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# Phenotypic variability for horticultural and fruit quality attributes in plastic house grown tomato

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## ABSTRACT

**In Sudan agro-ecological zone, tomato production is constrained by dearth of high fruit yielding and quality (*Solanum lycopersicum* [L.]) varieties for cultivation in polyhouse. Exotic and indeterminate tomato genotypes with high fruit yield and quality were evaluated to gain information on variation for fruit yield, quality, shape, and interdependence between traits in Sudan agroecology. Seed were sown during 2018 and 2019. Fruit yield, quality and phenomic traits were measured. Development, °Brix, and fruit yield responded to microclimate factors in the polyhouse over years. 'Bruno' was the best for fruit size and 'Tofi' for fruit number. Vine length at flowering, fruits/cluster, days to 50% flowering and days to first flowering and fruit brix are heritable. The genotype responses suggest the need for stable and to develop high yielding and quality tomato varieties for protected cultivation in the Sudan agro-ecological zone. Testing stable genotypes in locations could enhance breeding efficiency with respect to genotypic stability. The yield data gained under tropical conditions identified traits of superior genotypes for multiple environment study and to encourage tomato growers to consider protected cultivation in the tropics.**

**Keywords:** Character correlation, Fruit quality, Fruit shape, Fruit yield variability, Genotype by environment, Polyhouse and *Solanum lycopersicum*

## INTRODUCTION

Tomato (*Solanum lycopersicum* [L.]) diploid (2n=24) is the second most commonly cultivated fruit vegetable after potato throughout the world (FAOSTAT, 2018). It is an annual herb, erect to prostrate stems, dicotyledonous, and grow as a series of branching stem with a terminal bud, determinate or indeterminate growth habit. Anthesis, fruit formation, and retention are temperature sensitive (Mohanty, 2002), and cloudy conditions reduces ripening and fruit yield (Nakia *et al*., 2005). In West Africa, tomato production takes place in different agro-ecological zones under rain fed conditions, with a single cycle of tomato production annually. As an alternative, greenhouse production could likely allow 3 growth cycles annually. Tomato is a reliable source of nutrients (Arab and Steck, 2000; Ayandeji *et al*., 2011). Total soluble solids are a measure of several chemicals and a proxy for sugar content. Higher TSS positively influences likeability and reduces cost associated with processing tomato fruit (Beckles, 2012). Consumers' choice for fresh tomato fruit is driven by fruit size, color, shape, and texture. Tomato production in the greenhouse is influenced by temperature (high and low), humidity (high or low), day length, and cloud cover which affect physiological and reproductive processes, and attack by insects and pathological organisms (Singh and Ashey, 2005; Tadele, 2016). Beefsteak and cluster tomatoes types are grown in greenhouses throughout the world; limited trials have occurred in sub-Saharan Africa, where greenhouse cultivation of tomato is limited. Local cultivars have low fruit yield, poor fruit quality traits, susceptible to diseases and insect attack, and unsuitable for cultivation in plastic house. Growers rely on seeds (hybrids or open pollinated) shipped from Europe and Asia for planting in greenhouse. A drawback in attaining a sustainable supply of tomato fruit is absence of quality seeds of promising genotypes and unfavourable climatic conditions (within and between years) and climate shocks.

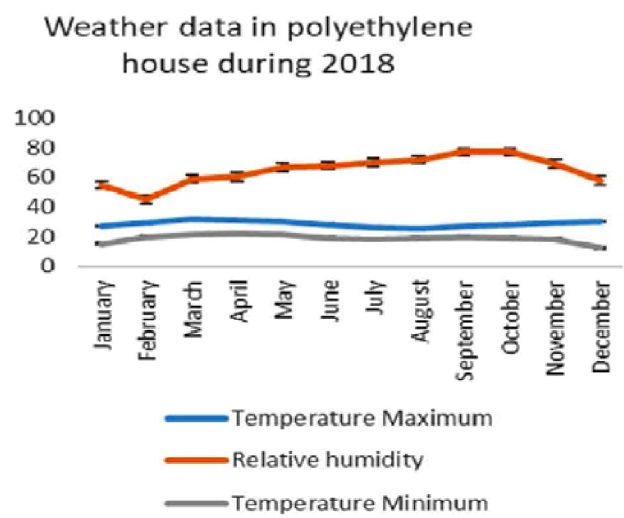
Under open field cultivation, high temperature and humidity are serious problems for crop production under tropical conditions. Tomato fruit set is very sensitive to low or high temperatures that affect pollen development and anther dehiscence (Gebisa *et al*., 2017). The cultivation of tomato under polyethylene house in the Sudan agro-ecological zone is limited due to inadequate knowledge of greenhouse production and absence of high yielding, early maturing and disease resistance with extended shelf-life and improved fruit quality traits. High temperature due to climate shocks have increased the incidence of heat stress in crops (Bitta and Gerrats, 2013), and in tomato grown under protected cultivation in Sudan agroecology. Exposure to temperature above 25ÚC during anthesis causes flower abortion, poor style development and pollen germination (Berry *et al.,* 1988; Peet *et al*., 1988), reduced fruit set and yield (Li *et al*., 2011; Zin *et al*., 2010; Giri *et al*., 2011). The genotypic response to both optimal and heat stressed conditions in the plastic house is important for fruit yield stability.

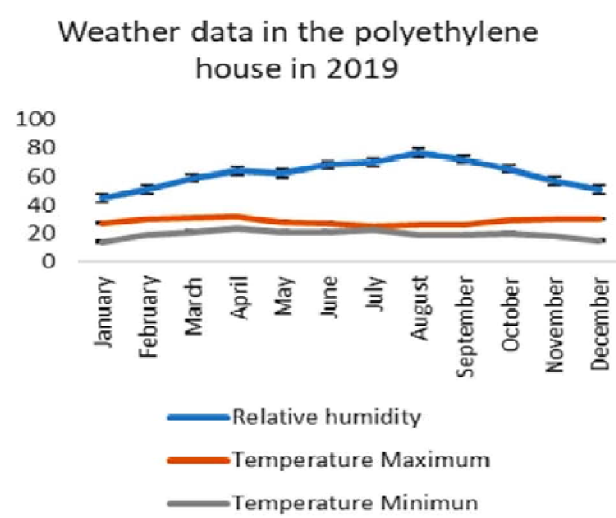
Tropical conditions encompass a wide array of environmental conditions and regions. Enhancing production in the tropics requires taking into consideration the diversity of climates and production systems that affect tomato production. Genotype x environment interaction results in variable performance of a genotype over time and space such that in many cases GXE interactions are treated as undesirable and confounding effects (Yan and Tinker, 2006), although they can provide breeding opportunities. The objectives of the research were to: a) evaluate variation for growth and development, fruit yield and fruit quality attributes, b) determine the magnitude of phenomic of fruit shape variability, c) estimate components of genetic variation, interdependence among developmental, fruit yield and fruit quality traits and heritability, and d) identify promising genotypes for fruit yield and fruit quality traits under Sudan agro-ecological zone.

## MATERIALS AND METHODS

**Location and nursery management**

Two cycles of experiments were carried out at Greenhouse of Taraba Vegetable, Ardo Kola Local Government Area, Taraba state (latitude 08°46'N, Long 11°22'E), at 222 m above sea level. The experiments were begun in 2 July (rainy season) 2018 and 2019. Humus soil and perlite (Jubaili Nigeria, Ltd., Jalingo, Nigeria) was mixed in the ratio 3:1 (w:w). Fifty-six extruded plastics nursery multicell seedling trays were filled with the mix. Seed of the indeterminate, beefsteak, tomato genotypes viz, Bruno 29402, Dominique 539, Tomato 29206, IND 27812, Tomato 20209 (hybrids), and 'Tofi' (open pollinated), developed by Hazera Seed (Telaviv, Isreal) and Jubaili Seed (Jalingo, Nigeria) companies, respectively, were sown in cells in trays; each planting tray accommodated 260 seedlings.



The greenhouse was 102.72 × 57 m (~5,855 $m^2$) and 18 m high of which 99.37 × 54.72 m (~5,438 $m^2$) was cultivated. The slightly acidic (pH 5.67) sandy loam soil was ploughed, harrowed, and flat ridges constructed with tractor mounted implements. Each ridge contained double rows, 0.5 m apart with a 1.1 m pathway between double rows. Sixty flat ridges were established in the polyethylene house. The temperature and relative humidity in the plastic house were recorded using a CR200X Data Logger (Campbell Scientific Inc., Australia). Tomato seedlings were hand transplanted (18 April 2018, 20 August 2019 for first and second trials, respectively) in ridges with an inter- and within-row spacing of 0.5 × 0.6 m. Each ridge accommodated 140 plants (70 plants/row). A total of 8,400 plants were established in the polyethylene house. The experiment was arranged in a completely randomized design, each genotype was assigned to a double ridge plot 43 m long and replicated 4 times. Fertigation was begun 2 weeks after transplanting, 25 kg of N18:P18:K18 was dissolved in 100 L of water and applied through the drip irrigation system to plants, each plant received 10 mL of fertilizer. At 4 weeks after transplanting, N17:P9:K27 was dissolved in 100 L of water and applied through the drip irrigation system, each plant received 10 mL of fertilizer. At 6 weeks after transplanting, K61 soluble fertilizer was dissolved in 100 L of water and applied through the drip irrigation system to plants, with each plant receiving 10 mL. Weeding was by hand. Abamectin® (EC) (50 mL; Control Solution Inc., Genea-Red Bluff, Pasadena, CA), 40 mL of Imidacloprid® (EC; Hebei Xintian Biological Technology Co., Ltd Shijiazhuang, Hebe, China), and Mancozeb® (WP; Sigma-Aldrich Chemie, Taufkirchen, Germany) powder (100 g) was dissolved in 30 L of water and applied at 3 weeks after transplanting to control insect pests and insect-transmitted diseases. A T-shaped rod was inserted at both ends of the plot; tomato vines were trained on twine connected to overhang rods to support plant growth upward. Each tomato plant received 0.59 L of water 4 times a day (2.38 L of water per day) via drip irrigation.

**Trait measurement and data analysis**

The number of days to first flower (d), days to 50% flowering (d), vine length at first flowering and maturity (m), vine length at 50% flowering (cm), days to first fruit (d), days to first ripe fruit (d), interval between first fruit and fruit maturity (d), individual fruit weight (g), fruit weight/plot (kg), fruit length (cm) and fruit width (cm) were measured. A net plot of 1.1 × 3 m was used for determination of fruit number, fruit number/plot and fruit yield (kg). Twenty randomly picked tomato fruit (5 fruit per replicate) were blended for determination of fruit pH (MP 220; Mettler Toledo, Barcelona, Spain), and soluble solids using hand-held refractometer (model ATC-1, Atago, Bellevue, WA). At maturity, 12 tomato fruits were randomly chosen to measurement of fruit phenomic metric traits. A longitudinal cut was made on each fruit and digitalized (Scanjet G4010 scanner, Hewlett-Packard, Palo Alto, CA) at a resolution of 300 dpi. Scanned fruit images were subjected to morphometric analysis using Tomato Analyzer ver. 3 software (Rodriguez *et al*. 2010; Ohio State University laboratory website, http://www.oardc.ohiostate.edu/vanderknaap/). Fifteen fruit descriptors viz. fruit area, fruit perimeter, fruit width mid-height, fruit maximum width, fruit maximum height, fruit mid-width height, fruit maximum width, internal fruit shape index, fruit shape index eccentricity I, fruit shape index eccentricity II, proximal eccentricity, distal eccentricity, obovoid and fruit curved shape and fruit lobes defined by the manufacturer, were automatically received from Tomato Analyzer software (Rodriguez *et al*., 2010).

Quantitative traits were summarized, all data were subjected to analysis of variance using PROC GLM of SAS (ver. 9.4, SAS Institute, Cary, NC). If the interaction was significant it was used to explain results. Pearson correlation was performed for each year. The formula of Syukur *et al*. (2012) was used to calculate variance due to genotype, coefficient of variation due to genotypic effect (GCV), and phenotype effect (PCV). Heritability in broad sense for each trait was computed following the method of Allard (1960). Broad-sense heritability values >82% = very high, 60-79% = moderately high, 40-59% = moderately low, and <40% = low.

## RESULTS AND DISCUSSION

A sustainable supply of fresh and high-quality tomato fruits to markets from polyethylene house requires development and deployment of high fruit yielding, early and medium maturity tomato varieties. This goal may be reached through the knowledge of phenotypic variability, association between traits and heritability. The combined analysis of variance showed statistically significant (Pd”0.05) mean squares among the genotypes for development traits (vine length at flowering and vine length at maturity), earliness (days to first flowering and days to 50% flowering) and fruiting cycle (appearance of first fruit, appearance of first mature fruit and interval (days) between appearance of first fruit and first mature fruit) (Table 1a). These traits are important to ensure 2 or 3 production cycles annually in polyethylene house. The variability for earliness, vegetative growth and fruit growth cycle (early, medium or late maturity groups) among the genotypes have implications for harvest, shipment, shelf-life and delivery of fresh tomato fruits to the markets.

**Table 1a. Combined analysis of variance and estimates of Genotypic variation ($\sigma^2G$), Phenotypic variation ($\sigma^2P$), Genotype by Year variation ($\sigma^2GY$), genotypic coefûcient of variation (GCV), phenotypic coefûcient of variation (PCV) and Heritability for developmental, earliness and fruiting cycle in tomato genotypes.**

| Source of variation maturity | df | Days to first flower | Days to 50% flowering | Vine length at appearance of first flower | Vine length at 50% flowering | Days to first fruit | Days to 1st ripe fruit | Interval(days) between first fruit & |
|---|---|---|---|---|---|---|---|---|
| Genotype (G) | 5 | 48.90** | 21.01** | 774.12** | 613.65*** | 19.28*** | 21.97*** | 30.14*** |
| Year (Y) | 1 | 1.22 | 14.40** | 93.64** | 18.15 | 38.03*** | 4.22** | 22.58** |
| G × Y | 5 | 7.78 | 2.58* | 63.43** | 76.40 | 7.52*** | 13.28*** | 13.00** |
| Error | 36 | 5.27 | 0.75 | 11.37 | 38.08 | 1.06 | 0.91 | 1.68 |
| CV (%) | | 3.88 | 1.30 | 5.43 | 7.73 | 1.05 | 1.37 | 4.58 |
| Mean | | 61.64 | 66.41 | 62.98 | 79.87 | 97.74 | 69.47 | 28.45 |
| $\sigma^2P$ | | 7.00 | 2.82 | 103.37 | 163.90 | 4.69 | 2.91 | 5.18 |
| $\sigma^2G$ | | 6.03 | 2.53 | 95.44 | 134.98 | 2.63 | 1.47 | 3.55 |
| $\sigma^2GY$ | | 0.68 | 0.40 | 13.02 | 9.58 | 3.09 | 1.62 | 2.83 |
| PCV | | 4.29 | 2.53 | 16.14 | 16.02 | 2.22 | 2.46 | 7.99 |
| GCV | | 3.98 | 2.39 | 15.51 | 14.55 | 1.65 | 1.75 | 6.62 |
| Hb (%) | | 85 | 89 | 92 | 82 | 56 | 51 | 69 |

*, **, *** significant at 5, 1, or 0.01%, level of probability, respectively, ANOVA.

Highly significant (Pd” 0.01) mean squares differences were recorded among the genotypes for individual fruit weight, number of fruits/plant, fruit weight/plot, number of fruits/plot, fruits/cluster, fruit length, fruit width, number of loculi/fruit, fruit pH and fruit brix (Table 1b). The foregoing may be associated with genetic factors and accumulation of photosynthates in the sink, in addition, the influence of microclimatic factors. Several authors (Dar and Sharma. 2011; Sharma and Singh (2015); Dhyani *et al*. 2017; Jindal *et al*. 2018) have reported significant genotypic effects for fruit yield and yield related traits among tomato varieties grown in polyethylene house condition.

The year (Y) effect significantly (Pd” 0.01) influenced days to 50% flowering, vine length at flowering, days to first fruit, days to first ripe fruit, interval between fruit appearance and maturity (Table 1a), and fruits/ plant, fruit weight/plot and fruit brix (Table 1b). Findings are in accordance with reports by Dar and Sharma (2011) and Dhyani *et al*. (2017) in tomato varieties grown in polyethylene house and open field respectively. These traits could have been responsive to temperature, humidity and precipitation with low predictability. Therefore, the need for continuous evaluation over years for reliable inferences. On the other hand, vine length at 50% flowering, fruit/plot, fruit/cluster, fruit width, loculi/fruit and fruit acidity were not affected by environmental factors during the

**Table 1b. Combined analysis and estimates of Genotypic variation ($\sigma^2G$), Phenotypic variation ($\sigma^2P$), Genotype × Year variation ($\sigma^2GY$), genotypic coefûcient of variation (GCV), phenotypic coefûcient of variation (PCV) and Heritability ($H_b$) for fruit yield, yield contributing traits and fruit quality attributes among genotypes.**

| Source of variation | df | Individual fruit weight | Number fruit/plant | Fruit weight/plot | Number fruit/plot | Number fruit/cluster | Fruit length | Fruit width | Number loculi/fruit | Fruit pH | Fruit Brix |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype (G) | 5 | 353.31** | 46.63** | 7105.08** | 496431.88*** | 7.14** | 0.67** | 3.34** | 10.95** | 0.27** | 3.48** |
| Year (Y) | 1 | 133.33 | 96.10** | 2788.9** | 60062.50 | 0.03 | 0.001 | 0.87 | 0.40 | 0.05 | 0.75* |
| G × Y | 5 | 155.18 | 34.41** | 3215.18** | 221164.93 | 0.08 | 1.16** | 0.80 | 0.40 | 0.06 | 0.91* |
| Error | 36 | 77.63 | 11.55 | 363.79 | 113708.08 | 0.05 | 0.05 | 0.28 | 0.19 | 0.05 | 0.26 |
| CV (%) | | 6.49 | 7.29 | 4.25 | 11.22 | 4.09 | 4.35 | 11.77 | 7.82 | 4.65 | 1.06 |
| Mean | | 135.75 | 46.58 | 446.37 | 3004.63 | 5.42 | 5.14 | 4.64 | 5.62 | 4.85 | 4.64 |
| $\sigma^2P$ | | 53.85 | 5.82 | 2207.63 | 1245.14 | 178.53 | 0.31 | 0.48 | 2.68 | 0.11 | 0.46 |
| $\sigma^2G$ | | 34.46 | 1.52 | 882.84 | 842.75 | 178.48 | 0.19 | 0.38 | 2.63 | 0.03 | 0.32 |
| $\sigma^2GS$ | | 19.39 | 5.72 | 1628.4 | 712.84 | 0.008 | 0.01 | 0.13 | 0.05 | 0.04 | 0.16 |
| PCV | | 5.41 | 5.19 | 10.52 | 1.17 | 247 | 10.83 | 14.93 | 29.13 | 6.84 | 14.62 |
| GCV | | 4.32 | 2.64 | 7.27 | 6.50 | 246 | 8.48 | 13.28 | 28.85 | 3.57 | 12.19 |
| Hb (%) | | 64 | 26 | 40 | 68 | 99 | 61 | 79 | 98 | 27 | 70 |

*, **,*** significant at 5, 1, or 0.01%, level of probability, respectively, ANOVA.

**Table 2. Mean squares for fruit metric traits among tomato genotypes grown in a greenhouse.**

| Source of variation | df | Perimeter | Area | Maximum width | Maximum length | Curve height | Ellipsoidal | Circular | Lobeness | Distal eccentricity | Eccentricity area index | Pericarp thickness | Proximal eccentricity | Obovoid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Genotype (G) | 5 | 96.44** | 261.66** | 7.69** | 6.34** | 0.65 | 0.02** | 0.01 | 14.72** | 0.05** | 0.13** | 0.006 | 0.003 | 0.87** |
| Year (Y) | 1 | 0.01 | 0.04 | 0.11 | 0.01 | 0.01 | 0.0001 | 0.0002 | 9.00 | 0.008 | 0.0008 | 0.0002 | 0.008 | 0.01 |
| G × Y | 5 | 0.05 | 0.10 | 0.06 | 0.12 | 0.04 | 0.003 | 0.0003 | 8.24 | 0.003 | 0.0009 | 0.0001 | 0.008 | 0.01 |
| Error | 24 | 12.59 | 59.01 | 0.65 | 0.63 | 0.54 | 0.001 | 0.007 | 8.66 | 0.009 | 0.0069 | 0.0069 | 0.006 | 0.009 |
| CV (%) | | 14.6 | 26.00 | 14.84 | 15.94 | 12.97 | 0.13 | 0.13 | 3.12 | 0.82 | 0.42 | 0.24 | 0.87 | 0.31 |
| Mean | | 24.21 | 29.24 | 5.46 | 4.99 | 5.68 | | | | | | | | |

*, **, *** significant at 5, 1, or 0.01%, level of probability, respectively, ANOVA.

years of evaluation, due to non-significant (Pe" 0.05) mean squares (Table 1b). The high impact of the microclimatic factors on earliness and fruit yield and fruit quality traits may be linked to the polygenic nature of these traits and influence of microclimatic factors. The genotype effect accounted for a large proportion of the total variation compared to the year effect and genotype by year interaction (GYI).

The performance of the tomato genotypes for days to 50% flowering, vine length at flowering, number of days to first fruit, number of days to first ripe fruit, interval between fruit appearance and maturity, number of fruits/plot and fruit length and fruit brix were inconsistent with little or no predictability due to highly significant (Pd" 0.01) genotype by year interaction (GYI) mean squares. There are a number of previous studies (Carli *et al*., 2011; Cebolla-Cornejo *et al.,* 2011) among tomato varieties cultivated in the open field with significant GYI for traits considered in this study. The magnitude of GYI variation for fruit brix (total soluble solids) was attributed to temperature, reduced air flow and light intensity within the polyethylene house (Causse *et al.,* 2003). The sugar accumulation in tomato fruits depend upon the translocation of photo-assimilates from the leaves during fruit ripening (Cebolla-Cornejo *et al.,* 2011). The prospects of genetic improvement for these traits may not be achieved in the short run. The magnitude of genotype by year interaction for traits is useful to select optimal genotypes for earliness, fruit yield and quality traits. The GYI for some traits was responsible for the cross over performance of some genotypes (Table 4). Therefore, selection and recommendation of the genotypes for earliness and fruit yield will be complex. However, insignificant GYI mean squares for fruit pH is in conformity with findings of Causse *et al.* (2003).

A popular morphological feature distinguishing tomato varieties from undomesticated accessions is fruit shape (elongated). The mean squares for genotypes were significant (Pe" 0.01) for fruit perimeter, fruit area, fruit maximum width, fruit maximum height, fruit distal eccentricity, eccentricity area index and obovoid (Table 3). Also, ellipsoidal, lobeness, distal eccentricity, eccentricity area index and obovoid had significant (Pe" 0.01) mean squares due to genotypes (Table 6b). The mean squares due to the genotype × year interaction on fruit metric and phenomic traits were not significant (Pe" 0.05) for all traits (Table 6a and 6b). The differences for fruit size and shape among tomato genotypes is similar to report of Berwer *et al.* (2007), they indicated that tomato fruit can be small to large, round, with many loci contributing to fruit shape and size.

**Table 3. Mean values for fruit yield, yield contributing traits and fruit quality attributes among tomato genotypes.**

| Genotype | Days to first flower | Vine length at 50% flowering | Individual fruit weight | Fruit width | Number fruit/ cluster | Number loculi/ fruit | Fruit pH | Number of fruit/plot |
|---|---|---|---|---|---|---|---|---|
| Burno | 61ab[a] | 80.09cd | 141.79a | 4.79b | 5b | 6b | 4.73b | 3074.9ab |
| Dominique | 59b | 84.29bc | 132.09ab | 5.05a | 5b | 5b | 4.93ab | 2996.3ab |
| IND 27812 | 65a | 81.08b | 137.78a | 5.23a | 5b | 5b | 4.65b | 2703.8b |
| Tom 29206 | 63a | 93.98a | 141.2a | 5.21a | 5b | 5b | 5.17a | 2765.ob |
| Tofi | 58b | 50c | 137.7ab | 3.83b | 8a | 8a | 4.83b | 3480.8a |
| Tom 20209 | 62a | 88.94b | 124.01b | 3.71b | 5b | 5b | 4.85ab | 3011ab |

As shown in Table 3a, days to first flower appearance was early 58 d ('Tofi' and 'Dominique') and late 65 d ('IND 27812'). The interval (days) between appearance of first flower and 50% flowering was 1 d in 'IND 27812' and 10 d in 'Tofi'. In contrast, between 38 and 49 d from transplanting to flowering was recorded in tomato genotypes under rain fed (Mesecret *et al.* 2012). 'Dominique' was early for appearance of immature and ripe fruit. The interval (days) between seeding and appearance of first fruit was 67 d in 'Dominique', and 72 d in 'Tomato 29206'. Tomato vines peaked (93.98 cm) in 'Tomato 29209', followed by 'Tomato 29206' with 88.94 cm. A vine length up to 154 cm occurred for determinate and indeterminate tomato genotypes grown in a

**Table 3b. Genotype and year interaction[a] effects on fruit yield and quality traits.**

| Genotype × | Year | Days to: | | | Fruit | | | Interval (days) from fruit first to maturity | Fruit number per plant (kg) |
|---|---|---|---|---|---|---|---|---|---|
| | | 50% flowering | first fruit appearance | first ripe fruit | Brix | Height (cm) | Weight per plot | | |
| Bruno | 1 | 63d | 67e | 98b | 4.97d | 5.73a | 380.5e | 31a | 50.53d |
| | 2 | 65c | 70b | 101a | 3.50e | 5.33c | 467.0b | 31a | 75.00a |
| Dominique | 1 | 65c | 67e | 96d | 5.25a | 5.33c | 465.6b | 29c | 59.13c |
| | 2 | 65c | 67e | 96d | 5.25a | 5.38b | 465.5b | 29c | 59.18c |
| IND 27812 | 1 | 65c | 68d | 97c | 3.65e | 4.45h | 439.8d | 25e | 58.53c |
| | 2 | 67b | 72a | 100a | 3.66e | 5.73a | 451.3c | 25e | 56.03b |
| Tofi | 1 | 67b | 72a | 97c | 5.25a | 5.31d | 425.3c | 28d | 58.44c |
| | 2 | 67b | 72a | 97c | 5.25a | 5.15e | 425.3c | 28d | 58.44c |
| Tom 209206 | 1 | 67b | 71a | 97c | 5.05c | 5.15e | 428.0c | 29a | 55.50c |
| | 2 | 69a | 68b | 99a | 5.20b | 4.45h | 413.8c | 30b | 55.67c |
| Tom 29209 | 1 | 69a | 69c | 97c | 3.50g | 4.80f | 509.3a | 26e | 68.84b |
| | 2 | 69a | 70b | 100a | 5.25a | 4.50g | 509.3a | 32a | 68.94b |

[a] data in the interaction analyzed with Least Squares Means and means separated with Least Significant Difference.

[b] values in columns followed by the same letter are not significantly different, P<0.05

greenhouse (Kallo *et al*., 2012). Length of tomato vines is associated with adaptation and physiology.

The numbers of fruit harvested per plot was highest in 'Tofi' (Table 3a), this is a common trait of cluster tomato). Medium to high fruit per plant is consistent with effective pollination, fruit set and retention, and small sized fruit. Fruits of 'Bruno', 'Dominique' and 'IND 27812' are large (fruit length and width). Tomato fruits are sold by weight, 'Bruno', 'Tom 29206' and 'Tofi' appear to hold promise for individual fruit weight (Table 3a), and fruit weight/plot (Table 3b). The mean values for individual fruit weight in this study are larger than those reported by Cheema *et al*. (2013) for indeterminate tomatoes grown in a greenhouse. This may be linked to hereditary factors, high fruit set, large fruit size and efficient accumulation of photosynthate. The number of fruits/cluster is an index for fruit weight, 'Tofi' recorded the highest fruits/cluster (Table 3a). High fruits/cluster may be attributed to long fruits than wide. The total soluble solids (°Brix) were low ('Tom 20209') moderate ('Dominique' and 'IND 27812'). The mean values recorded for fruit brix are closer to those reported by Purkayastha and Mahanta, (2011). 'Bruno' and 'Domonique' were best for fruit size (fruit length and fruit width).

The mean values for fruit perimeter was on par with 'Dominique' and 'Bruno' and greater than mean values for 'IND 27218' and 'Tofi'. 'Bruno', 'Tomato 29206' and 'Dominique' had the best fruit area, fruit maximum width, and fruit height which agrees with mean values reported for fruit height and fruit diameter (Table 4). The proportion of fruit area outside the ellipse to total fruit area is important for fruit size. 'Bruno' performed best, followed by 'Tom 20209' and 'Tom 20906'. A morphological feature influencing preference for tomato cultivar is fruit shape. 'Burno' are obovoid, indicating the greater proportion of the fruit is below the mid-fruit height. 'Bruno', 'Tom 20206' and 'Tom 20209' are circular and ellipsoidal compared to 'Dominique' and 'IND 27812'. Fruit height measured along a curved line through the fruit was long in 'Dominique', but short in 'IND 27812'. 'Bruno' performed best for distal eccentricity and eccentricity area index. The spherical fruit shape was observed in the genotypes with fruit shape index (0.86 – 0.99). Variation in fruit size (fruit length and diameter) is associated with genetic makeup and moderated by cell size and intercellular space of the flesh, as was observed by Regassa *et al*. (2012) and Jindal *et al*. (2015).

**Table 4. Mean values for some fruit phenomic traits among tomato genotypes grown in a greenhouse.**

| Genotype | Perimeter (cm) | Area(cm$^3$) | Maximum width (cm) | Maximum length(cm) | Ellipsoidal | Lobeness | Eccentricity area index | Distal eccentricity | Obovoid |
|---|---|---|---|---|---|---|---|---|---|
| Dominique | 28.79[a] | 19.52d | 5.59ab | 4.38ab | 0.20a | 6.97b | 0.21d | 0.21d | 0.31b |
| Bruno | 27.03a | 30.9b | 6.06a | 6.06a | 0.10c | 5.74d | 0.56a | 0.56a | 0.97a |
| Tom 29309 | 24.54b | 37.6a | 6.41a | 5.60ab | 0.08d | 6.17c | 0.49b | 0.50b | 0.09b |
| Tom 29206 | 22.27b | 30.9b | 5.73ab | 5.39b | 0.09a | 6.34bc | 0.49b | 0.50b | 0.06b |
| 1ND 27812 | 18.54c | 27.23c | 3.52c | 3.51b | 0.17ab | 9.77a | 0.32c | 0.33c | 0.09b |
| Tofi | 18.33c | 27.00c | 2.33d | 2.71c | 0.08a | 6.22c | 0.22d | 0.31c | 0.08bc |

[a] values in columns followed by the same letter are not significantly different, P<0.05 level, Tukey's test.

**Table 5. Pearson's correlation coefficient between agronomic, fruit metric and fruit quality attributes in tomato genotypes.**

| | D.50FL[a] | FAMP | Frpp | Frl | Frw | FrPl | FrW/Pl | Fr Cl | Lo Fr | Fr pH |
|---|---|---|---|---|---|---|---|---|---|---|
| FAMP | -0.36 | | | | | | | | | |
| FrPP | 0.78** | -0.78** | | | | | | | | |
| Frl | 0.35 | 0.32 | 0.28 | | | | | | | |
| Frw | -0.77** | 0.57 | -0.38 | -0.11 | | | | | | |
| FrPl | 0.40 | -0.29 | 0.77** | 0.77** | -0.77** | | | | | |
| FrW/P | 0.77** | -0.16 | 0.59 | 0.67 | -0.21 | 0.59 | | | | |
| Fr Cl | 0.78** | -0.15 | 0.48 | 0.79* | -0.66 | 0.86** | 0.66 | | | |
| Lo Fr | 0.87** | -0.26 | 0.59 | 0.76** | -0.57 | 0.78** | 0.83** | 0.91** | | |
| Fr pH | -0.43 | 0.77** | -0.63 | -0.08 | 0.84** | -0.63 | -0.13 | -0.61 | -0.43 | |
| Brix | -0.31 | -0.51 | -0.05 | -0.97** | 0.03 | -0.62 | -0.58 | -0.76** | -0.63 | -0.06 |

*, ** = significant at 1 and 5 % level of probability.

[a] D.50FL = Days to 50% Flowering, FAMP = Days between first and mature fruit, FrPP = Fruit/plant, Frl = Fruit Length, Frw = Fruit width, FrPl = Fruit/Plot, FrW/Pl = Fruit weight/plot, Fr Cl = Fruit/Cluster, Lo Fr = Loculi/Fruit, Fr pH = Fruit acidity, Brix = Total soluble solids.

The number of days to first flowering, days to first ripe fruit, fruit brix, fruit weight per plot were better during 2018 compared to 2019. Differences in solar radiation, temperature and humidity received in the polyethylene house over years influenced truss appearance and fruit yield. Pék and Helyes (2004) had noted differences in earliness and fruit yield in tomato varieties due to climatic factors. In contrast, fruit height, interval between fruit appearance and fruit maturity performed better during 2019 evaluation. Considering fruit weight per plot, 'Tom 29206' had higher fruit weight during 2018, while 'Bruno' and 'IND 27812' performed best during 2019. Trend of results for fruit yield and fruit quality traits in Sudan agro ecology may be due largely to inherent genetic factors and positive response by tomato genotypes to microclimate, which influences accumulation of photosynthate, growth and transpiration.

### Genetic variability and Heritability

The amount of phenotypic variability in a crop is predicated on inherent genetic variation, the phenotypic expression is essential for selection. For all traits, the magnitude of phenotypic variance is greater than their corresponding genotypic variance, environmental variance, and variance due to genotype by year interaction. (Table 1a and 1b). Also, the genotypic variance had larger, or smaller magnitude than variance due to genotype by year interaction depending on trait. This is associated with the influence of microclimatic factors in the expression of these traits. As shown in tables 1 and 2, the mean values for phenotypic variance were farther apart for vine length at first flowering and 50% flowering, individual fruit weight, fruit weight/ plot and fruit/plot). The estimates for phenotypic coefficient of variation were larger in magnitude than their corresponding genotypic coefficient of variation. In another study, Syukur and Rosidah (2014) reported large magnitude for PCV compared to GCV in pepper (*Capsicum annuum* L.). This suggest some influence of micro climatic factors. A little difference between PCV and GCV estimates indicates less environmental sensitivity. Therefore, selection based on phenotype will be worthwhile for improvement. Broad sense heritability estimates provides information about a trait and its interaction with the environment. It comprised additive and non-additive gene effects. Broad-sense heritability is classified as very high (e” 82%), moderately high (60-79%), moderately low (40-59%), and low (d” 40%). A high (e” 82%) broad sense heritability estimates were found for days to first flowering, days to 50% flowering, vine length at first flower, vine length at 50% flower, number of fruits per cluster, and number of loculi per fruit. This is indicative of high contribution of additive and non-additive gene effects compared to low contribution of microclimatic factors in phenotypic expression of these traits. These traits were least sensitive traits. In addition, fruit width and fruit brix had moderately high broad sense heritability estimates. This suggest a greater level of environmental sensitivity. A low (d” 40%) broad sense heritability indicates preponderance of environmental factors (precipitation and temperature) in the expression of these traits. However, it is possible to achieve improvements on a short run-in traits with high broad-sense heritability and with high phenotypic coefficient variance slightly larger than their genetic coefficient variance. In contrast, it would take more time to improve traits with low heritability, because of their low genetic variance component, and genetic coefficient of variation and genotype by year interaction.

The number of days to 50% first flowering had positive and significant correlation coefficient with fruit/plant (r= 0.78** P< 0.01, fruit weight/plot (r= 0.77** P< 0.01), fruit/cluster (r= 0.78** P< 0.01) and loculi per fruit (r= 0.87** P< 0.01). This suggest that early to medium flowering genotypes will account for higher fruits/plant and fruit yield. In addition, the desire to have 3 cycles of tomato production annually may be feasible. Similar findings were reported by Islam *et al*., 2010 and Tembe *et al*., 2017). The number of days between fruit appearance and mature fruit had significant negative correlation coefficient with fruits/plant (r= -0.78** P< 0.01) and significantly positive correlation coefficient with fruit pH (r= 0.78** P< 0.01). This suggest that genotypes with few days between fruit appearance and maturity will have low of fruit/plant and vice versa. 'IND 27812' had 25 d between fruit appearance and maturity with lowest fruit/plant. Results in this study are similar with those reported by Wali and Kabura, 2014 and Tembe *et al*., 2017). The correlation coefficient between number of fruit/plot and fruit/plant was positive and significant (r= 0.78** P< 0.01). Fruit length recorded positive and significant association with fruit/plant (r= 0.77** P< 0.01), fruit/cluster (r= 0.79** P< 0.01), loculi/fruit (r= 0.76** P< 0.01). This indicates that tomato fruits are oblong in shape and improvement in fruit length will account for more fruits/cluster. On the other hand, a significantly negative correlation coefficient was recorded in the association between fruit length and fruit brix (r= 0.97** P< 0.01). The number of fruits/plant correlated positively with fruit length (r= 0.84** P< 0.01) and number of loculi/fruits (r= 0.78** P< 0.01). The association between fruit weight/plant and number of loculi/fruit showed statistically significant (r= 0.83** P< 0.01).

Fruit development and size was dependent on micro climate, the 2019 evaluation was best for fruit yield. Moderate to high temperature, humidity, hot air and day length influenced physiological processes for high fruit yield and fruit quality, and earliness for 3 cycles of production annually. Tomato genotypes were responsive to microclimatic variables, inconsistent in fruit appearance, fruit development, fruit number and fruit brix, and fruit yield across years. Genotype × Year Interactions (GYI) are important to consider when developing stable varieties for a specific environment. For optimal performance, manipulation of micro-climate and breeding works are essential.

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