	namely
RWC	-	Relative water content

Introduction

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most accepted and extensively cultivated vegetables in the world, being a rich source of health building substances especially vitamins and minerals. It is a self-pollinated solanaceous vegetable crop originated in the Peru-Ecuador-Bolivia region (Rick, 1969).India is the second largest producer of tomato in the world. The production in India is 16.38 mt from an area of 0.7 mha with a productivity of 21t ha^{-1} in 2014- 2015 (NHB, 2016).

On a global scale, abiotic stress is the principal cause of crop loss, causing average yield loss of more than 50% for major crops. Of all the abioitic stresses limiting crop productivity, drought is considered as the most important. Several efforts have been made to improve crop productivity under conditions of water deficit. With the anticipated climate change, the destructive effects of drought are expected to increase. The Intergovernmental Panel on Climate Change (IPCC) predicts that during the next decades CO_2 concentration and average temperature will increase, the precipitation will decrease in most subtropical regions (Stikic *et al.,* 2014).

Vegetables are more sensitive to drought compared to many other crops (Kumar *et al.,* 2012). It is estimated that by the year 2025, one third of the world population will be debilitated by water scarcity. According to the fifth assessment report of IPCC (2014), drought is the significant impact of present climate related extremes.

Of the total geographical area of India, two third parts receive rainfall less than 1000 mm which is not distributed equally. India has only 40% water use efficiency of total existing irrigation projects. Around 68% of net sown area (140 mha) is affected by drought conditions and 50% of this area is known as severe region where drought regularly occurs (http://www.dsc.nrsc.gov.in).

Climate change acts as a triggering force for the occurrence of drought in many food-producing regions. (Reynolds and Ortiz, 2010). As climate change is drastically affecting crop production, in order to provide for the expected population of 9.6 billion people in 2050, the productivity has to be increased by atleast 60% (Cabot *et al.,* 2014). This can be achieved by bringing marginal lands affected by drought stress under cultivation. Factors such as timing, duration and severity of the stress, the cultivar involved and the developmental stage of the crop determine the effects of drought stress on a plant and the extent to which the plant withstands the stress (Jefferies, 1994).

Water deficit or drought stress is regarded as the most common abiotic stress factor that limits crop productivity (Gupta *et al.,* 2014). Most of the commercial tomato cultivars sensitive to drought at all stages of development, including seed germination, seedling emergence, vegetative growth and reproduction (Zdravkovic *et al.,* 2013).

Water stress adversely affects plant growth by limiting the rate of photosynthesis. Drought stimulates a reduction in plant tissue water content which subsequently reduces the water potential, leaf elongation, rate of photosynthesis and causes changes in protein synthesis, nitrogen metabolism and cell membrane properties, which ultimately limits the plant productivity (Saneoka *et al.*, 2004).

Low availability of soil moisture hampers seed germination and seedling growth. Various physiological processes in plants at different stages are adversely affected by drought, which reduces the quality and quantity of yield. In tomato, every stage from seed germination to harvesting is very susceptible to water stress. For high yield and good quality, tomato needs a controlled supply of water throughout the growing period .The crop is sensitive to water scarcity and water requirement is critical especially during flowering and fruit enlargement stages (Rao *et al.*, 2000). Water stress influences the growth and yield of tomato depending on the stage of crop growth during which stress occurs. The effects of water stress on the crop is

manifested as reduced growth, reduction in leaf surface area, flower shedding, mineral deficiency due to lack of absorption, reduction in fruit size, fruit splitting, puffiness and many physiological disorders related to calcium deficiency such as blossom end rot, poor seed viability etc.(Kumar *et al.*, 2012).

Despite of many decades of research drought continues to be a major challenge due to its unpredictable occurrence, timing, severity and duration. As the hazards of climatic change is drastically escalating, the selection and development of resistant vegetable genotypes to drought and other environmental stress factors seems to be one of the best precautions to cope up with hunger (Suyum *et al.*, 2012).

To prevail over the threats of water deficit and to improve crop productivity, it is vital to develop the drought tolerance associated traits in cultivated plants (Neumann, 2008). Therefore, food security in the 21st century will progressively rely on the release of cultivars with enhanced adaptation to drought conditions. Screening of various drought resistant genotypes can be useful in breeding programmes for release of drought resistant varieties of tomato.

For sustaining global food production, drought tolerant crops with consistent yield under extensive periods of mild or severe stress are essential (Morison *et al.*, 2008).Many of the modern cultivars and hybrids are mainly drought sensitive. Hence, the genotypes identified as adaptive in target areas will be useful to be introduced in breeding programs (Foolad, 2007).

The present investigation is thus aimed at identifying high yielding genotypes of tomato under water stress conditions. The promising genotypes identified can further be included in breeding programmes for the development of high yielding water stress tolerant varieties.

Review of Literature

2. REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L.) is one of the most important and widely cultivated crops in the world and the second most important vegetable consumed after potato. The crop hails its origin from the Peru- Ecuador- Bolivia region. Tomato, being a rich source of vitamins, sugars, minerals, and antioxidant compounds, is a major dietary component in many countries. Abiotic stress is the primary cause of crop loss worldwide, causing average yield losses of more than 50% for major crops (Boyer, 1982). Of all the abioitic stresses limiting crop productivity, drought is considered as the most important one and improving crop productivity under water-limiting conditions is a major concern in many crop improvement programmes (Cattivelli *et al.*, 2008).

Factors such as timing, extent and the harshness of the stress, the cultivar concerned and the growth stage of the crop determines the effects of drought stress on a plant and the extent to which the plant endures the stress (Haverkort *et al.*, 1990; Jefferies, 1994). One of the best safeguards to cope with hunger under the risk of climatic aberrations is the selection and development of resistant vegetable genotypes to drought and other abiotic stress factors (Suyum *et al.*, 2012).

The present study is reviewed under the following topics.

2.1. Growth characters

2.2. Flowering characters

2.3. Fruit and yield characters

2.4. Physiological and biochemical characters

2.5. Genetic parameters

2.6. Correlation studies

2.7. Path coefficient analysis

2.1. GROWTH CHARACTERS

Fisher and Nel (1990) studied the impact of water stress on tomato growth and yield components and reported an absence of response of tomato leaf growth to water stress, while yield and fruit size decreased with the increase of stress.

In a study conducted by Rao *et al.* (2000,) tomato (*Solanum lycopersicum* L.) plants were imposed water stress at vegetative, flowering, and fruiting stages of four cultivars of to understand the effects of stress on yield. Physiological characters such as net photosynthetic rate, stomatal conductance, transpiration rate, osmotic adjustment and crop water stress index were evaluated and reported that tomato is sensitive to water scarcity and requires large quantity of water for vegetative and reproductive growth, especially during flowering and fruit enlargement stage. The relative sensitivity of potato plant to water stress was reported by Yuan *et al.* (2003) emphasizing that soil water is one of the most crucial factors affecting the yield and quality.

Sanchez-Rodriguez *et al.* (2010) observed sensitivity differences among five cherry tomato cultivars under moderate water deficit conditions and concluded that tomato is sensitive to the drought stress.

The effect of different amounts of irrigation water applied to the crop were tested and found that plant height increased with increasing amount of applied irrigation water. Al-Mohammadi and Al-Zubi (2011) conducted an experiment to evaluate the optimum combinations of irrigation and fertilizer levels to develop the best tomato crop in terms of yield and quality. The study concluded that the irrigation and fertilizer levels had significant effects on the number of fruits plant $^{-1}$; however, plant height showed no significant change under any treatment.

According to Calcagno *et al.* (2011), the tomato plant growth was directly related to soil water availability. Severe water stress reduced the plant height by 24% compared to the control. The leaf area values were considerably reduced. The results pointed out that moderate and severe water deficit caused significant reduction in specific leaf area values.

Study conducted by Zlatev and Lidon (2012) revealed that drought stress inhibited cell division and enlargement leading to reduction in vegetative and reproductive growth. There was also characteristic reduction in leaf area and stem length due to decreased cell size.

2.2. FLOWERING CHARACTERS

Salter (1954) reported that reproductive stages in tomato such as flowering and fruiting stages were most sensitive to drought stress. The duration of tomato growth cycle was decreased under water deficit conditions by accelerating different growth and developmental stages. Desclaux and Roumet (1996) reported that the induction of drought stress hastened the conversion from vegetative to reproductive phase in tomato.

Kozlowski (1972) observed that during flowering and fruit growth, rapid accumulation of dry matter occurs, and water deficit during this stage caused reduction in the number of flowers produced. Even a slight water deficit resulted in the reduction of floral primodia initiation. Water stress at flowering stage not only limited flower formation but also amplified flower shedding. It was reported that the number of ripe fruits that will be produced largely depends on the flowering stage. Reduction in flower number diminished the final yield. Hence, moisture stress during the flowering stage have resulted in the highest reduction in yield.

Sionit and Kramer (1977) noticed that growing soybeans under water stress shortened the flowering period and caused flower abortion. According to Mahendran

and Bandara (2000), when plants were exposed to moisture stress at the flowering stage, a severe drop in flowering occurred in chilli.

In an experiment to evaluate the optimum combinations of irrigation and fertilizer levels to attain the best yield and quality of tomato crop, Al- Mohammadi and Al-Zubi (2011) observed that the irrigation and fertilizer levels had significant effects on the number of flowers plant^{-1}; however, plant height was not affected significantly by any treatment.

The effects of water stress on the growth and yield of tomatoes was studied by Sibomana *et al.* (2013) by subjecting to different soil moisture threshold levels. It was reported that water stress contributed to considerable decline in chlorophyll content, leaf relative water content and vegetative growth. Compared to the control, severe water deficit reduced the plant height by 24%, stem diameter by 18% and chlorophyll concentration by 32%. The highest yield reduction of 69% was observed in the most stressed plants. The decrease in plant growth and yield as a result of water stress was attributed to the effects water on the physiology of the crop. The most stressed plants showed the highest percentage (22%) of flower abortion. It was also noted that the number of flower buds that failed to form fruit primordia increased with a reduction in water levels.

2.3. FRUIT AND YIELD CHARACTERS

Salter and Goode (1967) studied the differential sensitivity of crops to water stress and established that internode elongation just before flowering and flower opening was the most critical stage of water stress sensitivity and yield was affected most adversely when water stress occurred during these periods. Most of the water is required for the development of reproductive organs during the flowering stage. It was also observed that when the plants were subjected to moisture stress during the flowering stage, it resulted in the highest reduction in the yield of tomato. This

pointed out that the flowering stage is the most critical stage of growth of tomato compared to the other growth stages.

The decrease in fruit size by water stress was primarily because of shorter fruit growth period (Salter and Goode, 1967). In tomato, it was observed that water stress accelerated the abscission process, leading in some cases to premature dropping of fruits (Kozlowski, 1972).

According to Kozlowski (1972), the major reason for yield reduction in the plants, when subjected to water stress during the early fruiting stage, was due to reduction in fruit size and fruit number. There observed characteristic difference between the sizes of fruits of plants treated at this stage with those of the control. Dropping of immature fruits was noticed as the major cause for considerable reduction in the number of fruits.

It was reported that during the period of fruit enlargement, considerable amounts of carbohydrates and water are transported to the fruits. Therefore, size of the fruit largely depends on this phase and water deficit during this stage critically reduced the size of fruits (Kozlowski, 1972).

Kramer (1983) reported that the quantum of damage caused by water stress depended to a considerable extent on the stage of plant growth at which it occur. According to Giardini *et al.* (1988), limited water condition reduced the yield and fruit size in tomato. Low water availability decreased the number of leaves, branches, flowers and fruits in tomato cultivars. Fruit quality, shape, diameter and weight got decreased under drought stress as compared to the normal condition.

Fisher and Nel (1990) studied the effect of water stress on tomato growth and yield components. The study revealed that leaf growth showed no significant response to water deficit, whereas substantial reduction was observed in yield and fruit size, with the increase of stress. Considerable differences were observed

between the treatments regarding the number of fruits plant^{-1} and average fruit diameter. Number of fruits plant^{-1} was reduced by between 25 to 34%, while the average equatorial diameter of the fruits subjected to the highest water stress was 11.5% to 19% lower compared to the control.

As per the study conducted by Ramadasan *et al.* (1993), stated that chlorophyll content has positive correlation with growth and yield. Water stress limits chlorophyll content, thus limiting the yield. Reduced nutrient uptake by crops during moisture stress also resulted in lower yield.

Zotarelli *et al.* (2009) noticed that when grown under water stress conditions tomato plants showed characteristic decline in the number and size of fruits. The yield components of tomato such as flower and fruit characters also reduced considerably in a study conducted by Birhanu and Tilahun (2010) under moisture-limited conditions.

Vijitha and Mahendran (2010) investigated the most critical stages of plant growth in tomato under water stress. During the growth stages such as vegetative, flowering, early fruiting and fruit ripening stages of tomato, water stress was imposed for a period of four days in each growth stage. It was observed that yield varied significantly between treatments. Moisture deficit limited the yield of tomato and stress during flowering stage caused the highest reduction in yield. Relatively lower yield reduction was observed for those plants stressed during the vegetative stage .The plants, imposed with moisture stress during the early fruiting and fruit ripening stages were also found to be significantly lower yielders than the control treatment. The flowering stage was identified the most vital stage of growth of tomato under moisture stress for the fruit yield.

Sibomana *et al.* (2013) subjected tomato plants to different soil moisture levels to study effects of water stress on the growth and yield of tomatoes. It was noticed that water stress caused a significant reduction in chlorophyll content, leaf

relative water content and vegetative growth. It was observed that there was a proportionate reduction in the yield with the increase in stress level. The lowest yield was obtained in the most stressed plants compared to the control.

To estimate the reduction in crop growth and yield under water deficit conditions, Shamim *et al.* (2014) examined eleven local/exotic tomato genotypes at different water regimes i.e., at 80% of field capacity (optimum watered) 60% and 40% of field capacity (water deficit). The findings revealed that soil water stress critically reduced all the yield and yield components for all the tomato genotypes. On the other hand, the performance of the tomato genotypes varied largely for these traits under soil water limited conditions. It was concluded that substantial genetic variation exists in tomato genotypes for water stress tolerance. This variation contributes to the better adaption under water stress which could be utilized in crop improvement for stress tolerance.

2.4. PHYSIOLOGICAL AND BIOCHEMICAL CHARACTERS

Plants adopted drought tolerance by means of three major physiological domains: a) maintaining high plant water status under drought stress; b) maintaining plant function at low plant water status; c) recovery of plant water status and plant function after stress (Naeem *et al.*, 2015). Among the physiological characters, relative water content, stomatal frequency, canopy temperature and proline content of the leaves were studied.

2.4.1. Relative Water Content

Under water stress conditions, leaf water content is considered as an important indicator of water status than other water potential parameters (Sinclair and Ludlow, 1985). RWC was proposed as a selection parameter for drought tolerance in wheat (Schonfeld *et al.*, 1988), barley (Martin *et al.*, 1989) and pigeonpea (Kimani *et al.*, 1994). Schonfeld *et al.* (1988) expressed that in wheat, RWC showed considerable

reduction with increase of water deficit. It was noticed that under conditions of moisture stress, the cultivars that are resistant to drought have more RWC.

Leaf relative water content estimates the current water content of the sampled leaf tissue relative to the maximum water it can hold at full turgidity. Plant revival from desiccation in agricultural crops is predominantly reliant on the capacity for maintaining higher RWC during desiccation (Blum *et al.*, 1999).

El Jaafari (2000) reported that water deficit showed a negative effect on relative water content. It was also observed that the survival of the plant under severe water deficits depended on the potential to restrict water loss through the leaf epidermis. Introduction of plants to drought stress considerably decreased the leaf water potential, relative water content and transpiration rate, with an associated rise in leaf temperature (Siddique *et al.*, 2001). In a large variety of crop plants, relative water content (RWC) was found to reduce in response to drought stress (Nayyar and Gupta, 2006).

Sibomana *et al.* (2013) studied the effects of moisture deficit on the growth and yield of tomatoes by growing them under varying soil moisture levels. Water stress resulted in significant decrease in leaf relative water content (RWC). It was reported that compared to the control, the leaf relative water content was reduced by 24.7% in the most stressed plants.

Under water stress condition, water stress tolerant rice genotypes recorded higher value of RWC as compared to susceptible genotypes at reproductive stage (Kumar *et al.* 2014).

2.4.2. Stomatal Characteristics

Crop water loss directly involves stomata as they control CO_2 uptake and transpiration. The adaptation of plants to harsh environmental conditions such as drought depends upon the number, distribution, and morphology of stomata on leaf

surfaces (Malone *et al.*, 1993). Stomata are the portals for gaseous exchange between the leaf mesophyll cells and the environment. They occupy between 0.5% and 5% of the leaf epidermis and are most abundant on the bottom or abaxial surface. They are the indicators of all environmental factors that affect the plant growth (Morison, 1998).

Several researches have shown that a substantial reduction in photosynthetic activity was noticed under drought stress due to stomatal or non-stomatal mechanisms (Del Blanco *et al.*, 2000; Samarah *et al.*, 2009). When plants are suddenly encountered drought, stomatal closure is the quickest response (Yordanov *et al.*, 2000). In response to drought, stomata express differential degrees of closure to limit water loss through transpiration.

Castrillo *et al.* (2001) found that in tomato, the stomatal conductance decreased in water stress, gradually by the changing of water potential. It was observed that in maize higher stomatal density under drought conditions effectively hindered transpirative water loss and thus ensured improved water balance. The reduction in soil water content caused an increase in stomatal density but a decreased stomatal size and aperture was noted, which subsequently reduced the rate of photosynthesis and transpiration (Bosabalidis and Kofidis 2002).

Plants with larger stomata open and close them slower and are hence less sensitive to drought. Whereas plants with higher stomatal density had smaller stomata, allowing for rapid stomatal conductance (Aasamaa *et al.*, 2001; Royer, 2001; Woodward *et al.*, 2002; Hetherington and Woodward, 2003). Hence, generally small and dense stomata are noticed under water stress conditions (Spence *et al.*, 1986; Pearce *et al.*, 2005; Sarker and Hara 2011). Smaller and denser stomata helped in a reducing the transpirative water loss (Yao, 2001; Goodger *et al.*, 2005).

According to Hetherington and Woodward (2003), the stomatal density and aperture largely determined the plant drought resistance. Tanaka *et al.* (2005) observed that stomata played a key role in controlling gas exchange, particularly in carbon dioxide uptake and in transpiration in response to changes in the surrounding environment.

Ren (2003) observed that in *Amaranthus tricolor,* the stomatal frequency increased under drought conditions. Small stomata could maintain the pores opening with lower guard-cell turgor pressures compared with larger stomata (Spence *et al.*, 1986).

In terrestrial plants, a major portion of the root-absorbed water from soil is lost through transpiration into the atmosphere. Barely 1–5% of the total absorbed water is used for structural composition and metabolism (Tesar *et al.*, 2007). When the plant encounters water deficit or stress, transpirative water loss through stomata becomes the crucial factor in limiting plant growth and development as well as crop yield. Under water deficit conditions, an efficient pathway to increase water use efficiency of plants and to lessen agriculture water use is by limiting transpirative water loss without affecting the growth and health of the plant (Wang *et al.*, 2007).

The exchange of CO_2 and water vapor with the atmosphere are synchronized in plants by adjusting their photosynthetic ability and varying stomatal aperture (Kamakura *et al.*, 2011).

Stomatal characteristics (including the size and density of stomata on the epidermis) and behavior (stomatal aperture) primarily controls the transpirative water loss from leaf. Earlier investigations have reported that in response to environmental factors such as light intensity, soil water availability, the concentration of atmospheric CO_2, and endogenous plant hormones, the functioning of stomata varies(Woodward *et al.*, 2002; Wang and Song, 2008; Aminian *et al.*, 2011; Busch, 2014).

Under drought conditions, the molecular mechanism of stomatal movement in response to environmental signaling has been established, particularly the abscisic-acid-mediated signaling cascade in guard cells (Sauter *et al.*, 2001; Hartung *et al.*, 2002; Schachtman and Goodger, 2008). It was noticed that plant species with larger stomata closes them more slowly, displaying lower drought sensitivity. On the contrary, small stomata are generally associated with higher density, which open and close more rapidly thereby allowing for rapid regulation of stomatal conductance (Aasamaa *et al.*, 2001; Royer 2001; Woodward *et al.*, 2002; Hetherington and Woodward, 2003). Hence, generally small stomata are noticed under drought stress (Spence *et al.*, 1986; Pearce *et al.* 2005; Sarker and Hara 2011), resulting in a reduction in transpirative water loss (Yao 2001; Goodger *et al.*, 2005). However, this decrease in stomatal aperture may also restrict photosynthetic CO_2 assimilation and, subsequently, plant growth and crop yield (Ripley *et al.*, 2007).

It was observed that in wheat under drought stress, the leaf stomatal density increased (Quarrie and Jones, 1977). Increased stomatal density under water deficit was also noted in *Populus trichocarpa* (Dunlap and Stettler, 2001), olive (Bosabalidis and Kofidis, 2002), and *Solanum melongena* (Fu *et al.*, 2013). A decreased stomatal density under stress was noticed in ginger (Xu *et al.*, 2003) and increased under moderate water deficit in *Leymus chinensis.* In addition, variations in stomatal density also influenced the CO_2 and water vapour exchanges between the leaf interior and the atmosphere (Xu and Zhou, 2008).

In a recent study by Lawson *et al.* (2014), no correlations between stomatal density and gas exchange parameters was observed in mutants of *Arabidopsis* mutants with different stomatal densities. water stress also induced a reduction in pore aperture but guard cell length was found to increase. Schluter *et al.* (2003) reported that in the *Arabidopsis* mutant though the stomatal density increased under water stress conditions, it had no significant influence on the net photosynthetic rate. Conversely, Tanaka *et al.* (2013) indicated that increased stomatal density increased

CO_2 gas exchange and the photosynthesis rate in *Arabidopsis thaliana* under water deficit conditions.

Zhao *et al.* (2015) reported that in maize stomata were frequently generated during leaf expansion and growth as reflected in increased stomatal number and a relatively-stable density, while stomatal size (length and width) remained basically unchanged.

2.4.3. Canopy Temperature

Tanner (1963) evaluated crop canopy temperature with an infrared thermo-detector to monitor crop water content. It was observed that canopy temperature was generally lower than air temperature under sufficient soil water conditions except noontime in wheat, maize and other dryland crops, and the daily changes in canopy-air temperature difference were gentle, while under water-deficit conditions, the canopy-air temperature difference varied largely, especially in the afternoon.

In 1977, Jackson *et al.* used infrared thermometers to measure canopy temperatures. Gardner *et al.* (1981) and Gonzalez-Dugo *et al.* (2006) has reported that canopy temperature detected using infrared thermometry can be a potent tool to monitor and quantify water stress. Canopy temperature increases when solar radiation is absorbed, but is cooled when that energy is used for evaporating water (latent energy or transpiration) rather than heating plant surfaces.

According to Jackson (1977), the association between surface temperature and water stress is based on the hypothesis that as the crop transpires, the evaporated water cools the leaves below that of air temperature. Under water stress, the rate of transpiration declines, which leads to increased leaf temperature. In water stressed crops, the relatively lower canopy temperature indicates a comparatively better ability for taking up soil moisture or for maintaining a relatively superior plant water statusby various plant constitutive or adaptive traits (Blum, 1990). Canopy

temperature measurement was employed as a tool by Stark *et al.* (1991) to identify drought tolerant genotypes in potato.

Crop water stress has been evaluated using canopy temperature because a reduced plant water status results in poorer transpiration rates which consequently leads to higher canopy temperatures. Water deficit in the crop root zone curtails the transpiration rate which contributes to canopy cooling, which results in increased canopy temperature and vice versa.

Canopy temperature is based upon the close, inverse relationship between leaf temperature and transpirational cooling (Jackson, 1977). Negative correlations between canopy temperature and water use have been reported for corn (Mtui *et al.*, 1981) and sorghum (Chaudhuri and Kanemasu, 1982). Chaudhuri and Kanemasu (1982) found that compared to plants grown under well watered conditions, the canopy temperature of the water-stressed sorghum was generally 3.2-3.7 ^{0}C warmer. Chaudhuri *et al.* (1986) observed that warmer sorghum and pearl millet genotypes were generally more productive than cooler genotypes, under drought stressed conditions. In another study, Stark *et al.* (1991) reported that warmer potato (*Solanum tuberosum* L.) genotypes under well-watered conditions were comparatively less susceptible to drought than cooler genotypes. It was observed that the comparatively high canopy temperatures of certain varieties were a clear indication of their high degree of drought resistance. The drought responses of genotypes with intermediate temperatures were more variable.

Zipoli *et al.* (1987) reported that wheat cultivars which had the warmest midday canopy temperatures under well-watered conditions used the least amount of water ($r = 0.95$; $p<0.01$ for water use and average canopy minus air temperature under well-watered conditions) during the season and had the highest relative yields when water was limited.

Blum *et al.* (1990) described yield stability in wheat under various moisture environments by employing canopy temperatures of drought stressed genotypes. A positive correlation was established between drought susceptibility and canopy temperature in stressed environments. Genotypes that experienced greater relative yield losses under drought stress had a tendency to have warmer canopies at midday. It was also noticed that certain drought tolerant genotypes of wheat demonstrated comparatively high canopy temperatures at midday.

2.4.4. Proline

Accumulation of proline in many plant species under a broad range of stress conditions such as water scarcity, salinity, severe temperatures, and elevated light intensity was reported by Delauney and Verna (1993), Hare *et al.*(1999) and Mansour (2000). Proline was identified as a compatible solute that protects folded protein structures against denaturation, stabilizes cell membranes by interacting with phospholipids, functions as a hydroxyl radical scavenger, or serves as an energy and nitrogen source (Samaras *et al.*, 1995).

Proline has an important role to sustain root growth under water stress condition. The increase in proline content due to drought stress was more severe at flowering stage than at the vegetative stage. The proline content depends on plant age, leaf age, leaf position or leaf part (Chiang and Dandekar, 1995).

In some plant species, proline plays a major role in osmotic adjustment such as in potato (Bussis and Heineke, 1998), while in others such as in tomato (Perez-Alfocea *et al.*,1993) proline accounts for only a small fraction of the total concentration of osmotically active solutes.

It has been suggested that accumulation of proline contributes to maintain proper balance between extra and intra-cellular osmolality under condition of water stress (Madhusudan *et al.*, 2002).

Nahar and Gretzmacher (2002) reported that the significant increase in proline and ascorbic acid in tomato fruits showed some tendency of this crop to adjust somatically to water stress. On the other hand, under the drought and salinity stress, proline content was more in resistant wheat cultivars than in sensitive cultivars. Proline accumulation under water stress was observed in crops such as chick pea (*Cicer arietinum*) (Ayerbe and Tenorio, 1998) corn (*Zea mays*) (Serraj and Sinclair, 2002) and peanut (*Arachis hypogaea*) (Smith *et al.*, 2002).

In many crop plants, proline accumulation is associated with the plants' drought tolerance. It has been reported that stress tolerant plants accumulated more proline compared to water stress sensitive plants. Proline helps to maintain membrane integrity under water stress and reduces oxidation of lipid membranes (Demiral and Turkan, 2004). Moreover, it also improves stabilization of sub-cellular structures, under stress conditions (Ashraf and Foolad, 2007).

Madhusudan *et al.* (2002) has suggested that water stress conditions, proline accumulation maintains proper balance between extra and intra-cellular osmolality. Claussen (2005) reported that proline accumulation under stress conditions may be caused either by induction or by activation of enzymes of proline biosynthesis or a decreased proline oxidation to glutamate, decreased utilization of proline in protein synthesis, and enhanced protein turnover. Proline accumulation has played adaptive roles in plant stress tolerance (Verbruggen and Hermans 2008). Accumulation of proline has been advocated as a parameter of selection for stress tolerance (Jaleel *et al.*, 2007).

According to Chen and Murata (2002), along with enzymes and other macromolecules, proline acted as an osmolite and consequently, protected the plant against low water potential and caused osmotic regulation in plant organs. It was also reported that proline acted as an electron receptor preventing photosystems injuries in dealing with reactive oxygen species function. Proline accumulation facilitated the

permanent synthesis of soluble substances in closing stomata. Under drought conditions, inorder to retain the water potential, cell turgor, and membrane stability to avoid drought stress-induced damage, osmoprotectants were accumulated.

Although proline accumulated in all vegetative organs and in fruits when plants were subjected to osmotic stress the highest concentration was found in growing leaves (Claussen, 2005).

Claussen (2005) reported that the average concentration of proline in tomato leaves accumulated during reproductive growth is a measure of the stress plants experienced during this period, which was indicated by a negative correlation ($r = -0.89$, $P < 0.05$) between proline content of leaves and fruit fresh weight.

According to Shtereva *et al.* (2008), PEG induced drought stress increased endogenous proline concentration in tomato calli. Anjum *et al.* (2011) reported that proline is a scavenger of OH- radical and plays an important role in osmotic adjustment during oxidative stress. It reduced the damaging effect of reactive oxygen species to the membrane lipid and protein, enzymes and DNA.

2.5. GENETIC PARAMETERS

Golani *et al.* (2007) evaluated 20 genotypes of tomato and elucidated high heritability with high GCV and genetic gain for fruits weight and fruit yield which could be improved by simple selection. The phenotypic and genotypic associations of fruit yield were significant and positive with fruits weight and fruit girth but significant and negative with plant height.

Khanom *et al.* (2008) studied the genotypic variability, heritability and genetic advance for yield and yield contributing characters for 55 tomato genotypes. High heritability estimates coupled with high genetic advance in percentage of mean were obtained for number of primary branches plant $^{-1}$, number of days to first flowering, plant height, number of bunches plant $^{-1}$, number of fruits plant $^{-1}$,

individual fruit weight and number of seeds per fruit which indicated the wide scope for improvement through selection of these traits.

Patel *et al.* (2013) investigated thirteen tomato genotypes and variability, heritability and genetic advance in yield and component characters were estimated. A high measure of variation was observed for all the characters studied. The highest GCV and PCV was observed for fruit yield plant^{-1} while lowest GCV was noticed for days to first harvest and days to 50 per cent flowering and PCV for days to 50 per cent flowering. High heritability with high genetic advance as percent of mean was observed for fruit yield plant $^{-1}$ and average fruit weight, which could be improved by simple selection.

Prajapati *et al.* (2015) evaluated 39 diverse genotypes of tomato. Analysis of variance showed significant variation among the genotypes for all evaluated traits. Number of fruits plant^{-1} showed the highest genotypic and phenotypic variance. High genotypic variance was observed for most of the characters indicating more contribution of genetic components for the total variation. Genotypic coefficients of variations (GCV) and phenotypic coefficient of variation (PCV) were highest for average fruit weight and number of seeds per fruit. Higher GCV and PVC were recorded for most of the characters indicating higher magnitude of variability for these characters. The highest heritability (broad sense) estimates were observed for average fruit weight. Highest genetic advance as percent of mean was recorded for average fruit weight (100.59%) and lowest for days to 50% fruit setting (2.89).

In an experiment with 35 genotypes of tomato for yield and various yield attributing characters, Singh (2009) observed high magnitude of phenotypic as well as genotypic coefficients of variation in case of fruit yield plant^{-1} followed by average fruit weight, number of locules per fruit, number of fruits plant^{-1}, plant height and number of primary branches plant $^{-1}$. High amount of GCV and PCV were observed for all the traits except days to 50 percent flowering, which showed very low

variability. High heritability along with high genetic advance in percent of mean was estimated for all the traits except days to 50 percent flowering. Fruit yield plant $^{-1}$ followed by average fruit weight, number of locules per fruit, number of fruits plant $^{-1}$ and plant height were the top five traits, which showed high level of genetic advance indicating opportunity for better selection response.

Naeem (2015) conducted a study to investigate the genetic variability of plant growth and physiological characters in thirty wheat genotypes under normal and drought stress conditions and higher genetic variance was observed between the genotypes for the cell membrane stability, relative water content, and proline under both conditions. It was suggested that these indices could be used as direct selection criteria for the crop improvement.

2.6. CORRELATION ANALYSIS

Haydar *et al.* (2007) reported that yield had a strong positive correlation with fruits plant $^{-1}$. Fruit length showed positive significant correlation both at genotypic and phenotypic level with fruit diameter.

Golani *et al.* (2007) observed that in tomato, the phenotypic and genotypic associations of fruit yield were significant and positive with 10-fruit weight, fruit girth, but significant and negative with plant height.

In a field experiment, 36 tomato genotypes were studied by Hidayatullah *et al.* (2008) to estimate the nature and magnitude of genetic variability in the germplasm for characters such as plant height, number of fruit plant^{-1}, fruit size, single fruit weight. Wide range of variation was observed among the characters. Fruit weight plant^{-1} showed high and positive genotypic and phenotypic correlation with number of fruits plant $^{-1}$. It was also reported that number of fruits plant $^{-1}$ showed positive association with fruit weight plant $^{-1}$.

According to the studies of Singh (2009) and Ara *et al.* (2009) in tomato, plant height showed significant positive association at phenotypic level with number of branches and fruits plant^{-1} while significantly negative correlation was found with average fruit weight, diameter and volume of fruit.

Islam (2010) noticed that yield plant^{-1} was found highly significant and positively correlated with flowers plant^{-1}, fruits plant^{-1}, fruit length, fruit diameter and individual fruit weight in tomato.Fruits plant^{-1} showed positive significant correlation both at genotypic and phenotypic level with yield plant $^{-1}$. Fruits plant $^{-1}$ showed negative significant correlation (both genotypic and phenotypic level) with individual fruit weight. Fruits plant $^{-1}$ showed negative significant correlation with fruit diameter at genotypic level.

Srivastava *et al.* (2014) investigated the associations among sixteen yield components in thirty tomato genotypes. The expression of the traits was considerably affected by genotypic coefficient of variation. Fruit yield plant^{-1} displayed high genetic advance along with high heritability. The contributions through heritable and non heritable components to the magnitude of phenotypic correlation coefficient were examined. It was observed that heritable components contributed maximum towards the magnitude of phenotypic correlation coefficient in most of the cases. In the minority cases environment factors reduced the magnitude of phenotypic correlation coefficient compared to its genotypic contributions.

Twenty genotypes of tomato were evaluated for yield and yield attributes by Nagariya *et al.* (2015). The results of the study showed that fruit yield plant^{-1} was positively associated with number of fruits plant^{-1} and yield per plot. Path coefficient analysis revealed that average fruit weight had the highest direct positive effect on fruit yield plant^{-1} followed by plant height, days to first fruit set and number of flowers cluster^{-1}.

2.7. PATH COEFFICIENT ANALYSIS

Correlation between yield and yield components were, partitioned into direct and indirect effects to know the particular factor responsible for that correlation. Path coefficient analysis is defined as a partial regression coefficient that divides the correlation coefficients into direct and indirect effects. The coefficients generated by path analysis measured the direct and the indirect influence of a variable upon another.

Verma and Sarnaik (2000) observed that in tomato, the number of branches plant^{-1} exhibited positive direct effect on yield.According to Islam (2010), fruits plant^{-1} showed the highest positive direct effect on yield plant^{-1} followed by individual fruit weight. The highest negative direct effect on yield plant^{-1} was shown by days to first flowering followed by fruit length. In path coefficient analysis days to first flowering showed negative direct effect (-0.277) on yield plant^{-1}. It was also noted that the indirect effects through flowers plant^{-1}, plant height at first flowering, branches plant^{-1}, pericarp thickness, fruits plant^{-1} and fruit length were positive and via fruit diameter and individual fruit weight were negative.

Positive correlation between plant height at first flowering and yield plant^{-1} was the cumulative contribution of these direct and indirect effects. Number of branches plant^{-1} had positive direct effect on yield plant^{-1}, whereas negative indirect effects were observed via days to first flowering, thickness of the pericarp, fruit diameter, and individual fruit weight. Positive indirect effects were found via flowers plant^{-1}, plant height at first flowering, fruits plant^{-1} and fruit length. Positive correlation (0.162) between branches plant^{-1} and yield plant^{-1} was the collective contribution of these direct and indirect effects.

Ullah *et al.,* (2016) reported that fruit diameter showed the highest positive direct effect (3.25) on fruit yield plant^{-1} followed by fruits plant^{-1}. Fruits plant^{-1}, fruit weight, fruit diameter and locule number per fruit showed significant positive

genotypic correlation with fruit yield plant^{-1}. The highest indirect effect of fruit weight was observed with fruit diameter. The characters showing high direct effect on yield plant^{-1} indicated that direct selection for these traits might be effective and there is a possibility of improving yield plant^{-1} through selection based on these characters.Dao *et al.* (2017) has reported that under water stress, there was positive correlation between plant height and yield plant $^{-1}$ in tomato, but the direct effect of plant height on yield was negative and high.

Materials and Methods

3. MATERIALS AND METHODS

The experiment entitled "Evaluation of tomato (Solanum *lycopersicum* L.) genotypes for yield under water stress conditions" was conducted at College of Agriculture, Vellayani, Thiruvananthapuram during the period 2015-2017. The experiment was carried out with the objective of identifying high yielding genotypes of tomato under water stress conditions.

3.1. MATERIALS

The materials for the experiment were collected from different sources. Twenty different genotypes of tomato, including twelve local collections from a previous project of the Department of Plant Breeding and Genetics entitled "Collection, conservation and genetic improvement of traditional land races and obsolete varieties of major vegetables in Kerala" as well as released varieties from different institutions were evaluated in the study (Table 1).

3.2 METHODS

3.2.1. Design and Layout

The experiment was conducted as a replicated field trial as follows:

Design : RBD (Randomized Block Design)

Replication : Three

Treatments : 20

Spacing : 60 cm x 60 cm

Plants plot^{-1} : 20

Plot size : 7.2 m^2

Table 1. List of genotypes used in the study (*Solanum lycopersicum* L.)

Genotype No.	Name of the Genotype	Source
A1	Nellanadu local	Thiruvananthapuram district
A2	Kuttichal local I	Thiruvananthapuram district
A3	Venpalavattam local	Thiruvananthapuram district
A4	Palakkad local	Palakkad district
A5	Vellayani local I	Thiruvananthapuram district
A6	Kottayam local	Kottayam district
A7	Kuttichal local II	Thiruvananthapuram district
A8	Kaithamukku local	Thiruvananthapuram district
A9	Pettah local	Thiruvananthapuram district
A10	Vellayani local II	Thiruvananthapuram district
A11	Haripad local	Alappuzha district
A12	Arka Alok	IIHR, Bangalore
A13	Thrissur local	Thrissur district
A14	Arka Vikas	IIHR, Bangalore
A15	Arka Saurabh	IIHR, Bangalore
A16	Arka Meghali	IIHR, Bangalore
A17	Vellayani Vijay	KAU
A18	Anagha	KAU
A19	Akshay	KAU
A20	Manulekshmi	KAU

Season : October 2016 – February 2017

3.2.2. Sowing and Cultural Operations

Seedlings were raised in in protrays during the month of October, 2016. The protray mix consisted of coco peat and vermicompost. One month old seedlings were transplanted to the main field. The main field was prepared by clearing weeds and thorough ploughing to yield a well tilled levelled land. Bunds and channels were then taken and farm yard manure was incorporated. The seedlings were planted at a spacing of 60cm x 60cm. All the cultural practices except irrigation were undertaken timely as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2011). Water stress was imposed by restricting the irrigation to once in three days at 10mm depth.

3.2.3. Main Items of Observation

3.2.3.1. Vegetative Characters

3.2.3.1.1. Plant height

Height of the observational plants was recorded from the ground level to the topmost bud leaf of the plants at the time of final harvest. Average was taken and presented in cm.

3.2.3.1.2 Primary Branches Plant^{-1}

The total number of primary branches of each observational plant at harvest was counted and the average was worked out.

3.2.3.1.3. Number of Leaves Plant^{-1}

The total number of leaves of each observational plant at harvest was counted and the average was worked out.

Plate 1. Seedlings in the nursery 15 DAS

Plate 2. Seedlings in the nursery 21 DAS

Plate 3. Field view 15 DAT

Plate 4. Field view at flowering

Day 1

Day 2

Day 3

Plate 5. Field view after stress imposition

Plate 6. Growth stages of tomato under water stress conditions

3.2.3.2. Flowering Characters

3.2.3.2.1. Days to 50 % Flowering

Number of days from the date of transplanting to 50% flowering of observational plants was recorded and the average was obtained.

3.2.3.3. Fruit and Yield Characters

3.2.3.3.1. Fruits Cluster^{-1}

Number of fruits cluster^{-1} of the observational plants were recorded and the mean was obtained.

3.2.3.3.2. Fruits Plant^{-1}

Total number of the fruits harvested per observational plant till last harvest was recorded and the mean was calculated.

3.2.3.3.3. Fruit Length

Random fruits were selected from observational plants and fruit length was measured as the distance from pedicel attachment of the fruit to the apex using vernier calipers. Average was taken and expressed in cm.

3.2.3.3.4. Fruit Girth

Fruit girth was taken as diameter at the maximum width of the fruit using vernier calipers. The average was worked out and expressed in cm.

3.2.3.3.5. Fruit Volume

Fruit volume was taken as the volume of displaced water when fruits where placed in a vessel filled with water to the brim. The average was taken and expressed in cm^3.

3.2.3.3.6. Fruit Weight

Weight of fruits used for recording fruit length and girth was taken and average was found out and expressed in g.

3.2.3.3.7. Yield Plant[1]

Weight of all fruits harvested from each observational plant was recorded and expressed in g.

3.2.3.4. Biochemical Characters

3.2.3.4.1. Stomatal Frequency

Stomatal frequency is the number of stomata present per unit area of leaf. Fresh leaves were collected and a solution of thermocol dissolved in xylene was smeared on both surfaces of the leaves and allowed to dry. The transparent layer of epidermis was peeled off and observed under the microscope. The number of stomata in the microscopic field was counted using a 40X objective and 10X eyepiece. The frequency was then calculated using the formula,

$$\text{Stomatal frequency} = \frac{\text{Number of Stomata}}{\text{Area of the microscopic field}}$$

3.2.3.4.2. Relative Water Content

Known number of leaf discs was taken from the experimental plants and the fresh weight, turgid weight and dry weight were measured. Turgid weight was taken by immersing the discs in water for three hours. The samples were then oven dried, at a temperature of 80^0 C for three consecutive days till constant weight was reached and the dry weight was recorded.

Relative Water Content (RWC) was calculated using the formula

$$RWC = \frac{\text{Fresh weight- Dry weight}}{\text{Turgid weight- Dry weight}} \times 100$$

3.2.3.4.3. Canopy Temperature

Canopy temperature of the plant canopy in each treatment was measured at 12 noon using an infrared thermometer and expressed in °C.

3.2.3.4.4. Proline Content of Leaves

Proline content of the genotypes was analysed one month after imposing stress. Proline present in the leaves was extracted using sulphosalicylic acid. The extracted proline was made to react with ninhydrin in acidic condition to form a red colour. Intensity of the red colour developed was measured at 520 nm using a spectrophotometer (Sadasivam and Manikam, 1992).

Reagents

Acid Ninhydrin

Aqueous sulphosalicylic acid (3%)

Glacial acetic acid

Toluene

Proline

Procedure

The extract was made by homogenizing 0.5 g of plant material in 10 ml of 3% aqueous sulphosalicyclic acid. The homogenate was filtered and 2 ml of filtrate was taken in a test tube and 2 ml of glacial acetic acid and 2 ml acid ninhydrin were added

in a sequence. The mixture was heated in the boiling water bath for one hour. After an hour, the reaction was stopped by placing the tube in ice bath. 4 ml toluene was then added to the reaction mixture and stirred well. The toluene layer was separated and warmed to room temperature. The red colour intensity was then measured at 520 nm. A series of standards with pure proline in a similar way was made and a standard curve was prepared. The amount of proline in the test sample was determined from the standard curve.

Calculation

Proline content in μmoles g^{-1} tissue = $\frac{(\mu g \text{ proline/mL} \times \text{mL toluene})}{115.5} \times \frac{5}{\text{g sample}}$,

where 115.5 is the molecular weight of proline.

3.2.3.5. Statistical Analysis

3.2.3.5.1. Analysis of Variance (ANOVA)

Based on the mean value for each treatment per replication, Analysis of Variance (ANOVA) (Panse and Sukhatme, 1967) for each character was carried out.

Sources of variation	Degrees of freedom	Sum of squares	Mean square	F ratio
Replications	t-1	SSR	MSR	MSR/MSE
Treatment	r-1	SST	MST	MST/MSE
Error	(r-1)(t-1)	SSE	MSE	
Total	rt-1			

where r= number of replications t= number of treatments

SSR= Sum of squares for replications

SST= Sum of squares for treatments

SSE= Sum of squares for error

Critical Difference, CD= $t_{\alpha}\sqrt{\frac{2MSE}{r}}$

Where t_{α} is the table value of students' t distribution at error degrees of freedom and α is the level of significance (5% or 1%).

3.2.3.5.2. Estimation of Genetic Parameters

a. Genetic components of variance

Expected value of mean squares (MS) was equated to the respective variance components to estimate the phenotypic and genotypic components of variance for each character (Jain, 1982).

Genotypic variance (V_G) $V_G=\frac{MST-MSE}{r}$

Phenotypic variance (V_P) $V_P= V_G+V_E$

Environmental Variance (V_E) $V_E= MSE$

b. Coefficient of variation

Estimates of V_G, V_P, and V_E were used to work out genotypic, Phenotypic and Environmental Coefficient of variation , expressed in percentage for each trait.

i. Genotypic coefficient of variation, GCV= $\frac{\sqrt{VG}}{X}$ x 100

ii. Phenotypic coefficient of variation, PCV= $\frac{\sqrt{VP}}{X} x$ 100

iii. Environmental coefficient of variation, ECV= $\frac{\sqrt{VE}}{X} x$ 100

Where X=grand mean

Categorization of the range of variation was followed as reported by Sivasubrahmanian and Menon (1973).

Low: <10%

Medium : 10-20%

High :>20%

c. Heritability in broad sense

Refers to the proportion of genotypic variance to the total observed variance in the population, calculated and expressed in percentage (Allard, 1960).

$H^2 = \frac{VG}{VP} \times 100$

Range of heritability estimates (Johnson *et al.*, 1955)

Low:<30%

Medium : 30- 60%

High :>60%

d. Genetic advance

The expected genetic gain or improvement in the next generation by selecting superior individuals under certain amount of selection pressure. Genetic advance was estimated from the heritability estimates using the formula by Burton (1952).

$GA = KH^2\sqrt{VP}$

Where K= selection differential, value is 2.06 at 5% selction intensity.

GAM= GA/ X x 100

The range of genetic advance percent of mean was also computed (Johnson *et al.*,1955)

Low: 10%

Moderate: 10-20 %

High: > 20 %

3.2.3.5.3. Estimation of Correlation

Correlation refers to the degree and direction of association between two variables.

Correlation coefficients were calculated at genotypic and phenotypic level using the formulae suggested by Falconer (1964).

Genotypic coefficient of correlation $(r_g) = r\,(x_i.x_j)_g = \frac{Cov(xi.xj)g}{\sqrt{V(xi)g.V(xj)g}}$

Phenotypic coefficient of correlation $(r_p) = r\,(xi.xj)_p = \frac{Cov(xi.xj)p}{\sqrt{V(xi)p.V(xj)p}}$

Error coefficient of correlation $(r_e) = r\,(xi.xj)_e = \frac{Cov(xi.xj)e}{\sqrt{V(xi)e.V(xj)e}}$

3.2.3.5.4. Path Coefficient Analysis

Path coefficient analysis is a standardized partial regression coefficient which separates the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959).

$r_{1y} = P_{1y}r_{11}+P_{2y}r_{12}+P_{3y}r_{13}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+P_{ny}r_{1n}$

$r_{2y} = P_{1y}r_{21}+P_{2y}r_{22}+P_{3y}r_{23}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+P_{ny}r_{2n}$

$r_{ny} = P_{1y}r_{n1}+P_{2y}r_{n2}+P_{3y}r_{n3}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots+P_{ny}r_{nn}$

Where,

$1,2.....n$ =Independent variables

y = Dependent variable

$r_{1y}, r_{2y}.....r_{ny}$ =coefficient of correlation between independent variables 1 to n on dependent variable y

$P_{1y}, P_{2y}.....P_{ny}$ =direct effect of character 1 to n on character y

The above equation can be written in matrix form

$$\begin{pmatrix} r_{1y} \\ r_{2y} \\ . \\ . \\ . \\ r_{ny} \end{pmatrix} \quad \begin{pmatrix} 1 & r_{12} & r_{13}.....r_{1n} \\ r_{21} & 1 & r_{23}.....r_{2n,} \\ . & . & . \\ . & . & . \\ . & . & . \\ r_{n1} & r_{n2} & r_{n3}.....1 \end{pmatrix} \quad \begin{pmatrix} P_{1y} \\ P_{2y} \\ . \\ . \\ . \\ P_{ny} \end{pmatrix}$$

then $B = C^{-1}A$ where C^{-1} =

$$\begin{pmatrix} C_{11} & C_{12} & C_{13}.....C_{1n} \\ C_{21} & C_{22} & C_{23}.....C_{2n} \\ . & . & . \\ . & . & . \\ . & . & . \\ C_{n1} & C_{n2} & C_{n3}.....C_{nn} \end{pmatrix}$$

Direct effects:

$P_{1y} = \sum_{i=1}^{k} C1i\ riy$

$P_{2y} = \sum_{i=1}^{k} C2i\ riy$

$P_{ny} = \sum_{i=1}^{k} Cni\ riy$

Residual effect, $PR_y = \sqrt{1 - r^2}$

Where, $r^2 = (P_{1y} r_{1y} + P_{2y} r_{2y} + P_{3y} r_{3y} \ldots\ldots\ldots\ldots + P_{ny} r_{ny})$

P_{iy} = direct effect of X_i on y

r_{iy} = correlation coefficient of x_i on y

i = 1,2,3….n

Results

4. RESULTS

4.1. VARIABILITY

The performance of the 20 genotypes was evaluated and the genotypes showed significant differences for the traits under study.

4.1.1. Mean Performance

Table 2 gives the mean values of the 20 genotypes for yield and other traits.

Plant height was observed to be the highest for the genotype A19 (77.00 cm), which was on par with other genotypes like A8 (75.00 cm), A10 (74.33 cm), genotype A1 (73.33 cm), A15 (73.00 cm), A7 (71.33 cm), A14 (71.00 cm), A17 (70.67 cm), A3 (70.33 cm), A2 (68.67 cm) and A9 (68.33 cm). The least plant height was observed for A16 (52.67 cm) which was on par with A18 (60.00 cm).

The number of primary branches varied from 6.00 (genotype A1) to 2.33 (A7). The genotype A1 showed the highest number of leaves (45.00). The lowest number of leaves was observed in A15 (19.00). Genotype A1 was on par with A18 (39.67) and A3 (39.33).

Genotype A3 registered the longest days to 50% flowering (67.00). This was on par with A14 (66.00), A10 (65.67), A17 (64.00), A16 (63.33) and A15 (62.667). The duration for days to 50% flowering was the least in A2 (52.00) which was on par with A6 (53.00), A11 (53.33), A13 (53.33) and A4 (53.67).

Number of fruits cluster^{-1} was the maximum for genotype A14 (4.33) which was on par with ten other genotypes *viz*, A4 (4.33), A5 (4.33), A3 (4.00), A6 (4.00), A15 (4.00), A1 (3.67), A16 (3.67), A17 (3.67), A19 (3.67) and A8 (3.67). The

Table 2. Mean performance of 20 tomato genotypes for 15 characters under water stress

Genotype No.	Name of the genotype	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
A1	Nellanadu local	73.33	6.00	45.00	58.00	3.67	10.67	3.00	10.30	11.00	23.00	102.63	257.67	71.88	32.33	11.65
A2	Kuttichal local I	68.67	3.67	30.67	52.00	3.33	15.10	4.00	11.60	22.67	28.35	420.17	636.33	77.00	36.42	55.12
A3	Venpalavattam local	70.33	4.00	39.33	67.00	4.00	8.03	3.63	12.60	18.67	32.45	262.00	347.33	68.35	32.17	20.78
A4	Palakkad local	64.33	3.67	34.00	53.67	4.33	11.13	3.80	11.77	16.33	36.11	402.33	518.67	75.67	35.23	56.97
A5	Vellayani local I	64.67	3.00	30.00	62.33	4.33	10.17	3.87	11.90	16.33	30.73	347.33	458.00	70.45	34.40	6.33
A6	Kottayam local	65.67	3.33	26.00	53.00	4.00	19.90	4.17	14.43	29.00	40.47	603.67	743.33	78.95	36.57	57.72
A7	Kuttichal local II	71.33	2.33	36.00	59.00	3.33	12.83	4.37	13.47	29.00	39.03	434.00	545.67	76.33	35.20	49.75
A8	Kaithamukku local	75.00	3.33	30.33	61.67	3.67	6.47	3.23	11.37	11.33	29.00	185.67	417.33	75.25	32.03	13.97
A9	Pettah local	68.33	4.33	31.00	61.33	2.67	7.73	3.10	11.37	14.33	26.88	210.00	325.67	52.67	31.17	14.63
A10	Vellayani local II	74.33	3.67	30.67	65.67	3.33	4.60	3.73	13.90	26.67	39.51	181.33	166.67	66.33	33.47	17.76

X1-Plant Height
X2-Number of Primary Branches/ Plant
X3-Number of Leaves/ Plant
X4-Days to 50% Flowering
X5-Number of Fruits /Cluster
X6-Number of Fruits /Plant
X7-Fruit Length
X8-Fruit Girth
X9-Fruit Volume
X10- Fruit Weight
X11-Yield/ Plant
X12-Stomatal Frequency
X13-Relative water content
X14-Canopy Temperature
X15-Proline content

Table 2. Continued

Genotype No.	Name of the genotype	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
A11	Haripad local	67.00	3.67	21.33	53.33	3.00	5.27	3.30	12.50	21.33	29.11	161.00	345.00	54.98	33.23	14.14
A12	Arka Alok	65.67	2.67	19.67	59.33	2.67	12.63	4.33	13.30	25.33	43.00	404.33	344.67	71.14	31.30	16.87
A13	Thrissur local	64.33	3.00	24.00	53.33	3.33	4.77	3.37	12.40	23.67	38.48	186.67	262.67	66.85	32.67	6.03
A14	Arka Vikas	71.00	2.67	32.00	66.00	4.33	4.83	4.33	14.17	29.33	45.66	140.33	335.00	65.79	34.90	12.92
A15	Arka Saurabh	73.00	3.00	19.00	62.67	4.00	8.37	3.23	10.23	12.33	26.09	238.33	448.00	65.68	31.07	37.86
A16	Arka Meghali	52.67	3.00	27.33	63.33	3.67	12.50	3.63	11.33	24.33	28.69	397.33	708.35	71.25	36.03	7.00
A17	Vellayani Vijay	70.67	3.67	22.00	64.00	3.67	7.67	3.47	12.80	24.00	34.00	195.00	612.25	72.46	31.43	28.23
A18	Anagha	60.00	5.00	39.67	59.67	3.33	9.67	4.23	14.47	27.00	31.34	274.60	464.33	70.90	32.90	32.97
A19	Akshay	77.00	4.33	33.67	58.33	3.67	10.27	3.37	12.93	21.00	26.78	281.67	423.67	68.52	32.27	15.22
A20	Manulekshmi	66.00	4.00	24.33	61.33	2.67	7.07	3.03	11.20	20.67	31.00	177.33	216.00	63.41	31.77	2.84
	S.E.	3.11	0.28	2.10	1.53	0.32	0.74	0.27	0.71	1.44	2.42	14.42	5.13	1.51	1.71	2.43
	C.D. 5%	8.90	0.81	6.01	4.39	0.91	2.11	0.76	2.04	4.13	6.93	41.28	14.68	10.34	3.45	6.96

X1-Plant Height
X2-Number of Primary Branches/ Plant
X3-Number of Leaves/ Plant
X4-Days to 50% Flowering
X5-Number of Fruits /Cluster
X6-Number of Fruits /Plant
X7-Fruit Length
X8-Fruit Girth
X9-Fruit Volume
X10- Fruit Weight
X11-Yield/ Plant
X12-Stomatal Frequency
X13-Relative water content
X14-Canopy Temperature
X15-Proline content

genotype A9 had the lowest number of fruits cluster^{-1} i.e. 2.67, which was on par with the genotypes A12 (2.67) and A20 (2.67).

Number of fruits plant^{-1} was observed maximum in genotype A6 (19.90). The lowest number of fruits plant^{-1} was recorded in A10 (4.60). This was on par with A14 (4.83), A11 (5.27) and A8 (6.47).

The length of the fruit was recorded the highest for genotype A7 (4.37 cm) which was on par with eleven other genotypes *viz*, A12 (4.33 cm), A6 (4.17 cm), A2 (4.00 cm), A5 (3.87 cm), A4 (3.80 cm), A18 (4.23 cm), A14 (4.33 cm), A10 (3.73 cm), A3 (3.63 cm), A16 (3.63 cm). The least fruit length was recorded in the genotype A1 (3.00 cm).

The highest average fruit girth was observed for the genotype A18 (14.47 cm) which was on par with A16 (14.43 cm), A14 (14.17 cm), A10 (13.90 cm), A7 (13.47 cm), A12 (13.30 cm), A17 (12.80 cm), A19 (12.93 cm), A3 (12.60 cm) and A11 (12.50 cm). The least fruit girth was recorded in the genotype A15 (10.23 cm), which was on par with A6 (11.93 cm), A5 (11.90 cm), A4 (11.77 cm), A2 (11.60 cm), A9 (11.37 cm), A8 (11.37 cm) and A20 (11.20 cm).

Genotype A14 (29.33 cm^3) recorded the highest fruit volume. Fruit volume was the least for genotype A1 (11.00 cm^3) which was on par with the genotypes A4 (16.33 cm^3), A5 (16.33 cm^3), A9 (14.33 cm^3) and A15 (12.33 cm^3).

The genotype A14 had the highest fruit weight (45.66g) and it was on par with genotypes A12 (43.00g), A6 (40.47g) and A10 (39.51g). The genotype A1 had the lowest fruit weight (23.00g).

The genotype A6 recorded the highest yield plant^{-1} (603.67g) and was significantly superior to all other genotypes. The lowest yield plant^{-1} was observed in

genotype A1 (102.63g). The genotype A1 was on par with the genotype A14 (140.33g).

Stomatal frequency ranged from 166.67 cm^{-2} (A10) to 743.33 cm^{-2} (A6). The genotype A6 was significantly superior to the other genotypes.

The highest relative leaf water content (78.95%) was recorded in the genotype A6, which was on par with the genotypes A2 (77.00%), A7 (76.33%), A4 (75.67%), A8(75.25%), A17 (72.46%), A1 (71.88%) , A16 (71.25%) and A12(71.14%), A18 (70.9%) and A5 (70.45%) . Relative water content was the lowest for the genotype A9 (52.67%).

Canopy temperature was recorded the highest for the genotype A2 (36.57℃). This was on par with the genotypes, A6 (36.42℃), A16 (36.03℃), A4 (35.23℃), A7 (35.20℃), A14 (34.90℃), A5 (34.40℃), A10 (33.47℃), A11 (33.23^{0}C). The lowest canopy temperature was recorded for the genotype A9 (31.17^{0}C).

The proline content of the leaves ranged from 6.03 µmol g^{-1} (A13) to 57.72 µmol g^{-1} (A6). A6 was on par with the genotypes A4 (56.97µmol g^{-1}) and A2 (55.12µmol g^{-1}).

4.2. INCIDENCE OF PESTS AND DISEASES

No incidence of pests and diseases were observed.

4.3. GENETIC PARAMETERS

The phenotypic, genotypic and environmental coefficients of variation, heritability and genetic advance were worked out and presented in Table 3 .

Table 3. Genetic parameters for 15 characters under water stress condition in tomato

Characters	GCV	PCV	ECV	Variance			Heritability (%)	Genetic Advance (as % of Mean)
				Genotypical	Phenotypical	Environmental		
Plant Height	6.94	10.52	7.90	22.41	51.38	28.97	43.61	9.45
Primary Branches/ Plant	22.45	26.25	13.60	0.66	0.90	0.24	73.16	39.56
Leaves/ Plant	22.45	25.56	12.21	44.76	58.00	13.24	77.17	40.63
Days to 50% Flowering	7.36	8.6	4.44	19.34	26.39	7.05	73.29	12.98
Fruits /Cluster	12.04	19.64	15.52	0.18	0.49	0.30	37.58	15.21
Fruits / Plant	42.93	45.13	13.91	15.54	17.18	1.63	90.5	84.14
Fruit Length	8.97	15.5	12.64	0.11	0.32	0.21	33.52	10.7
Fruit Girth	6.79	12.04	9.95	0.71	2.22	1.52	31.75	7.88
Fruit Volume	30	32.02	11.20	44.83	51.07	6.24	87.78	57.9
Fruit Weight	15.81	20.54	13.11	25.56	43.14	17.58	59.26	25.07
Yield/ Plant	45.58	46.44	8.91	16322.39	16946.09	623.70	96.32	92.15
Stomatal Frequency	36.14	36.2	2.05	24408.63	24487.51	78.89	99.68	74.33
RWC	9.7	12.69	8.18	55.05	94.19	39.14	58.44	15.28
Canopy Temperature	5.86	10.77	9.04	3.52	11.88	8.36	29.62	6.58
Proline Content	66.02	68	16.30	291.30	309.05	17.75	94.26	132.03

4.3.1. Coefficient of Variation

4.3.1.1. Phenotypic Coefficient of Variation

The phenotypic coefficient of variation (PCV) was found high for proline content of the leaves (68.00), yield plant^{-1} (46.44), fruits plant^{-1} (45.13), stomatal frequency (36.2), fruit volume (32.02), primary branches plant^{-1} (26.25), leaves plant^{-1} (25.56) and fruit weight (20.54). Moderate phenotypic coefficient of variation was observed for fruits cluster^{-1} (19.64), fruit length (15.50), relative water content (12.69), fruit girth (12.04), canopy temperature (10.77) and plant height (10.52). Days to 50% flowering (8.6) had low phenotypic coefficient of variation.

4.3.1.2. Genotypic Coefficient of Variation

The value of genotypic coefficient of variation (GCV) ranged from 5.86 for canopy temperature to 66.02 for proline content of leaves. High GCV was observed for proline content of leaves (66.02), yield plant^{-1} (45.58), fruits plant^{-1} (42.93), stomatal frequency (36.14), fruit volume (30.00), number of leaves plant^{-1} (22.45) and number of primary branches plant^{-1} (22.45). Characters like fruit weight (15.81) and number of fruits cluster^{-1} (12.04) showed moderate genotypic coefficient of variation. Low GCV was observed for relative water content (9.70), fruit length (8.97), days to 50% flowering (7.36), plant height (6.94), fruit girth (6.79) and canopy temperature (5.86).

4.3.1.3. Environmental Coefficient of Variation

ECV was observed moderate for proline content (16.30), fruits cluster^{-1} (15.52), number of fruits plant^{-1} (13.91), primary branches plant^{-1} (13.60), fruit weight (13.11), fruit length (12.64), number of leaves plant^{-1} (12.21) and fruit volume (11.2). Characters such as fruit girth (9.95), canopy temperature (9.04), yield plant^{-1}

(8.91), relative water content (8.18), plant height (7.90), days to 50% flowering (4.44) and stomatal frequency (2.05) exhibited a low ECV.

4.3.2. Heritability

High heritability was obtained for stomatal frequency (99.68%) followed by yield plant^{-1} (96.32%), proline content of leaves (94.26%), number of fruits plant^{-1} (90.5%), fruit volume (87.78%), number of leaves plant^{-1} (77.17%), days to 50% flowering (73.29%) and number of primary branches plant^{-1} (73.16%). Moderate heritability was observed for fruit weight (59.26%), relative water content (58.44%), plant height (43.61%), fruits cluster^{-1} (37.58%), fruit length (33.52%) and fruit girth (31.75%). Heritability was the least for canopy temperature (29.62%).

4.3.3. Genetic Advance (as Percentage of Mean)

The highest estimate of genetic advance obtained was 132.03% (proline content) followed by 92.15% (yield plant^{-1}), 84.14% (fruits plant^{-1}), 74.33% (stomatal frequency), 57.9% (fruit volume), 40.63% (number of leaves plant^{-1}), 39.56% (number of primary branches plant^{-1}) and 25.07% (fruit weight). Moderate genetic advance was recorded for relative water content (15.28%), fruits cluster^{-1} (15.21%), days to 50% flowering (12.98%) and fruit length (10.7%). Low genetic advance was observed for plant height (9.45%), fruit girth (7.88%) and canopy temperature (6.58%).

4.4. CORRELATION COEFFICIENT ANALYSIS

Genotypic, phenotypic and environmental correlation coefficients were worked out as the correlation between different characters. The results are presented here.

4.4.1. Genotypic Correlation Coefficient

The genotypic correlation coefficients are given in Table 4.

The genotypic correlation coefficients are given in Table 4. The interrelationship of plant height was positive with the characters yield plant^{-1} (0.5529), primary branches plant^{-1} (0.4198), number of fruits plant^{-1} (0.3606), days to 50% flowering (0.3572), and number of leaves plant $^{-1}$ (0.3236). Negative association was observed with canopy temperature (-0.8165), fruit weight (-0.3978) and fruit length (-0.3916).

The number of primary branches plant^{-1} showed positive correlation with number of leaves plant^{-1} (0.7792), plant height (0.4198) and days to 50% flowering (0.3855). Negative correlation was observed with fruit length (-0.5460), canopy temperature (-0.3526).

Positive correlation was recorded for number of leaves plant^{-1} with number of primary branches plant^{-1} (0.7792), plant height (0.3236), days to 50% flowering (0.3879) fruit girth (0.4441) and yield plant^{-1} (0.4314). Significant negative correlation was observed with relative water content (-0.6120).

Days to 50% flowering had positive association with plant height (0.3572), number of leaves plant^{-1} (0.3879), number of primary branches plant^{-1} (0.3855) and relative water content (0.3615). Negative association was observed with proline content (-0.4825), canopy temperature (-0.4616) and fruit girth (-0.3550).

Number of fruits cluster^{-1} showed positive correlation with number of fruits plant^{-1} (0.6399), yield plant $^{-1}$ (0.5444), canopy temperature (0.2965), and number of leaves plant^{-1} (0.2910). The association was significantly negative with fruit volume (-0.3636) , proline content (-0.3400), individual fruit weight(-0.3154).

Number of fruits plant $^{-1}$ showed high positive correlation with yield plant $^{-1}$ (0.8912), fruits cluster^{-1} (0.6399), plant height (0.3606), and fruit length (0.5554). Negative correlation was observed for individual fruit weight (-0.7608), followed by canopy temperature (-0.6553), proline content (-0.4512), and stomatal frequency (-0.4135)

Fruit length was positively correlated with number of fruits plant^{-1} (0.5554), yield plant $^{-1}$ (0.4783) and canopy temperature (0.3947). Negative correlation was observed with proline content (-0.5764), primary branches plant^{-1} (-0.5460) and relative water content (-0.3873).

Fruit girth showed significant positive correlation with fruit volume (0.8450), stomatal frequency (0.6835), individual fruit weight (0.6491), leaves plant^{-1} (0.4441) and yield plant^{-1} (0.3767). It had negative association with relative water content (-0.8750), and days to 50% flowering (-0.3550).

Positive correlation was recorded for fruit volume with Fruit girth (0.8450), yield plant^{-1} (0.4270) and fruit weight (0.3645). The association was negative for number of fruits cluster^{-1} (-0.3636).

Fruit weight had positive correlation with yield plant^{-1} (0.4748), fruit girth (0.6491), fruit volume (0.3645), stomatal frequency (0.5439) and proline content of leaves (0.4820). Negative correlation was recorded for number of fruits plant^{-1} (-0.7608), plant height (-0.3978), canopy temperature (-0.3562) and number of fruits cluster^{-1} (-0.3154).

Yield plant^{-1} showed positive correlation with almost all the characters. The highest positive correlation was observed for fruits plant^{-1} (0.8912), proline content (0.7241), relative water content (0.6252), plant height (0.5529), number of fruits cluster^{-1} (0.5444), stomatal frequency (0.4911), fruit length (0.4783), fruit weight

Table 4. Genotypic correlation coefficients among the 15 characters under water stress condition

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1	1.0000	0.4198**	0.3236*	0.3572*	0.0456	0.3606*	-0.3916*	-0.1963	-0.2742*	-0.3978	0.5529**	0.2057	-0.3367	-0.8165*	0.1381
X2		1.0000	0.7792**	0.3855*	-0.147	0.1698	-0.5460*	-0.0645	-0.1024	0.2951	0.1881	0.1484	-0.1559	-0.3526*	-0.0248
X3			1.0000	0.3879*	0.291*	-0.0783	-0.1879	0.4441**	-0.0859	0.049	0.4314**	0.3243*	-0.6120*	-0.2204	-0.1302
X4				1.0000	0.0876	-0.0318	0.1121	-0.3550*	-0.0236	-0.0738	-0.1616	0.2191	0.3615*	-0.4616*	-0.4825*
X5					1.0000	0.6399**	0.1814	-0.098	-0.3636**	-0.3154	0.5444**	-0.0299	-0.2995	0.2965	-0.3400*
X6						1.0000	0.5554*	-0.2761*	-0.204	-0.7608	0.8912**	-0.4135*	-0.0986	-0.6553**	-0.4512*
X7							1.0000	0.0266	-0.1889	0.2373	0.4783**	0.2713*	-0.3873	0.3947*	-0.5764*
X8								1.0000	0.8450**	0.6491**	0.3767*	0.6835*	-0.8750*	-0.0765	-0.1989
X9									1.0000	0.3645*	0.4270**	0.2719*	0.3151	0.0488	-0.0412
X10										1.0000	0.4748**	0.5439*	-0.0254	-0.3562**	0.4820*
X11											1.0000	0.4911**	0.6252**	0.4278*	0.7241**
X12												1.0000	-0.2192	-0.0032	0.0128
X13													1.0000	-0.3081*	0.4223**
X14														1.0000	-0.038
X15															1.0000

X1-Plant Height
X2-Number of Primary Branches/ Plant
X3-Number of Leaves/ Plant
X4-Days to 50% Flowering
X5-Number of Fruits /Cluster
X6-Number of Fruits /Plant
X7-Fruit Length
X8-Fruit Girth
X9-Fruit Volume
X10- Fruit Weight
X11-Yield/ Plant
X12-Stomatal Frequency
X13-Relative water content
X14-Canopy Temperature
X15-Proline content

*significant at 5% level **significant at 1% level

(0.4748), canopy temperature (0.4278), number of leaves plant^{-1} (0.4314) and fruit volume (0.4270). Negative correlation was observed for days to 50% flowering (-0.1616).

Stomatal frequency showed positive correlations with characters such as fruit girth (0.6835), followed by individual fruit weight (0.5439) and yield plant^{-1} (0.4911). stomatal frequency showed negative correlation with number of fruits plant^{-1} (-0.4135).

Relative water content had positive correlation with yield plant^{-1} (0.6252), proline content (0.4223) and days to 50% flowering (0.3615). Negative correlation was observed with fruit girth (-0.8750) number of leaves plant $^{-1}$ (-0.6120) and fruit length (-0.3873).

Interrelationship of canopy temperature was significantly positive with the characters yield plant^{-1} (0.4278) and fruit length (0.3947). Negative correlation was observed for plant height (-0.8165), number of fruits plant^{-1} (-0.6553), days to 50% flowering (-0.4616), individual fruit weight (-0.3562), and number of primary branches plant^{-1} (-0.3526).

Proline content of the leaves showed positive correlation with yield plant^{-1} (0.7241), followed by fruit weight (0.4820), Relative water content (0.4223). Negative correlation was recorded with fruit length (-0.5764), days to 50% flowering (-0.4825), number of fruits plant^{-1} (-0.4512) and number of fruits cluster^{-1} (-0.3400).

4.4.2. Phenotypic Correlation Coefficient

The phenotypic correlation coefficients are given in Table 5. The interrelationship of plant height was positive with the characters, number of fruits

plant^{-1} (0.5573), and canopy temperature (0.2975). Negative association was observed with individual fruit weight (-0.3222).

The number of primary branches plant^{-1} showed positive correlation with number of leaves plant $^{-1}$ (0.7757), and days to 50% flowering (0.3265). Negative correlation was observed with fruit length (-0.5275) and canopy temperature (-0.3028).

Positive correlation was recorded for number of leaves plant^{-1} with number of primary branches plant^{-1} (0.7757), days to 50% flowering (0.5370) fruit girth (0.2694). Significant negative correlation was observed with relative water content (-0.3310).

Days to 50% flowering had positive association with number of leaves plant^{-1} (0.5370), number of primary branches plant^{-1} (0.3265) and relative water content (0.3248). Negative association was observed with proline content (-0.4609) and fruit girth (-0.3131).

Number of fruits cluster^{-1} showed positive correlation with number of fruits plant^{-1} (0.5895), yield plant^{-1} (0.3572), canopy temperature (0.3271). The association was significantly negative with fruit volume (-0.3228), proline content (-0.3129), individual fruit weight (-0.3082).

Number of fruits plant^{-1} showed high positive correlation with yield plant^{-1} (0.8503), fruits cluster^{-1} (0.5895), plant height (0.5573), and fruit length (0.5479). Negative correlation was observed for individual fruit weight (-0.5596), followed by stomatal frequency (-0.3696).

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Fruit length was positively correlated with number of fruits plant^{-1} (0.5479), yield plant^{-1} (0.2864). Negative correlation was observed with primary branches plant^{-1} (-0.5275).

Fruit girth showed significant positive correlation with fruit volume (0.8192), stomatal frequency (0.6499), and fruit weight (0.6326). It had negative association with relative water content (-0.2777), and days to 50% flowering (-0.3131).

Positive correlation was recorded for fruit volume with fruit girth (0.8192), and fruit weight (0.3284). The association was negative for number of fruits cluster^{-1} (-0.3228).

Fruit weight had positive correlation with fruit girth (0.6326), stomatal frequency (0.5233), proline content of leaves (0.4530), yield plant^{-1} (0.3712) and fruit volume (0.3284). Negative correlation was recorded for number of fruits plant^{-1} (-0.5596), plant height (-0.3222), canopy temperature (-0.3103) and number of fruits cluster^{-1} (-0.3082).

Yield plant^{-1} showed positive correlation with almost all the characters. The highest positive correlation was observed for number of fruits plant^{-1} (0.8503) followed by stomatal frequency (0.4313), proline content (0.3959), fruit weight (0.3712) and number of fruits cluster^{-1} (0.3572). Negative correlation was observed for characters such as canopy temperature (-0.3625).

Stomatal frequency showed positive correlations with characters such as fruit girth (0.6499), followed by individual fruit weight (0.5233) and yield plant^{-1} (0.4313). Characters like number of fruits plant^{-1} (-0.3696) showed negative correlation.

Table 5. Phenotypic correlation coefficients among the 15 characters under water stress condition

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1	1.0000	0.1997	0.1857	0.2108	0.1050	0.5573*	-0.1501	0.1680	-0.0777	-0.3222*	0.1665	0.1557	0.0523	0.2975	0.106
X2		1.0000	0.7757**	0.3265	-0.1370	0.1302	-0.5275*	0.0220	-0.0988	0.0982	0.1474	0.1838	-0.0142	-0.3028*	-0.0112
X3			1.0000	0.5370**	0.2420	-0.0330	-0.0699	0.2690	-0.0087	0.0182	-0.0591	0.2089	-0.3310*	-0.0983	-0.1105
X4				1.0000	0.0700	-0.0208	0.0576	-0.3130	-0.0077	-0.0056	-0.0992	0.1347	0.3248*	-0.1078	-0.4609*
X5					1.0000	0.5895**	0.1017	-0.0015	-0.3228	-0.3082	0.3572*	-0.0313	-0.0412	0.3271*	-0.3129
X6						1.0000	0.5479**	-0.1813	-0.1774	-0.5596*	0.8503**	-0.3696*	-0.0593	-0.2426	-0.1451*
X7							1.0000	0.0242	0.0916	0.0078	0.2864	0.1518	-0.1484*	0.1269	-0.1531*
X8								1.0000	0.8192**	0.6326**	0.0552	0.6499**	-0.2777*	-0.1231	-0.1422
X9									1.0000	0.3284	0.0421	0.1786	-0.1237	0.1155	-0.0714
X10										1.0000	0.3712	0.5233*	-0.1247	-0.3103*	0.4530**
X11											1.0000	0.4313**	0.1078	0.3625**	0.3959**
X12												1.0000	-0.1622	-0.0141	0.0225
X13													1.0000	-0.0491	0.5328**
X14														1.0000	-0.0307
X15															1.0000

X1-Plant Height
X2-Number of Primary Branches/ Plant
X3-Number of Leaves/ Plant
X4-Days to 50% Flowering
X5-Number of Fruits /Cluster
X6-Number of Fruits /Plant
X7-Fruit Length
X8-Fruit Girth
X9-Fruit Volume
X10- Fruit Weight
X11-Yield/ Plant
X12-Stomatal Frequency
X13-Relative water content
X14-Canopy Temperature
X15-Proline content

*significant at 5% level **significant at 1% level

Relative water content had a positive correlation with proline content (0.5328) and days to 50% flowering (0.3248). Negative correlation was observed with number of leaves plant^{-1} (-0.3310) and fruit girth (-0.2777).

Interrelationship of canopy temperature was significantly positive with the character plant height (0.2975), fruit girth (0.3271) and yield plant^{-1} (0.3625). Negative correlation was observed for individual fruit weight (-0.3103) and number of primary branches plant^{-1} (-0.3028).

Proline content of the leaves showed positive correlation with relative water content (0.5328), followed by yield plant^{-1} (0.3959) and individual fruit weight (0.4530). Negative correlation was observed with days to 50% flowering (-0.4609) and number of fruits cluster^{-1} (-0.3129).

4.5. PATH COEFFICIENT ANALYSIS

Path coefficient analysis was used to estimate the direct and indirect effects of component characters on yield. The path correlation coefficients representing the direct and indirect effects are given in Table 6.

Plant height showed a negative direct effect on yield (-0.33). A high positive indirect effect was shown through relative water content (0.61) and canopy temperature (0.59). Indirect effects through number of leaves (-0.71) and fruit weight (-0.48) were negative. Plant height showed a high and positive correlation of 0.55 with yield plant^{-1}.

The direct effect of number of primary branches plant^{-1} on yield was positive (0.76). It also showed a high negative indirect effect through number of leaves plant^{-1} (-1.70). Indirect effect through fruit weight (0.36) and fruit length (0.32) was positive.

The genotypic correlation of number of primary branches plant^{-1} was low and negative with yield (-0.19).

Number of leaves plant^{-1} showed a negative direct effect on yield (-0.18). The indirect effect through number of primary branches plant^{-1} (0.59), number of fruits cluster^{-1} (0.29) and days to 50% flowering (0.28) were positive. Negative indirect effect was observed through fruit girth (-0.50). It showed a positive correlation with yield (0.43).

Days to 50% flowering showed high negative direct effect on yield (-0.7096). Indirect effect through number of leaves plant^{-1} (-0.85) was negative. Positive indirect effect through characters such as canopy temperature (0.34), number of primary branches plant^{-1} (0.29) and fruit girth (0.24) was also observed. The genotypic correlation between days to 50% flowering and yield was insignificant and negative.

Fruits cluster^{-1} had high positive direct effect (1.34) on yield plant^{-1}. Its indirect effects through other characters were low. It had a high positive genotypic correlation with yield (0.54).

Number of fruits plant^{-1} had a low positive direct effect on yield (0.17). Indirect effect through canopy temperature (0.48) and number of fruits cluster^{-1} (0.86) was found positive. Indirect effect through fruit weight (-0.92) was negative. In addition, the character showed a significantly high correlation with yield (0.8912).

Fruit length showed a negative direct effect on yield (-0.58). Its indirect effects through number of leaves plant^{-1} (0.41) and fruit weight (0.29) were positive and negative *via* canopy temperature (-0.29). The genotypic correlation of fruit length with yield was positive (0.48).

The direct effect of fruit girth on yield was positive (0.79). The indirect effect through other characters like number of leaves plant^{-1} (-0.97), fruit weight (-0.69) were negative. Fruit girth showed a high positive indirect effect on yield through relative water content (1.58). Fruit girth showed a significant correlation with yield (0.38).

Fruit volume had a positive direct effect on yield (0.36). It showed a positive indirect effect on yield through fruit girth (0.57) and fruit volume (0.44). The correlation of fruit volume with yield was high and positive (0.43).

The direct effect of individual fruit weight on yield was high and positive (1.21). Indirect effect through canopy temperature (0.26) and number of primary branches plant^{-1} (0.22) were found positive. Negative indirect effects were shown through fruit girth (-0.44) and fruits cluster^{-1} (-0.42). The genotypic correlation of individual fruit weight was positively significant (0.47).

Stomatal frequency had a positive direct effect on yield (0.57). Indirect effects were negative through number of leaves plant^{-1} (-0.71), fruit girth (-0.46) and fruit length (-0.16). It showed a positive significant genotypic correlation with yield plant^{-1} (0.52).

Relative water content showed a positive direct effect on yield (0.80). It had a negative indirect effect through number of primary branches plant^{-1} (-0.42), number of fruits cluster^{-1} (-0.40), number of fruits plant^{-1} (-0.42), fruit volume (-0.41), proline content (-0.15) and fruit weight (-0.31). However, it showed positive indirect effects on yield through characters such as number of leaves plant^{-1} (0.83), days to 50% flowering (0.26), fruit length (0.23), plant height (0.11), canopy temperature (0.22), and fruit girth (0.19). Relative water content showed a genotypic correlation of 0.62 with yield plant^{-1}.

Table 6. Path Coefficients representing direct and indirect effects of component characters on yield

Characters	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X12	X13	X14	X15	Genotypic correlation
X1	-0.33	0.32	-0.71	0.25	0.06	0.06	0.23	0.13	-0.10	-0.48	-0.09	0.61	0.59	-0.01	0.55
X2	-0.14	0.76	-1.70	0.27	-0.20	0.03	0.32	0.04	-0.04	0.36	-0.06	0.28	0.24	0.02	0.19
X3	-0.11	0.59	-0.18	0.28	0.29	-0.21	0.11	-0.50	-0.03	0.06	-0.13	0.10	0.16	0.01	0.43
X4	-0.12	0.29	-0.85	-0.71	0.12	-0.01	-0.07	0.24	-0.01	0.09	-0.09	0.60	0.34	0.01	-0.16
X5	-0.02	-0.11	-0.63	0.06	1.34	0.11	-0.11	0.07	-0.13	-0.38	0.01	0.54	-0.22	0.01	0.54
X6	-0.12	0.13	0.17	-0.02	0.86	0.17	-0.32	0.19	-0.07	-0.92	0.17	0.18	0.48	0.02	0.89
X7	0.13	-0.42	0.41	0.08	0.24	0.09	-0.58	-0.02	-0.07	0.29	-0.11	0.70	-0.29	0.02	0.48
X8	0.06	-0.05	-0.97	-0.25	-0.13	-0.05	-0.02	0.79	0.30	-0.69	-0.28	1.58	0.06	0.01	0.38
X9	0.09	-0.08	0.19	-0.02	-0.49	-0.03	0.11	0.57	0.36	0.44	-0.11	-0.57	-0.04	0.01	0.43
X10	0.13	0.22	-0.11	-0.05	-0.42	-0.13	-0.14	-0.44	0.13	1.21	-0.22	0.05	0.26	-0.02	0.48
X12	-0.07	0.11	-0.71	0.16	-0.04	-0.07	-0.16	-0.46	0.10	0.66	0.57	0.40	0.02	0.01	0.49
X13	0.11	-0.42	0.83	0.26	-0.40	-0.42	0.23	0.19	-0.41	-0.31	0.09	0.80	0.22	-0.15	0.62
X14	0.27	-0.27	0.38	-0.33	0.40	-0.11	-0.23	0.05	0.02	-0.43	0.01	0.36	0.33	0.01	0.43
X15	-0.05	-0.22	0.24	-0.34	-0.46	-0.18	0.34	0.13	-0.17	0.58	-0.05	0.50	0.03	0.35	0.72

X1-Plant Height
X2-Number of Primary Branches/ Plant
X3-Number of Leaves/ Plant
X4-Days to 50% Flowering
X5-Number of Fruits /Cluster
X6-Number of Fruits /Plant
X7-Fruit Length
X8-Fruit Girth
X9-Fruit Volume
X10- Fruit Weight
X12-Stomatal Frequency
X13-Relative water content
X14-Canopy Temperature
X15-Proline content

Canopy temperature showed a positive direct effect on yield (0.33). Number of leaves plant^{-1} (0.38), relative water content (0.36) and plant height (0.27) showed a positive indirect effect on yield. Indirect effects through other characters were negative and low. It showed a positive genotypic correlation of 0.44 with yield plant^{-1}.

The direct effect of proline content on yield was positive (0.35). Indirect effect of proline content on yield was negative through number of fruits cluster^{-1} (-0.46), days to 50 % flowering (-0.34), number of primary branches plant^{-1}s (-0.22), number of fruits plant^{-1} (-0.18), and fruit volume (-0.17). Positive indirect effects on yield was shown through fruit weight (0.58), relative water content (0.5), fruit length (0.34),number of leaves plant^{-1} (0.24) and fruit girth (0.13). A high and positive genotypic correlation (0.72) was observed for proline content with yield.

The residual effect obtained was 0.07.

4.6. SELECTION INDEX

The selection index for all the genotypes were worked out based on yield and the physiological characters contributing to stress tolerance. The genotypes were ranked according to the scores obtained based on the characters selected. The scores were worked out for each genotype and are given in Table 7.

The genotype A6 (Kottayam local) was ranked first with a score 1394.32, followed by A4 (1138.64), A2 (1111.09) and A7 (1015.39).

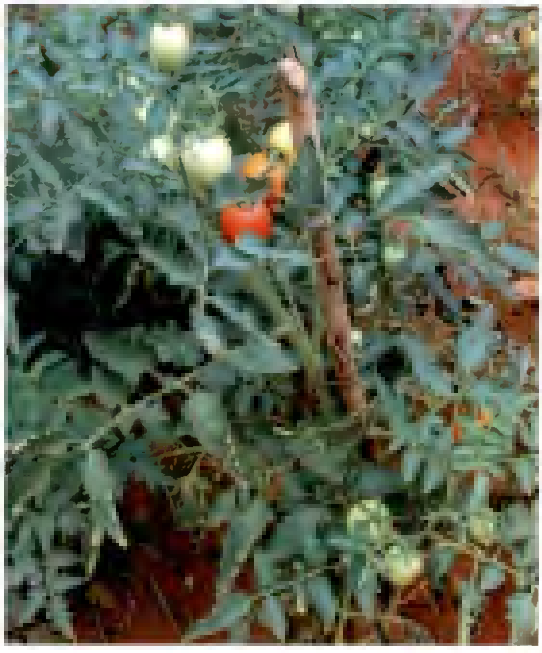
Table 7. Selection index for 20 tomato genotypes under water stress condition

Genotype No.	Genotype	Score
A6	Kottayam Local	1394.32
A4	Palakkad Local	1138.64
A2	Kuttichal Local I	1111.09
A7	Kuttichal local II	1015.39
A16	Arka Meghali	964.43
A17	Vellayani Vijay	812.04
A5	Vellayani Local I	784.50
A18	Anagha	759.49
A12	Arka Alok	741.51
A15	Arka Saurabh	719.63
A19	Akshay	698.59
A3	Venpalavattam Local	604.64
A8	Kaithamukku Local	603.76
A9	Pettah Local	530.26
A11	Haripad Local	501.69
A14	Arka Vikas	471.48
A20	Manulekshmi	458.53
A13	Thrissur Local	439.35
A10	Vellayani local II	352.06
A1	Nellanadu Local	329.12

Plate 7. Selected Superior tomato genotypes with good yield under water stress condition

Kottayam Local

Palakkad Local



Kuttichal Local I

Kuttichal Local II

Discussion

5. DISCUSSION

The success of any breeding programme depends upon the extent of variability present in the germplasm, which could be exploited through selection. The present investigation was conducted at Department of Plant Breeding and Genetics, College of Agriculture, Vellayani to identify suitable high yielding tomato (*Solanum lycopersicum* L.) genotypes under water stress conditions. The promising genotypes identified in the study can be used in further crop improvement programmes for developing water stress tolerant varieties.

5.1. VARIABILITY

The degree of variability of a population with respect to yield and other morphological characters is best characterized by the phenotypic variation present in the population. In the present study, fifteen characters were studied and all the characters showed considerable variation among the twenty genotypes evaluated.

Analysis of variance revealed significant differences among the genotypes for all the 15 traits studied indicating presence of significant variability in the germplasm that could be exploited through selection. Similar results were noticed in tomato by Cheema and Singh (2005), Basavaraj *et al.* (2010), Kaushik *et al.* (2011) and Dar and Sharma (2011).

Yield plant^{-1} showed the greatest range of variation followed by proline content ,number of fruits plant^{-1}, stomatal frequency, fruit volume , and number of leaves plant $^{-1}$. Supporting evidences were given by Golani *et al.* (2007), Haydar *et al.* (2007), Mehta and Asati (2008), Ghosh *et al.* (2010), and Kaushik *et al.* (2011).

The accession A6 (Kottayam local) produced the highest yield plant^{-1} followed by A4 (Palakkad local), A7 (Palappoor local), A2 (Kuttichal local II).

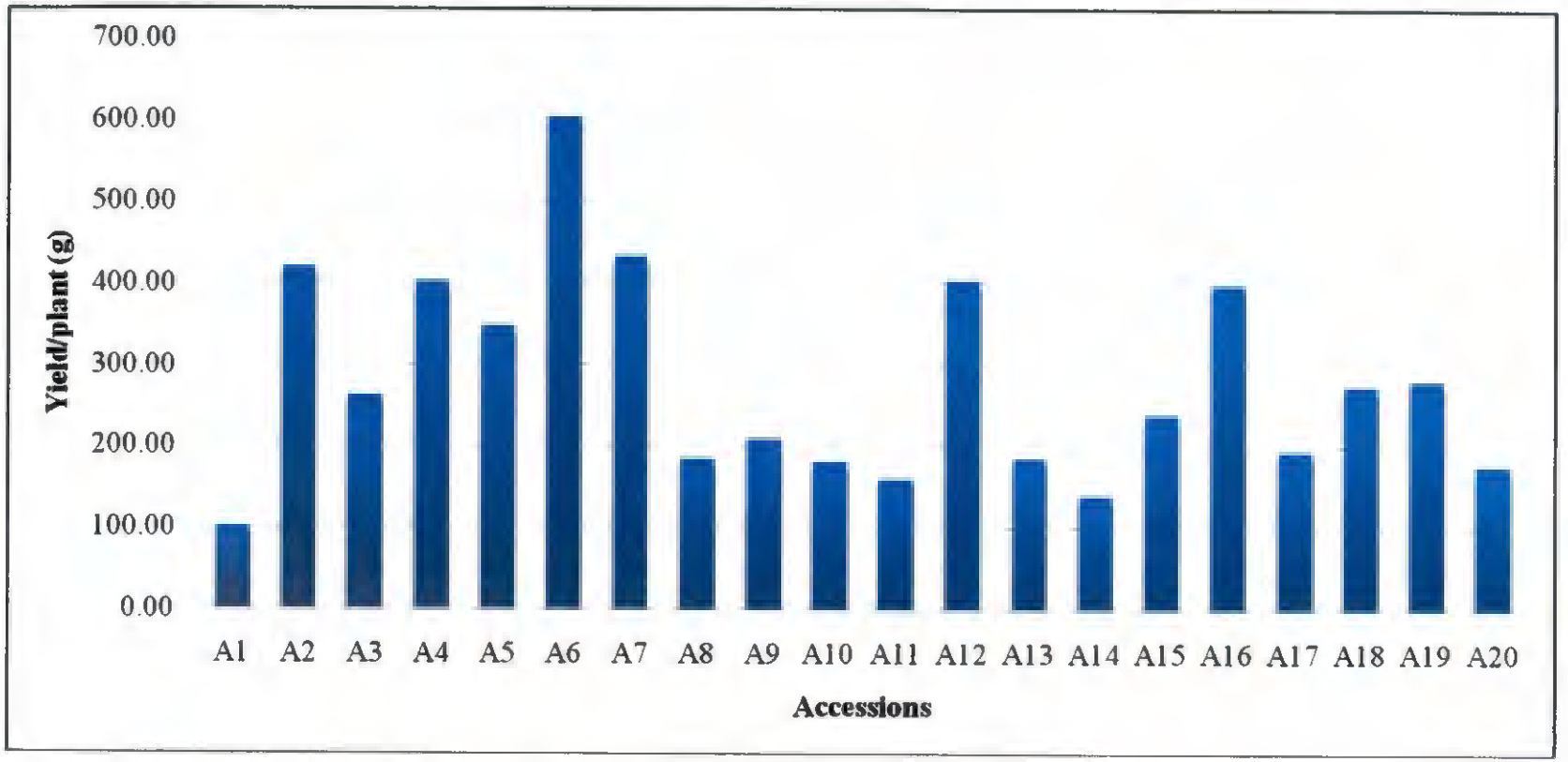


Fig.1. Comparative mean yield performance of twenty tomato genotypes under water stress conditions

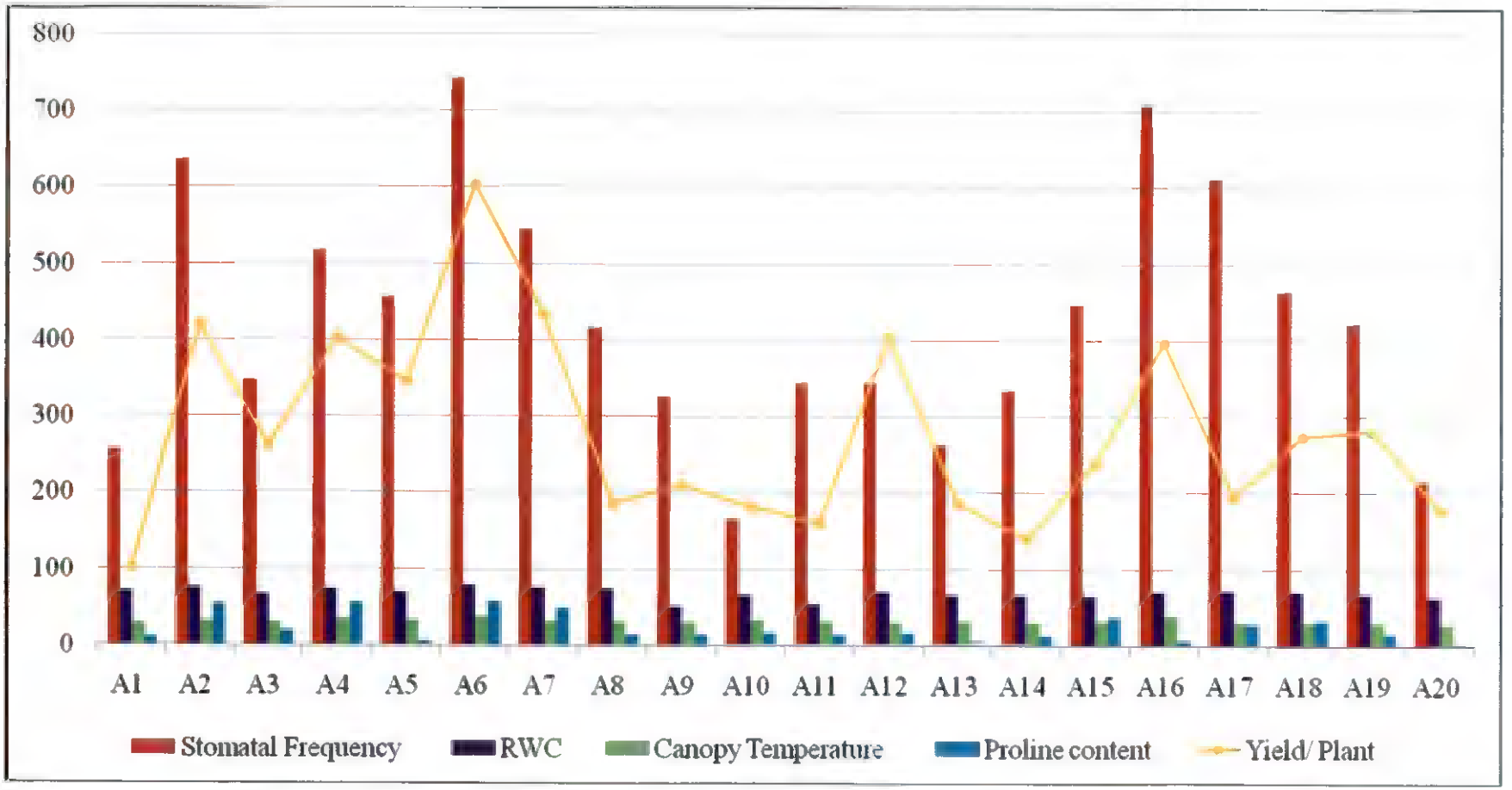


Fig.2. Comparative performance of 20 tomato genotypes based on yield and physiological characters contributing to water stress tolerance

Accession A6 was found superior to other genotypes for number of fruits plant^{-1}, relative water content, stomatal frequency and proline content.

5.2. COEFFICIENT OF VARIATION

The success of breeding programme depends upon quantum of variability present in the available germplasm. The variability present in the germplasm was then estimated using genetic parameters such as genotypic coefficient of variation (PCV), phenotypic coefficient of variation (GCV), environmental coefficient of variation (ECV), heritability in broad sense (H^2_b) and genetic advance as percent of mean to understand the nature of variation present.

The coefficient of variation measures the range of variability present in the population. The total variation is divided into phenotypic, genotypic and environmental. The genotypic coefficient of variation is used to estimate the heritable portion of total variation. Phenotypic expression is the result of interaction of the genotype with the environment.

The value of genotypic coefficient of variation (GCV) ranged from 5.86 for canopy temperature to 66.02 for proline content of leaves. High genotypic variance was observed for most of the characters such as proline content, yield plant^{-1}, number of fruits plant^{-1}, stomatal frequency, number of primary branches plant $^{-1}$, number of leaves and fruit volume which indicated that the total variation was mainly contributed by the genetic component . Therefore, these characters could be considered and exploited for selection. These results were in accordance of the results obtained in tomato by Mohanty (2003), Lecomte *et al.* (2004), Hayder *et al.* (2007), Ghosh *et al.* (2010) and Bernousi *et al.* (2011).

In the study, there was close association between the estimates of GCV and PCV. High PCV and GCV were observed for the characters proline content, fruit

yield plant^{-1} and number of fruits plant^{-1}. Similar results of high PCV and GCV were reported by Manna and Paul (2012), Naik *et al.* (2012), Patel *et al.* (2013), Agrawal *et al.* (2014) and Khapte and Jansirani (2014).

Canopy temperature showed very low variation. Moderate variation was observed for number of primary branches plant^{-1}, individual fruit weight, stomatal frequency, days to 50% flowering, number of fruits per cluster. Narolia *et al.* (2012) and Kaushik *et al.* (2011) have also reported similar findings for plant height, average fruit weight and number of branches.

The estimates of phenotypic coefficient of variation (PCV) were higher than genotypic coefficient of variation (GCV) for all the traits studied. Comparable findings were reported by Golani *et al.* (2007), Dar and Sharma (2011), Kaushik *et al.* (2011), Rani and Anitha (2011) and Chernet *et al.* (2013).

Most of the characters showed genotypic coefficient of variation close to the phenotypic coefficient of variation. The major portion of PCV was contributed by GCV for most of the characters. For all the characters, the environmental coefficient of variation was comparatively low indicating the lower influence of environment on these traits.

High values of GCV are an indication of high genetic variability among the germplasm and thus the scope for improvement of these characters through simple selection would be better. High magnitude of phenotypic as well as genotypic coefficients of variation were observed in case of fruit yield plant^{-1}, number of primary branches plant^{-1}, and number of fruits plant^{-1}. This indicated the possibility of obtaining higher selection response with respect to these traits. The high estimates of PCV and GCV for these characters were also reported in tomato by Dar and Sharma (2011) and Rani and Anitha (2011).

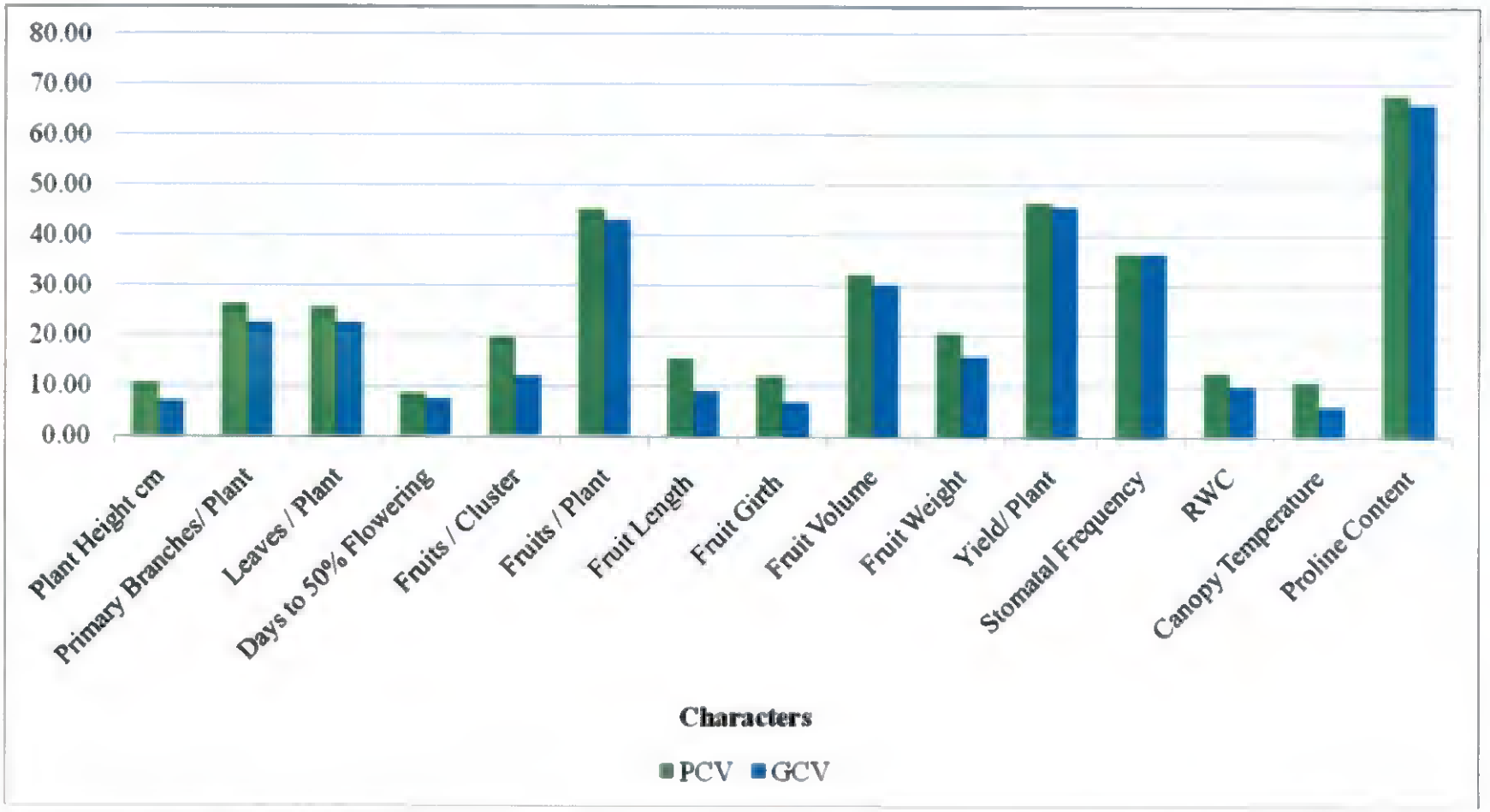


Fig.3. Phenotypic, Genotypic and Environmental Coefficients of variation for 15 characters under water stress

Moderate coefficient of variability both at phenotypic and genotypic level were observed for number of fruits per cluster. Fehmida and Ahmad (2007), Ara *et al.* (2009), Dar and Sharma (2011), Buckseth *et al.* (2012), Rahaman *et al.* (2012), Manna and Paul (2012), Kumar *et al.* (2013), Patel *et al.* (2013), Chadha and Bhusan (2013), Sidhva *et al.* (2014), Khapte and Jansirani (2014), Kumar (2014), and Rai *et al.* (2016) also noticed similar results.

Low estimates of GCV and PCV were observed for plant height and days to 50 per cent flowering. Low variability for these traits in tomato were also reported by Manna and Paul (2012).

5.3. HERITABILITY AND GENETIC ADVANCE

Heritability is the heritable portion of phenotypic variance. It indicates the degree at which a character is transmitted from the parent to its offspring. A high value of heritability indicates that the influence of environment on the character is low and selection for the improvement of such a character will be effective. Higher broad sense heritability magnitude revealed that greater proportion of the entire variance was due to the greater genotypic variance influenced less by environmental factors therefore having high heritable variations.

In the study, the heritability estimates ranged from 99.68% for stomatal frequency to 29.62% for canopy temperature. High heritability was obtained for stomatal frequency followed by yield plant^{-1}, proline content of leaves, number of fruits plant^{-1}, fruit volume, number of leaves plant^{-1}, days to 50 % flowering and number of primary branches plant^{-1}. Moderate heritability was observed for fruit weight, relative water content, plant height, fruits cluster^{-1}, fruit length and fruit girth. Heritability was observed low for canopy temperature.

Fruit yield showed high heritability in broad sense, in accordance with the results of Golani *et al.* (2007) in tomato. This clarified that they were least affected by environmental modification and selection based on phenotypic performance would be reliable. High heritability was observed for characters such as number of fruits plant^{-1}, days to 50 % flowering and number of primary branches plant^{-1}. Similar results were reported by Patel *et al.* (2015) in tomato.

High heritability with high estimates of genetic gain was observed for number of primary branches plant$^{-1,}$ number of leaves plant^{-1}, number of fruits plant^{-1}, fruit volume, yield plant^{-1}, stomatal frequency and proline content. High heritability coupled with high genetic advance was reported for plant height, number of fruits plant^{-1} and yield plant^{-1} in tomato by Reddy *et al.* (2013).The present results are in accordance with the findings of Rai *et al.* (2016) in tomato.

In the present study, heritability estimates were moderate for fruit length. The results were contradictory to that observed by Golani *et al.* (2007) who reported high estimates of heritability coupled with low GCV and genetic gain for fruit length, which might be attributed to non-additive gene action controlling its expression. Simple selection would not be rewarding, but could be improved by development of hybrid varieties or utilization of trangressive segregants in heterosis breeding programme. The present results are in confirmation with the results of Padmini and Vadival, 1997; Prasad and Rai, 1999; Singh *et al.*, 2002 and Mohanty, 2003 in tomato.

The highest estimate of genetic advance obtained was 132.03% for proline content followed by yield plant^{-1} , number of fruits plant^{-1}, stomatal frequency, fruit volume, number of leaves plant$^{-1,}$ number of primary branches plant^{-1} and fruit weight. Results reported by Sidhva *et al.* (2014) for number of fruits plant^{-1}, fruit

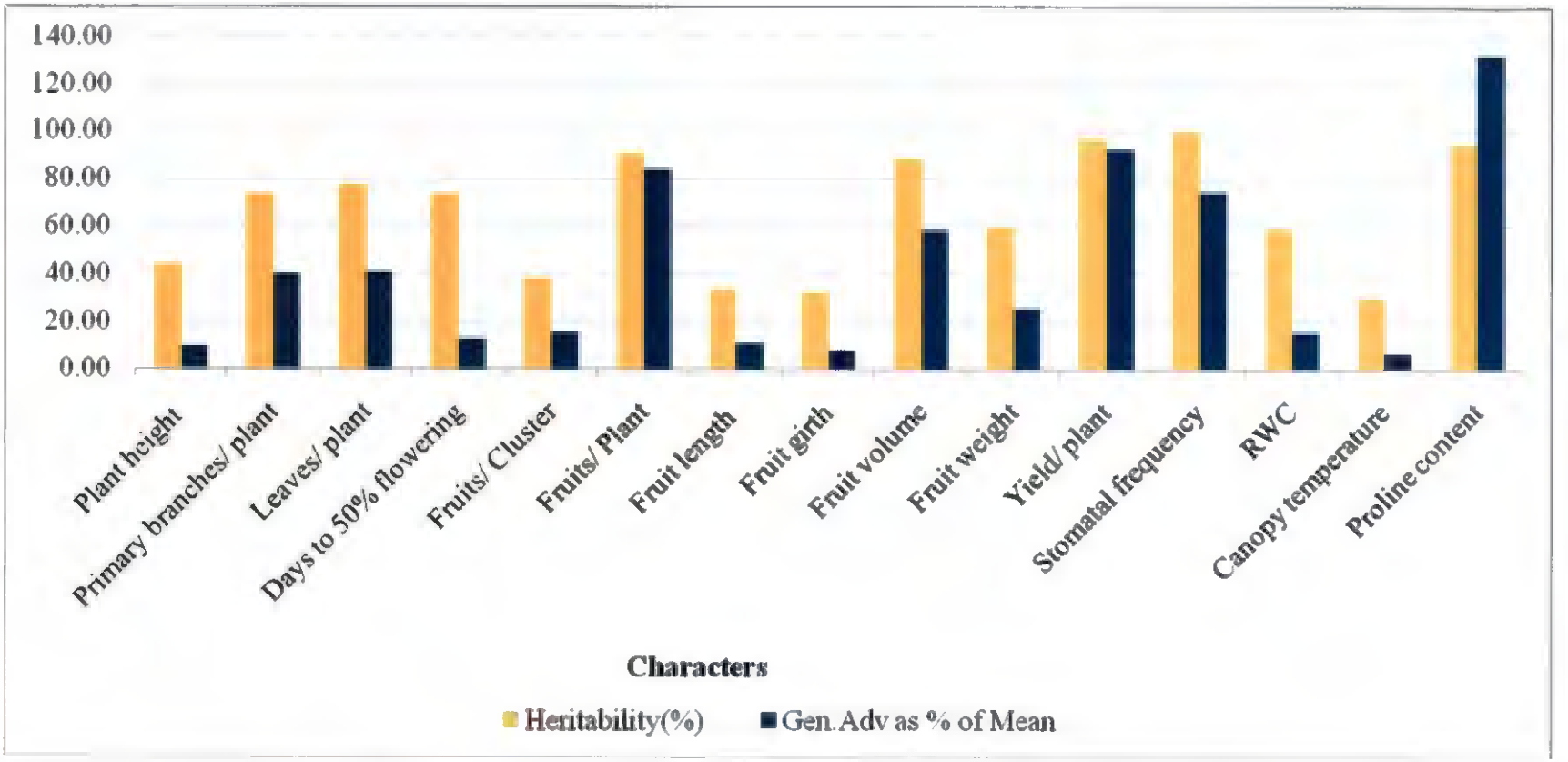


Fig. 4. Heritability and genetic advance for 15 characters of 20 tomato genotypes under water stress

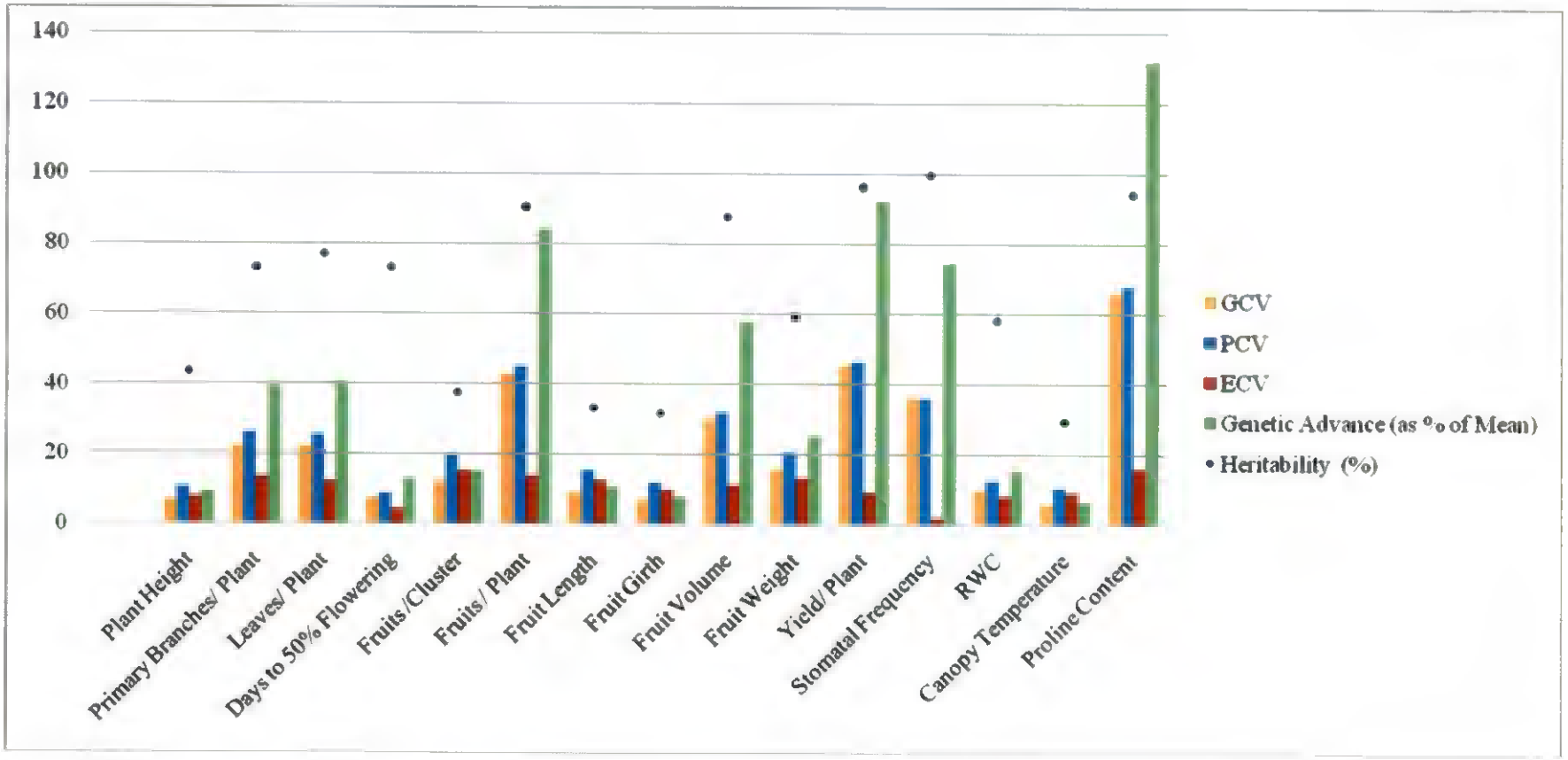


Fig.5. Genetic parameters for 15 characters in 20 tomato genotypes under water stress condition

weight and yield plant^{-1} in tomato were in agreement with the findings of the present study.

Moderate genetic advance was recorded for relative water content, fruits cluster^{-1}, days to 50% flowering and fruit length. Reddy *et al.* (2013) has also observed similar findings in tomato. Low genetic advance was observed for plant height, fruit girth and canopy temperature.

5.4. CORRELATION COEFFICIENT ANALYSIS

A number of yield characters were studied in the present investigation. Correlation analysis between yield and component characters showed that in most of cases the genotypic correlation coefficients were higher than the respective phenotypic correlation coefficients. In addition, narrow difference between phenotypic and genotypic correlation coefficient was noticed for almost all the pairs of characters studied showing that masking or modifying effects of the environment was little. This indicated the presence of an innate association among these characters. The estimates of phenotypic and genotypic correlation coefficients described that the genotypic correlations were higher in magnitude than the corresponding phenotypic ones for most of the characters combinations establishing predominant role of heritable factors.

High positive correlation was noted for number of fruits plant^{-1}, plant height, number of fruits cluster^{-1}, fruit length, fruit girth, fruit volume and individual fruit weight with yield. The trend of this result is contrary to the findings of Prasad and Rai (1999) but in accordance with Mohanty (2003) who reported high positive direct effect of average fruit weight on yield of tomato.

Number of fruits plant^{-1} had negative correlation with fruit size and fruit weight which is in accordance with the results of Mohanty (2003) in tomato.In the

study, plant height showed a positive correlation with yield plant^{-1}. This is contrary to the results obtained by Golani *et al.* (2007) who observed that the phenotypic and genotypic associations of fruit yield were significant and negative with plant height.

The present study showed significant difference between the genotypes for canopy temperature. This is consistent with the results of a study by Blum *et al.* (1982) which showed that canopy temperature differences of various wheat and triticales strains were minimal when plants had a favorable moisture status but showed significant differences as water stress increased.

A positive correlation was observed between canopy temperature and yield plant^{-1} in the study. The positive correlation between canopy temperature and yield is consistent and in accordance with the results of Chaudhuri *et al.* (1986) and Hatfield *et al.* (1987) who observed that crops with the warmest canopies such as cotton, sorghum, and millet genotypes produced the greatest biomass or yield under water deficit conditions. Hatfield *et al.* (1987) proposed that genotypes with high water conserving ability would transpire less under optimal soil water conditions, thereby reducing transpirational cooling and increasing canopy temperature. The resulting lower crop water use should allow these genotypes to conserve more water for use during periods of drought.

In the study, it was noted that high yielding genotypes had higher canopy temperatures. This is in accordance with the results of Chaudhuri *et al.* (1986) who found that warmer sorghum and pearl millet genotypes were generally more productive than cooler genotypes, under drought stressed conditions. Similar results have also been reported for potatoes (Stark and Pavek, 1987).

Zipoli *et al.* (1987) reported that wheat cultivars which had the warmest midday canopy temperatures under well-watered conditions used the least amount

of water during the season and had the highest relative yields when water was limited. The drought tolerant lines had a lower transpirative water loss which resulted in higher canopy temperatures. A positive and significant correlation ($r = 0.80$; $p<0.01$) was also observed between relative yields under water stress and average canopy minus air temperature under well-watered conditions. In another study, Stark *et al.* (1991) reported that warmer potato (*Solanum tuberosum* L.) genotypes under well-watered conditions were also generally less susceptible to drought than cooler genotypes. Stark *et al.* (1991) has also reported that in potato, the comparatively high canopy temperatures of certain varieties were a clear indication of their high degree of drought resistance.

Positive and significant correlation was observed between proline content of the leaves and yield plant^{-1}. These results are in a harmony with those obtained by Nahar and Gretzmacher (2002) who reported significant increases in proline and ascorbic acid in tomato fruits that showed some tendency to adjust osmotically to water stress. Claussen (2005) reported that proline accumulation under stress conditions might be by either induction or activation of enzymes of proline biosynthesis or a decreased proline oxidation to glutamate, decreased utilization of proline in protein synthesis, and enhanced protein turnover. Accumulation of proline has been advocated as a parameter of selection for stress tolerance (Jaleel *et al.*, 2007). Proline accumulation has played adaptive roles in plant stress tolerance (Verbruggen and Hermans, 2008). In addition, accumulation of proline has been reported under the drought stress in other crops such as chick pea (Sanchez *et al.*,1998) corn (Serraj and Sinclair, 2002) and peanut (Smith *et al.*, 2002).

Proline content of the leaves showed positive correlation with yield under water stress conditions. Similar results were recorded by Keyvan (2010), who reported that there is a high and significant correlation between grain yield and

proline (r= 0.860**) under drought conditions in wheat. Proline content of the leaves showed a positive correlation with fruit weight. This is in contradiction to the results of Claussen (2005) who reported that the average concentration of proline in tomato leaves accumulated during reproductive growth is a measure of the stress plants experienced during this period, which was indicated by a negative correlation ($r = -0.89$, $P < 0.05$) between proline content of leaves and fruit fresh weight.

A positive and significant correlation was observed between relative water content and yield plant^{-1}. The results are similar to the works of Schonfeld *et al.*, (1988) and Bayoumi *et al.*, 2008. Keyvan (2010) also observed high and significant correlation between grain yield and RWC (r=0.880**) under drought conditions in wheat.

The genotypes evaluated in the study showed significant difference among themselves for RWC. The difference in RWC of cultivars under drought stress might be due to the difference in ability of absorption of water from soil or ability of stomata to reduce the loss of water from the plant. These results of the present study are in conformity with the reports of Sinclair and Ludlow (1985). Schonfeld *et al.* (1988) also observed that RWC in wheat decreased with increase of drought stress and those cultivars that are resistant to drought have more RWC.

A positive correlation was observed between stomatal frequency and yield plant $^{-1}$ under water stress conditions. Small stomata could maintain the pore opening with lower guard-cell turgor pressures compared with larger stomata (Spence *et al.*, 1986). Hence, higher stomatal density might have effectively inhibited transpirative water loss and ensured better water balance thus contributing to a better yield (Bosabalidis and Kofidis, 2002).The results of the

present study are similar to previous observations on *Amaranthus tricolor* (Ren, 2003).

Zhao *et al.* (2015) reported that irrespective of developmental stage, severe drought, significantly increased stomatal density in maize, consistent with numerous previous studies (Dunlap and Stettler, 2001; Bosabalidis and Kofidis, 2002; Pearce *et al.*, 2005; Fu *et al.*, 2013), but contradictory to the results of Xu *et al.* (2003) and Xu and Zhou (2008).

5.5. PATH COEFFICIENT ANALYSIS

Correlation between yield and yield components were partitioned into direct and indirect effects to know the particular factor responsible for that correlation. Path coefficient divides the correlation coefficients into direct and indirect effects. This measures the direct and indirect contribution of independent characters on dependent character (Fig.5).

In the study, characters such as number of fruits cluster^{-1}, fruit weight, RWC, fruit volume, number of primary branches plant^{-1} and stomatal frequency showed high positive direct effect on yield. Supporting evidence of direct positive influence of number of fruits plant^{-1} on yield plant^{-1} was reported earlier by Rani *et al.* (2008) and Islam *et al.* (2010). This is also in agreement with the results of Mahapatra *et al.* (2013) which also revealed that number of fruits plant^{-1} and fruit weight had maximum direct effect on fruit yield at genotypic level.

Characters like days to 50% flowering, fruit length, plant height and number of leaves plant^{-1} showed a negative direct effect on yield. The positive genotypic correlation for these characters was due to the indirect effect through other independent variables. The negative direct effect of days to 50% flowering on yield was similar to the findings of Mageswari *et al.* (1999). The results were in

line with findings of Rahaman *et al.* (2012) and Saleem *et al.* (2013). According to Islam *et al.*(2010), fruits plant^{-1} showed the highest positive direct effect on yield plant^{-1} followed by individual fruit weight. On the other hand, the highest negative direct effect on yield plant^{-1} was shown by days to first flowering followed by fruit length.

It was observed that number of branches plant^{-1} exhibited positive direct effect on yield. The result was in harmony with the findings of Verma and Sarnaik (2000) who have reported that the number of branches plant^{-1} showed positive direct effect on yield and the positive correlation between branches plant^{-1} and yield plant^{-1} was the cumulative contribution of the direct and indirect effects through other characters. The direct effect of plant height on yield was negative and high, which was found under severe drought conditions by Khalili *et al.* 2013. The residual effects appeared to be considerably low which indicated that the characters included in this study explained almost all variability towards yield.

The study revealed that accumulation of proline in leaves is an important mechanism contributing to tolerance under water stress conditions. The promising genotypes identified in the study can be used in further crop improvement programmes for developing water stress tolerant varieties.

The results of the study imply that in order to select high yielding genotypes under water stress conditions, emphasis must be placed on important traits such as number of fruits cluster^{-1}, fruit weight, RWC, fruit volume, number of primary branches plant^{-1}, proline content and stomatal frequency.

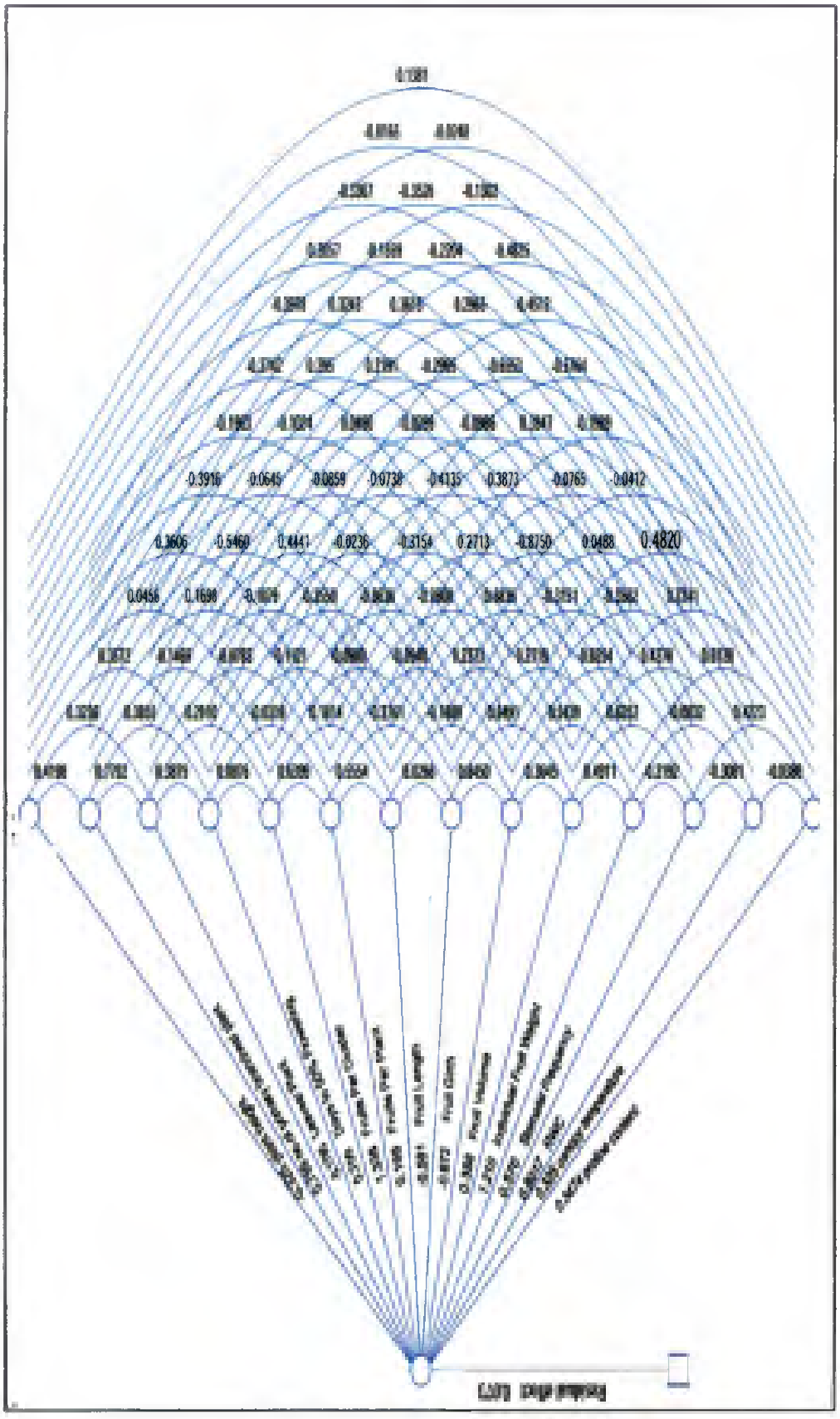


Fig. 6. Path diagram showing direct and indirect effect of different characters on yield

Summary

6. SUMMARY

The present investigation on "Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for yield under water stress conditions" was conducted at the Department of Plant breeding and Genetics, College of Agriculture, Vellayani, during 2015-2017 with the objective of identifying high yielding genotypes of tomato under water stress condition.

Twenty genotypes including twelve accessions from the previous project in the Department of Plant Breeding and Genetics entitled "Collection, conservation and genetic improvement of traditional land races and obsolete varieties of major vegetables in Kerala" *viz.,* Nellanadu local, Kuttichal local I, Venpalavattam local, Palakkad local, Vellayani local I, Kottayam local , Kuttichal local II, Kaithamukku local, Pettah local, Vellayani local II, Haripad local and Thrissur local along with eight released varieties Arka Alok, Arka Vikas, Arka Saurabh, Arka Meghali, Vellayani Vijay, Anagha, Akshay and Manulekshmi were evaluated in a Randomized Block Design (RBD) with three replications during October 2016- February 2017. Seedlings were raised in the nursery in protrays. One month old seedlings were transplanted to the main field. The seedlings were planted at a spacing of 60cm x 60cm.

All the cultural practices were undertaken timely as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2011). Water stress was imposed from flowering onwards by restricting the irrigation to once in three days at 10mm depth. The genotypes were evaluated for following traits *viz.,* plant height (cm), number of primary branches plant^{-1}, number of leaves plant^{-1} , days to 50 % flowering, number of fruits cluster^{-1}, number of fruits plant^{-1}, fruit length (cm) , fruit girth (cm), fruit volume (cm^3), fruit weight (g), yield plant^{-1}(g), stomatal frequency, relative water content (%), canopy temperature (^{0}C) and proline content of leaves (µmol g^{-1}). Various statistical analyses were carried out.

Analysis of variance showed that significant variation was present in the germplasm for the characters studied.

The mean performance of the genotypes for fifteen characters studied revealed that accession A6 (Kottayam local) was superior in terms of yield plant^{-1} (603.67g), stomatal frequency (743.33 cm^{-2}), relative water content (78.95%) and proline content (57.72 µmol g^{-1}). Highest Canopy temperature was recorded for the accession A2 (36.57 ^{0}C).

The proline content of leaves exhibited the highest GCV (66.02 %) and PCV (68.00 %). High GCV was observed for yield plant^{-1}, fruits plant^{-1}, stomatal frequency, fruit volume, number of leaves plant^{-1} and number of primary branches plant^{-1}. High heritability coupled with high genetic advance was observed for stomatal frequency, yield plant^{-1}, proline content, number of fruits plant^{-1}, fruit volume, number of leaves plant^{-1} and number of primary branches plant^{-1}. Characters like fruit weight (15.81%) and number of fruits per cluster (12.04%) showed moderate genotypic coefficient of variation. Low GCV was observed for relative water content (9.70%), fruit length (8.97%), days to 50% flowering (7.36%), plant height (6.94%), fruit girth (6.79%) and canopy temperature (5.86%). High heritability with high estimates of genetic gain was observed for number of fruits plant^{-1}, yield plant^{-1}, fruit weight, stomatal frequency and proline content.

The yield plant^{-1} was found to be significantly and positively correlated with plant height, number of primary branches plant^{-1}, number of fruits cluster^{-1}, number of fruits plant^{-1}, fruit length, fruit girth, fruit volume, fruit weight, stomatal frequency, relative water content, canopy temperature and proline content of leaves both at genotypic and phenotypic levels. Days to 50% flowering was found to be negatively correlated with yield plant^{-1}.

In the study, characters such as number of fruits cluster^{-1}, fruit weight, RWC, fruit volume, number of primary branches plant^{-1} and stomatal frequency

showed high positive direct effect on yield. The path analysis revealed that number of fruits cluster^{-1} and fruit weight had the maximum positive direct effect on yield plant^{-1}, whereas characters like days to 50% flowering, fruit length, plant height and number of leaves plant^{-1} showed a negative direct effect on yield. The positive genotypic correlation for these characters was due to the indirect effect through other independent variables. The residual effects appeared to be considerably low which indicated that the characters included in this study explained almost all variability towards yield.

The selection index for all the genotypes were worked out based on yield and the physiological characters contributing to stress tolerance. The genotypes were ranked according to the scores obtained. The genotype A6 (Kottayam local) was ranked first, followed by A4 (Palakkad local), A2(Kuttichal local I) and A7(Kuttichal local II).

The study revealed that accession A6 (Kottayam local) was superior in yield performance under water stress condition followed by the accession A4 (Palakkad local), accession A2 (Kuttichal local I) and accession A7 (Kuttichal local II). The accession A6 (Kottayam local) also recorded the highest relative water content, stomatal frequency and proline content. Accumulation of proline in leaves was found to be an important water stress tolerance mechanism. The promising genotypes identified in the study can be used in further crop improvement programmes for developing water stress tolerant varieties.

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Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for yield under water stress conditions

by

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ABSTRACT

The present study entitled "Evaluation of tomato (*Solanum lycopersicum* L.) genotypes for yield under water stress conditions" was carried out in the Department of Plant Breeding and Genetics, College of Agriculture, Vellayani during 2015-2017, with an objective to identify high yielding genotypes of tomato under water stress conditions.

Twenty genotypes including 12 accessions from the previous project in the Department *viz.,* Nellanadu local, Kuttichal local I, Venpalavattam local, Palakkad local, Vellayani local I, Kottayam local , Kuttichal local II, Kaithamukku local, Pettah local, Vellayani local II, Haripad local and Thrissur local along with 8 released varieties Arka Alok, Arka Vikas, Arka Saurabh, Arka Meghali, Vellayani Vijay, Anagha, Akshay and Manulekshmi were evaluated in a Randomized Block Design (RBD) with three replications during October 2016- February 2017. Water stress was imposed from flowering onwards by restricting the irrigation to once in three days at 10mm depth. The analysis of variance was calculated for the characters under study *viz.,* plant height (cm), number of primary branches plant^{-1}, number of leaves plant^{-1} , days to 50 % flowering, number of fruits cluster^{-1}, number of fruits plant^{-1}, fruit length (cm) , fruit girth (cm), fruit volume (cm^3), fruit weight (g), yield plant^{-1}(g), stomatal frequency, relative water content (%), canopy temperature (^{0}C) and proline content of leaves (µmol g^{-1}) and was found to be significant for all the genotypes evaluated.

The mean performances of the genotypes for the characters under study were evaluated. The maximum yield was recorded for the accession A6 (Kottayam local) and the minimum yield was observed for accession A1 (Nellanadu local). The accession A6 (Kottayam local) showed the highest mean values for stomatal frequency, relative water content and proline content.

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The proline content of leaves exhibited the highest GCV (66.02 %) and PCV (68.00 %). High heritability coupled with high genetic advance was observed for stomatal frequency, yield plant^{-1}, proline content, number of fruits plant^{-1}, fruit volume (cm^3), number of leaves plant^{-1} and number of primary branches plant^{-1}. The yield plant^{-1} was found to be significantly and positively correlated with plant height (cm), number of primary branches plant^{-1}, number of fruits cluster^{-1}, number of fruits plant^{-1}, fruit length (cm), fruit girth (cm), fruit volume (cm^3), fruit weight (g), stomatal frequency (number cm$^{-2)}$, relative water content (%), canopy temperature (^{0}C) and proline content of leaves (µmol g^{-1}) both at genotypic and phenotypic levels. Days to 50% flowering was found to be negatively correlated with yield plant^{-1}. The path analysis revealed that number of fruits cluster^{-1} and fruit weight had the maximum positive direct effect on yield plant^{-1}.

The study revealed that accession A6 (Kottayam local) was superior in yield performance under water stress condition followed by the accession A4 (Palakkad local), accession A2 (Kuttichal local I) and accession A7 (Kuttichal local II). The accession A6 (Kottayam local) also recorded the highest relative water content, stomatal frequency and proline content. Accumulation of proline in leaves was found to be an important water stress tolerance mechanism.