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# Prostrate or upright growth habit in tomato cultivars: contributory roles of stem diameters and fruit weight under fertilizer application

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All relevant data are within the paper and its Supporting Information files.

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The authors declare no competing interests.

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**Abstract: For increased production of fresh market tomato fruits, identification of cultivars that combine upright growth habit (UGH) and increased fruit weight under increased fertilizer rates is essential. Six tomato cultivars comprising five improved types namely Tropimech, Buffalo, Roma VF, Roma Savana, UC 82 and a local cultivar Kerewa were evaluated to identify cultivars that combined average fruit weight with UGH under different rates of NPK 15:15:15 fertilizer (0, 30, 50, and 80 kg ha$^{-1}$). Aerial and basal stem diameter (ASD and BSD), and weight per fruit (WPF) cumulatively accounted for the largest significant variation (47.17 **) in growth habit of the tomato cultivars with ASD being the most determinant of all. Increased fertilizer rates resulted in increased morphological and yield parameters but promoted prostrate growth habit in tomato cultivars. At 30 kg ha$^{-1}$, Roma VF and Roma Savanna combined UGH with ample yield per plant while at 50 and 80 kg ha$^{-1}$ of fertilizer, UC 82 consistently maintained the most UGH with higher yield. Growing UC 82 at 50 kg ha$^{-1}$ of fertilizer is recommended for better UGH and higher yield. Consideration should be given to ASD, BSD, and WPF in future improvements of tomato for UGH and yield.**

## 1. Introduction

One of the challenges confronting tomato production is the inability of the crop to maintain an upright growth habit at full fruit formation due to increased fruit weight and weak stem. This attributes manifest more in most improved tomato cultivars that are bred purposely for high yield and do not exempt the local ones. Maintenance of upright growth habit in tomato cultivars at maturity is an important attribute in harvesting high percentage of fresh tomato fruits considering the prevalence of diseases that occur with contact of fruits with bare soil (Santamaría and Toranzos, 2003). Tomato fruit is perishable and the contact with soil can promote rotting and scorching and increase disease prevalence that can lead to low quality fruits and greater yield loss (Naika *et al*., 2005). Tomato plant are often staked or trellised in order to minimize the contact of fruit with soil however, the cost incurred on staking during production of fresh market tomato fruits are among the highest for any vegetable crop (Davis and Estes, 1993; Kemble *et al*., 1994; Frasca *et al.*, 2014). Identifying tomato cultivars with most upright growth characteristics can prevent scorching and rottenness often associated with tomato fruit at maturity and could contribute to increased fruit quality and fruit yield and reduce cost of staking in tomato production.

The permanent displacement of plant from its upright position otherwise termed 'lodging' is one major cause of yield loss in most crops (Crook and Ennos, 1995). It usually occurs due to inability of plants to withstand strong winds and poor anchorage of plant roots to its substratum. Terminal and axillary weights from fruits can contribute to plant inability to stay erect. The height of the plant as well as thickness of the basal stem are some of the contributing factors to lodging in plants (Zhang *et al.*, 2014). In tomato, variations in stem diameter occur along the height of the crop. The basal section of the stem which is usually thinner though could be more lignified is unable to support the uppermost part which is characterized by robust stem and heavy fruit weights at fruiting stage in most cultivars. The variation in stem diameter usually observed along the stem of tomato cultivars could be a factor contributing to lodging in tomato. Assessing the extent of this variation along the height of the crop along with other morphological traits could provide information on morphological traits that should be considered in future improvement of tomato cultivars for upright growth and yield.

Plant response to fertilizer application occurs through expansion of various plant parts culminating eventually in surface area expansion. Application of inorganic fertilizer at high dosage rates can increase yield but may also increase susceptibility of the crop to lodging due to reduced structural carbohydrates content and lignin deposition resulting in weakening of the stem (Zhang *et al*., 2014; Zhang *et al.,* 2016). Conversely, poor fertilization culminating in nitrogen deficiency can instigate stem diameter variation attributable to reduced transpiration and assimilate loadings which ultimately affects storage tissue concentration (De Swaef *et al.*, 2015). In tomato, application of inorganic fertilizers such as calcium nitrate at different rates increased plant height and fruit yield (Montagu and Goh, 1990; Souri and Dehnavard, 2018). This could also induce bioaccumulation of salt in plant tissue at higher rates which often affect growth of tomato (Romero-Aranda *et al.,* 2006; Tuna *et al.,* 2007; Caruso *et al.,* 2011). Finding a balance in upright growth, increase in dosage rates of nitrogen fertilizer applied and ample fruit yield is therefore a necessity in ensuring maximum gains from tomato cultivation. Little studies have explored the contribution of stem diameter variation and fruit weight on upright growth of improved tomato cultivars. Past breeding objectives in tomato has focused mainly on yield, shelf-life, taste and nutritional quality (Bai and Lindhout, 2007), however evaluation of morphological traits that could contribute indirectly to these traits is also necessary. Documented findings should assist in identifying cultivars that combine high yield with upright growth under different rates of fertilizer application. The following questions were raised and addressed in this study (i) Does variation in stem diameter contribute to growth habit of tomato cultivars? (ii) Do tomato cultivars maintain similar growth habit at physiological maturity when maximum weight of fruits is achieved and when fruits are turning red? (iii) Do fertilizer rates influence growth habit of tomato cultivars? and (iv) Does fruit weight, number of fruits or both contribute to upright growth habit of tomato cultivars?

## 2. Materials and Methods

*Experimental site*

The experiment was conducted at Ilaraa, a tomato production area located in the derived savanna zone of Yewa North Ogun state, Nigeria (7.4°N, 2.7°E, 188 m asl). The area is characterized by erratic rainfall at early and later part of the year which usually remains stable around June to July. The soil is well drained and is characterized by high proportion of sand with relatively lower proportion of clay and silt and hence supports good growth of tomato. The commonly grown cultivar, Kerewa, is supplied in commercial quantities to adjoining markets and Lagos, a neighbouring state.

*Soil sample collection and preparation*

Prior to establishment of the trial, the experimental field was divided into three rectangular blocks each with 3 m x 6 m in dimension. Core soil samples were taken at 0-15 cm along the diagonals of each block after which they were bulked to form composite samples. The soil samples were air dried and sieved with 2 mm sieve after which they were subjected to laboratory soil analysis.

*Laboratory analysis of soil sample*

The pH of the soil was determined in 1:2 soil water ratios with a glass electrode pH meter (McLean, 1982). Particle size distribution was determined by hydrometer method (Gee and Bauder, 1986). Exchangeable bases (Ca, Mg, K and Na) in the soil were extracted using ammonium acetate method (Thomas, 1982). Following extraction of exchangeable bases, Ca and Mg were determined with Buck Scientific 210 VGP model, Atomic Absorption Spectrophotometer (AAS), while K and Na were read on flame photometer. The exchangeable acidity was determined by titration method (Anderson and Ingram, 1993). Effective Cation Exchange Capacity (ECEC) was estimated by the summation of exchangeable bases and exchangeable acidity (Anderson and Ingram, 1993). Base saturation of the soil was calculated as the fraction of the exchangeable bases and ECEC expressed in percentage. Total nitrogen was determined by Kjeldahl method (Bremner, 1996). Organic carbon was determined by the wet oxidation method as described by Walkley-Black (Nelson and Sommer, 1996). Available phosphorus was determined by Bray-1 method (Bray and Kurtz, 1945).

*Experimental methods*

The experimental protocol was based on the factorial combination of six cultivars and three fertilizer rates plus a non-fertilized control. Six tomato cultivars comprising five improved types namely Roma VF, Roma Savana, UC 82, Tropimech -with determinate growth habit, Buffalo and the local cultivar-Kerewa, which are both an indeterminate cultivars that require staking. Buffalo has a large fruit with thick flesh and few seeds. Tropimech has an egg-shaped fruit and high fruit setting. UC 82 in addition to having determinate growth is an early maturing cultivar with square to egg-shaped red fruit. The seeds of the tomato cultivars were all obtained from Agro service station and were nursed for 3 weeks. The seedlings were later transplanted onto a prepared field at a spacing of 50x50 cm between plants along and between rows. The plot dimension was 1 m x 1.5 m with six plants. Spacing between plots and replicates was 50 cm and 1 m, respectively (Fig. 1). Fertilizer as N:P:K 15:15:15 in the form of elemental nitrogen (N), phosphate ($P_2O_5$) and potash ($K_2O$) respectively, was applied at the rates of 30, 50 and 80 kg ha$^{-1}$ at 8 weeks after planting while plot with no fertilizer application served as the control. The experimental treatments were distributed in the field according to the Randomized Complete Block Design (RCBD) with three replicates. Harvesting of tomato fruits commenced at physiological maturity, when assimilates had been fully partitioned into the fruits as confirmed by fully formed fruits, and when fruits were turning red. The fruits were counted and weighed using Electronic Compact Scale (ATOM A-110C), China.

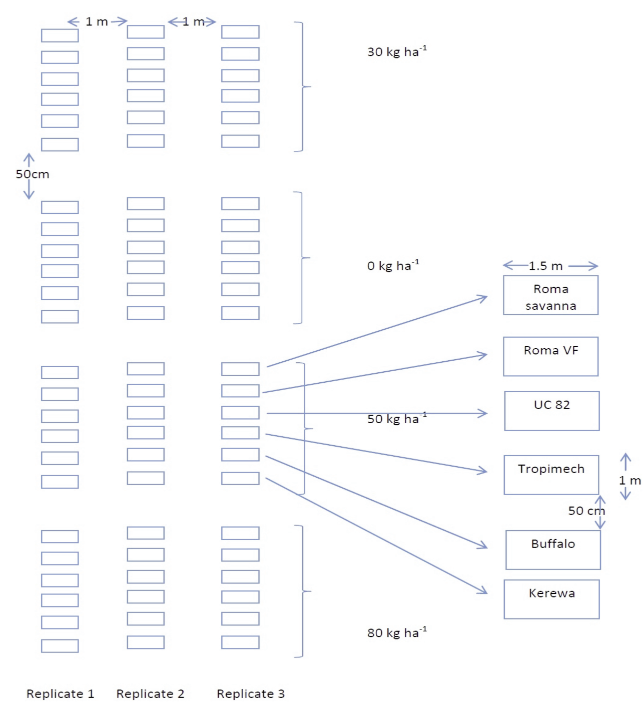


Fig. 1 - Plot layout of the field showing the arrangement of plots within the field. Plots in group of six represent the cultivars arranged randomly within each group.

*Data collection*

At physiological maturity of tomato fruits, plant basal stem diameters was measured at 5 cm above the soil mark while aerial diameter was measured near the last leaf at the top using plant leaf thickness gauge (Model YH-1 Top instrument). Height measurement was performed on the primary stem axis from soil mark to the base of the last leaf. The growth habit of the tomato cultivars was assessed using visual scoring on a scale of 1 to 5:1 represents upright growth, 2 for 30° deviation, 3 for 45° deviation, 4 for 70° deviation and 5 for fully prostrate stem (Ozminkowski *et al.*, 1990). Fruit production per plant was obtained by harvesting all fruits on a plant at physiological maturity which were later counted and weighed. Total fruit weight per plant was obtained by weighing all fruits harvested within a plot and divided by the total number of plants per plot. Stem diameter variation (mm $cm^{-1}$) was computed using the following formula:

$$\text{Stem diameter variation (mm cm}^{-1}\text{)} = \frac{ASD - BSD}{PH} \times 100$$

Where ASD = aerial stem diameter; BSD = Basal stem diameter; and PH = Plant height. These parameters were selected for measuring stem diameter variation (SDV) based on their ability to measure difference in terminal stem diameters (ASD and BSD) in relation to average distance between the two as measured by plant height (PH).

*Statistical analyses*

Data of growth and yield parameters were subjected to Analyses of Variance (ANOVA) using Genstat 12th Edition (Payne *et al.*, 2009) package. The means relevant to the variables significantly affected by the experimental treatments were separated using Fischer's Protected Least Significant Difference at p≤0.05. Correlation and stepwise regression analyses of the morphological and yield parameters were conducted to study the association among the variables and to identify the traits with largest contribution to growth habit of tomato at physiological maturity. Multivariate analysis was also conducted to identify cultivars that combined an upright growth habit with high yield among the tomato cultivars. In correlation, regression and principal component analyses (PCA) carried out, logarithm transformation was conducted on the data before analyses. The mean of the transformed values for each of the variable across fertilizer rates were first computed for each cultivar before conducting PCA. The PCA was conducted using correlation matrix method.

## 3. Results

The routine soil analysis of the experimental site is presented in Table 1. The pH of the soil (6.9) is neutral and has higher proportion of sand (886.0 g $kg^{-1}$ equivalent to 88.6% of 1 kg soil sample) as compared with that of silt and clay (69.33 and 44.67 g $kg^{-1}$ respectively) amounting to 6.9 and 4.5% respectively of 1 kg soil sample. Exchangeable Ca and Mg contents of 3.72 and 1.48 cmol $kg^{-1}$, respectively were moderately high. However, potassium (0.08 cmol $kg^{-1}$) level in the soil was very low compared to critical level of 0.15 cmol $kg^{-1}$. Exchangeable sodium (0.10 cmol $kg^{-1}$) was also low while the ECEC of 5.43 cmol $kg^{-1}$ was lower than critical level of 8.0 cmol $kg^{-1}$ for low soil fertility in tropical soils. There was low exchangeable acidity (0.05 cmol $kg^{-1}$) and high base saturation percentage of 99.12 %. Total nitrogen (0.70 g $kg^{-1}$) and organic carbon (6.43 g $kg^{-1}$) were very low. Available phosphorus (26.02 mg $kg^{-1}$) was very high and in several folds higher than critical level of 8.0 mg $kg^{-1}$ in non-degraded soils.

Table 1 - Pre-experimental characteristics of soil

| Physicochemical properties | Soil composition |
|---|---|
| pH | 6.92 |
| Sand (g $kg^{-1}$) | 886.00 |
| Silt (g $kg^{-1}$) | 69.33 |
| Clay (g $kg^{-1}$) | 44.67 |
| Texture | Sandy |
| Ca (cmol $kg^{-1}$) | 3.72 |
| Mg (cmol $kg^{-1}$) | 1.48 |
| K (cmol $kg^{-1}$) | 0.08 |
| Na (cmol $kg^{-1}$) | 0.10 |
| Al+H (cmol $kg^{-1}$) | 0.05 |
| ECEC_(cmol $kg^{-1}$) | 5.43 |
| BS_% | 99.12 |
| N (g $kg^{-1}$) | 0.70 |
| OC (g $kg^{-1}$) | 6.43 |
| Av_P (mg $kg^{-1}$) | 26.02 |

The effects of fertilizer rates and cultivars on morphological and yield parameters of tomato are presented in Table 2. Significant effects (p≤0.01) of fertilizer rate and cultivar were observed on all the parameters with the exception of basal stem diameter (BSD) and weight of fruit per plant (WFPP) which were not significantly affected by cultivar. Increased application rate of NPK 15:15:15 fertilizer from 30 to 80 kg $ha^{-1}$ resulted in a significant increase in all morphological parameters of the tomato cultivars. A more enhanced prostrate growth habit (PGH) was however observed in tomato plants with increased rate of fertilizer. The control recorded 2.17 growth habit score (GHS) while fertilizer application rate of 50 kg $ha^{-1}$ and 80 kg $ha^{-1}$ recorded 3.33 and 3.17 in GHS, respectively. Among the cultivars, the widest aerial stem diameter, ASD (8.46 mm) and stem diameter variation (SDV) (5.75 mm $cm^{-1}$) were observed in Buffalo, while Kerewa had the highest number of fruit per plant, NFPP (5.61) but the least upright plant with mean GHS of 3.42. The highest weight per fruit

(WPF 25.65 g) was however observed in UC 82. No significant interaction between fertilizer rate and cultivar was observed for all the parameters studied.

Table 3 shows the correlation coefficients among the morphological and yield parameters of the tomato cultivars. Significant correlations were observed among most of the parameters with correlation between NFPP and WFPP being the highest (0.79**) and followed by correlation between ASD and SDV (0.76**). The lowest significant correlation was observed between plant height (PH) and SDV (0.24*). The correlation of WPF was significant (0.50**) only with WFPP. Among the yield parameters, WPF did not show significant correlation (0.05 NS) with SDV. Growth habit score had positive significant correlation with all the morphological and yield parameters with the exception of WPF (-0.02 NS).

The percentage variations (adjusted $R^2$) of subsets regression of morphological and yield parameters on growth habit of tomato cultivars across fertilizer application rates are presented in Table 4. Under each parameter contribution to growth habit i.e. one term, ASD accounted for the highest (44.89**) significant variation among the growth and yield parameters while WFPP contributed the least (9.82**) significant variation. The WPF did not solely account for significant variation in growth habit of the tomato cultivars. Across the various subsets of regression i.e. two terms and above, ASD in most cases, was consistent in its significant contribution to variations in growth habit of tomato cultivars. The highest significant variation (47.17**) in GH of tomato cultivars was obtained when three terms consisting ASD, BSD, and WPF were included in the regression model while other cumulative inclusions accounted for lesser significant variation in growth habit of tomato cul-

Table 2 - Effects of fertilizer rate and cultivar on morphological and yield parameters of improved tomato cultivars

| Sources of variation | Levels of variation (kg) | Aerial stem diameter (mm) | Basal stem diameter (mm) | Plant height (cm) | Stem diameter variation (mm $cm^{-1}$) | Number of fruit $plant^{-1}$ | Weight $fruit^{-1}$ (g) | Weight of fruit $plant^{-1}$ (g) | Growth habit |
|---|---|---|---|---|---|---|---|---|---|
| Fertilizer Rates (F) (kg $ha^{-1}$) | 0 | 5.66 | 5.32 | 31.96 | 0.01 | 2.78 | 18.46 | 49.68 | 2.17 |
| | 30 | 6.89 | 5.87 | 41.01 | 0.03 | 3.96 | 22.40 | 83.35 | 2.83 |
| | 50 | 7.52 | 5.91 | 42.68 | 0.04 | 4.27 | 21.70 | 84.29 | 3.33 |
| | 80 | 7.70 | 6.23 | 42.62 | 0.03 | 5.20 | 25.77 | 126.80 | 3.17 |
| | LSD | 0.64 | 0.50 | 4.31 | 0.01 | 0.14 t | 4.43 | 28.49 | 0.10 t |
| | Significance | ** | ** | ** | ** | * | * | ** | ** |
| Cultivars (C) | Roma VF | 6.12 | 5.68 | 39.51 | 0.01 | 3.03 | 24.63 | 76.25 | 2.33 |
| | UC 82 | 6.82 | 5.69 | 36.39 | 0.03 | 3.78 | 25.65 | 93.99 | 2.58 |
| | Roma Savana | 6.45 | 5.83 | 38.73 | 0.01 | 2.98 | 20.72 | 64.87 | 2.42 |
| | Buffalo | 8.46 | 6.08 | 39.17 | 0.06 | 5.58 | 19.08 | 107.79 | 3.33 |
| | Tropimech | 6.64 | 5.45 | 43.66 | 0.03 | 3.26 | 25.90 | 85.36 | 3.17 |
| | Kerewa | 7.19 | 6.25 | 39.96 | 0.02 | 5.61 | 16.53 | 87.93 | 3.42 |
| | LSD | 0.78 | 0.61 | 5.28 | 0.01 | 0.17 t | 5.43 | 34.90 | 0.12 t |
| | Significance | ** | NS | * | ** | * | ** | NS | ** |
| F x C | | NS | NS | NS | NS | NS | NS | NS | NS |

** and * = significant at p≤0.01 and 0.05 probability level respectively; NS= non-significant. Least significant difference (LSD) with 't' are from transformed data.

Table 3 - Correlation analysis showing the relationships among growth and yield parameters of improved tomato cultivars grown in Ilaraa

| Parameters | Aerial stem diameter, ASD (mm) | Basal stem diameter, BSD (mm) | Plant height (cm) | Stem diameter variation (mm $cm^{-1}$) | Number of fruit $plant^{-1}$ | Weight $fruit^{-1}$ (g) | Weight of fruit $plant^{-1}$, (g) | Growth habit score |
|---|---|---|---|---|---|---|---|---|
| Arial stem diameter | | | | | | | | |
| Basal stem diameter | 0.69** | | | | | | | |
| Plant height | 0.52** | 0.36** | | | | | | |
| Stem diameter variation | 0.76** | 0.10 NS | 0.24* | | | | | |
| Number of fruit per $plant^{-1}$ | 0.55** | 0.57** | 0.34** | **0.28*** | | | | |
| Weigh $fruit^{-1}$ | 0.12 NS | 0.14 NS | 0.13 NS | 0.05 NS | -0.14 NS | | | |
| Weigh of fruit $plant^{-1}$ | 0.56** | 0.59** | 0.38** | 0.27* | **0.79**** | 0.5** | | |
| Growth habit score | 0.68** | 0.35** | 0.38** | 0.61** | 0.40** | -0.02 NS | 0.33** | |

** and * = significant at p≤0.01 and 0.05 probability level respectively; NS= non-significant. Values in bold are the highest and lowest significant correlations values from the parameters involved.

Table 4 - Adjusted R2 of subsets linear regression of morphological and yield parameters against growth habit of tomato cultivars across rates of fertilizer

| One term | Two terms | Three terms | Four terms | Five terms | Six terms |
|---|---|---|---|---|---|
| 44.89 (1**) | 47.00 (1**, 2 NS) | 47.17 (1**, 2 NS, 6 NS) | 46.88 (1**, 2 NS, 5 NS, 7 NS) | 46.24 (1**, 2 NS, 3 NS, 5 NS, 7 NS) | 45.46 (1**, 2 NS, 3 NS, 5 NS, 6 NS, 7 NS) |
| 36.13 (4**) | 46.21 (1**, 4 NS) | 47.09 (1**, 2*, 5 NS) | 46.85 (1**, 2*, 5 NS, 6 NS) | 46.20 (1**, 2 NS, 3 NS, 5 NS, 6 NS) | 45.41 (1 NS, 2 NS, 3 NS, 4 NS, 5 NS, 7 NS) |
| 14.78 (5**) | 45.28 (1**, 6 NS) | 46.42 (1**, 4 NS, 6 NS) | 46.83 (1**, 2*, 6 NS, 7 NS) | 46.17 (1**, 2 NS, 3 NS, 6 NS, 7 NS) | 45.37 (1 NS, 2 NS, 3 NS, 4 NS, 5 NS, 6 NS) |
| 13.36 (3**) | 44.40 (1**, 7 NS) | 46.37 (1*, 2 NS, 3 NS) | 46.59 (1*, 2 NS, 3 NS, 6 NS) | 46.16 (1*, 2 NS, 4 NS, 5 NS, 7 NS) | 45.37 (1*, 2 NS, 4 NS, 5 NS, 6 NS, 7 NS) |
| 10.65 (2**) | 44.23 (1**, 3 NS) | 46.28 (1*, 2 NS, 4 NS) | 46.44 (1*, 2 NS, 4 NS, 6 NS) | 46.13 (1*, 2 NS, 4 NS, 5 NS, 6 NS) | 45.34 (1 NS, 2 NS, 3 NS, 4 NS, 6 NS, 7 NS) |
| 9.82 (7**) | 44.21 (1**, 5 NS) | 46.22 (1**, 2 NS, 7 NS) | 46.40 (1**, 2* ,3 NS, 5 NS) | 46.11 (1**, 2 NS, 5 NS, 6 NS, 7 NS) | 45.09 (1*, 3 NS, 4 NS, 5 NS, 6 NS, 7 NS) |
| <0.00 (6 NS) | 43.52 (2**, 4**) | 46.07(1**, 3 NS, 4 NS) | 46.38 (1*, 2 NS, 4 NS, 5 NS) | 46.10 (1*, 2 NS, 4 NS, 6 NS, 7 NS) | 44.08 (2 NS, 3 NS, 4**, 5 NS, 6 NS, 7**) |
| | 41.18 (3**, 4**) | 46.00 (1*, 4 NS, 5 NS) | 46.37 (1**, 3 NS, 4 NS, 6 NS) | 45.85 (1*, 3 NS, 4 NS, 5 NS, 7 NS) | 44.61 (1 NS, 2 NS, 3 NS, 4 NS, 5 NS, 6 NS, 7 NS) for 7 terms |

** and * = significant at p≤0.01 and 0.05 probability level respectively; NS= non-significant. Adjusted R2 presented are the first few highest ranked adjusted R2 from each subset. The bold-italic adjusted R2 in the column for six terms represents the adjusted R2 when all terms are included in the regression model. Values in parenthesis represent the parameters and their significant level of contribution to the adjusted R2 in each subset. 1= Aerial Stem Diameter; 2= Basal Stem Diameter; 3= Plant height; 4= Stem Diameter Variation; 5= Number of fruits per plant; 6= Weight per fruit; and 7= Weight of fruit per plant.

tivars.

The comparison of growth habit and WFPP (yield) of tomato cultivars at each fertilizer rate for identification of cultivar with best combination of high yield with the most upright growth is presented in figure 2. For the control (0 kg ha$^{-1}$), the logarithm of WFPP exceeded that of the growth habit for all the tomato cultivars except Kerewa. With application of fertilizer, overlapping relationship between growth habit score and WFPP were observed among the cultivars. At 30 kg ha$^{-1}$ of fertilizer, Roma VF and Roma Savana maintained higher yield than their respective growth habit while at higher doses, UC 82 consistently maintained higher yield combined with the most upright growth habit. Across the fertilizer rates, growth habit score of Buffalo, Tropimech and Kerewa exceeded their respective WFPP.

Figure 3 shows the principal component biplot of the cultivars using all morphological parameters. The lines in the biplot represent the direction of increase of the variables with the side of the line with the label having the highest value for the variable. The two axes of the biplot accounted for 79.9% variation among the cultivars. At one side of the plot are Tropimech, Buffalo and Kerewa with the cultivars having the highest SDV, PGH, NFPP, WFPP and PH while UC 82, Roma VF and Roma Savana are at the other side where the values for these traits are lower. The cultivar, UC 82 however falls within the center of polygon while other cultivars are at the vertices position.

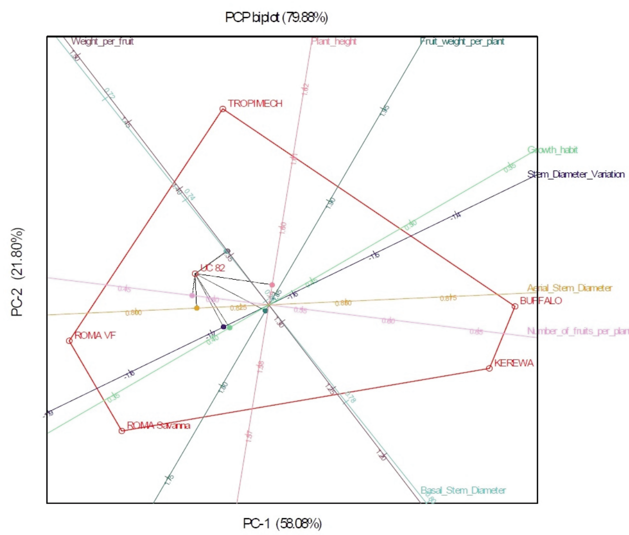


Fig. 3 - Principal Component's biplot showing the differential performance of the tomato cultivars for the morphological and yield parameters.

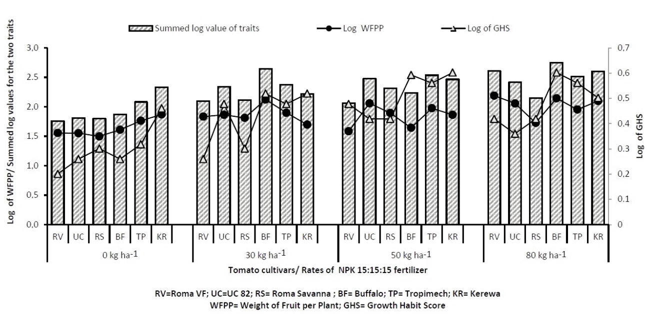


Fig. 2 - Comparison of growth habit and weight of fruit per plant for identification of tomato cultivar with better combination of traits under different fertilizer rates.

## 4. Discussion and Conclusions

Stem diameter variation measurement is not common in tomato cultivars assessment but its measurement along the height of the crop provides useful information on the susceptibility of tomato to prostrate growth at maturity. The need to improve tomato cultivars for upright growth while maintaining higher yield, particularly under the tropical humid condition where fruits get in contact with moist soil due to the weight of fruits, is quite imperative.

Among the various morphological and yield parameters examined, the ASD and BSD, and WPF were among the most contributory traits that cumulatively influenced the growth habit of tomato with ASD of the tomato cultivars being the most influential on growth habit of the tomato cultivars. The non-significant cumulative contribution of NFPP to growth habit of the tomato cultivars underscores the importance of WPF present on a plant. The likely concentration of heavy-weight fruits at one side of the plant could have promoted prostrate growth habit of the tomato cultivars. The mean fruit weight of tomato fruits has been regarded as a strong varietal character in determining the marketable yield of tomato (Moreno and Moreno, 2008; De Sio *et al*., 2018). This therefore implied that WPF in addition to stem diameter of both basal and aerial stems but most importantly the aerial stem should be focused on in future improvement of tomato cultivars, particularly where infection and damage by soil borne pathogens are prevalent.

Improved tomato cultivars though varied in their individual growth responses, are similar in response to increased fertilizer rates as also reported in previous research (Ercolano *et al*., 2015). Virtually all the morphological and yield parameters showed increase response with increase rate of fertilizer with the highest performance observed at 80 kg $ha^{-1}$. The low level of nitrogen observed in the soils could have elicited the responses of the tomato cultivars to doses of fertilizer applied. The low levels of N and organic carbon in soil with low clay has been attributed to leaching of nitrates and high rate of mineralization of organic matter that characterize very highly degraded tropical soils such as the type in the experimental site (Snakin *et al.,* 1996). Nitrate leaching in sandy soils can be prevented by using organic or organo-mineral forms of nitrogen fertilizer, which also reduces the accumulation of this anion in plant edible parts (Caruso *et al.,* 2011). The low N content in the soil in the present research can also be attributed to low ECEC of the soil which was a reflection of higher sand particle and low activity clay of the soil which encouraged leaching of cations (Udoh *et al.*, 2013). The low exchangeable acidity and high base saturation also observed in the soil is an indication that the soil's exchange site was dominated by basic cations.

The increase in vegetative growth such as ASD and BSD, observed with higher dosage rate of fertilizer would have been the cumulative effect of increase nitrogen content of the fertilizer. The increase in basal stem diameter (BSD) observed with increase fertilizer rates did not however translate to upright growth in most of the improved tomato cultivars selected as there were corresponding increases in fruit weight and robustness of the ASD. In rice, reduced structural carbohydrates content and lignin deposition is usually associated with increased fertilizer application and can contribute to PGH (Zhang *et al.,* 2016). This could also have been responsible for PGH exhibited by the tomato cultivars in the present research. Increased fruit yield observed in the tomato cultivars with increased fertilizer rates can be attributed to increased dosage rate of phosphorus and potassium in the fertilizer that complimented soil available phosphorus, as both stimulate yield increase in crop (Vance *et al.*, 2003). In previous investigations (Amalfitano *et al*., 2017; Morano *et al.,* 2017), the increase of macronutrients supply to plants led to yield increase up to a crop system dependant threshold. High level of available P in this soil may have been caused by the pH level of the soil. At soil pH of 6.92, phosphorus is more likely to be available than at lower pH of 4 to 4.5 where P is more likely to be fixed (DeForest *et al.,* 2012).

Plotting the log values of traits against their summed log values as obtained in figure 3 can be an alternative way of selecting cultivars of plant with good combination of traits. The plot of log of WFPP and growth habit against their summed log values at each rate of fertilizer applied provided the opportunity to identify cultivars with better performance for these two traits under a given fertilizer rate. The plots indicated upright growth habit for lower logarithm values of growth habit and higher yield for higher logarithm value of WFPP. It was revealed that under no fertilizer application, higher WFPP of all the cultivars except Kerewa combined with upright growth habit whereas this varied among the cultivars under application of fertilizers. With NPK 15:15:15 fertilizer, most of the cultivars especially Buffalo, Tropimech and Kerewa maintained PGH in combination with higher yield. This corroborated the earlier findings that increased fertilizer application rates can increase yield but also increase the susceptibility of plant to lodging (Zhang *et al.,* 2014). Roma VF and Roma Savanna were however identified as cultivars that combined average yield with the most upright growth among the cultivars at 30 kg $ha^{-1}$ of fertilizer. At higher doses i.e. 50 kg $ha^{-1}$ and 80 kg $ha^{-1}$, UC 82 consistently maintained the most upright growth combined with higher yield among the cultivars. However, higher rates of chemical fertilizer that can cause increased accumulation of salt in soil and tissue of tomatoes as reported by Widders and Garton (1992) and Tuna *et al.* (2007) may therefore make it necessary to recommend application of 50 kg $ha^{-1}$ of the fertilizer for upright growth habit and higher yield and for possible reduction in accumulation of the salt in tissues of tomato.

The inclusion of other morphological parameters in the multivariate principal component analyses further revealed the cultivars performance for other morphological traits. The selected cultivar in addition to combining high yield with most upright growth was able to maintain a reduced variation in basal and aerial stem diameter with a reduced height coupled with a reduced NFPP. These important traits are to be considered in the breeding of cultivars for upright growth habit and high yield in future breeding programs for tomato. The positioning of the tomato cultivar UC 82 at the center of the polygon further indicated the average performance of the cultivar for the important traits considered in this study while the polygon with other cultivars positioned at its vertices identified cultivars with exceptional performance for some specific traits. Tropimech for example maintained a closer relationship with PH and WFPP in the biplot which confirmed the highest value it recorded for these traits. Furthermore, the positioning of Buffalo and Kerewa in the direction of ASD and NFPP also indicated their higher performance for these traits while Roma VF positioned at opposite end of these vertices had lower performance for the traits. Based on the average performance of UC 82 among the cultivars for all the traits, the cultivar is therefore recommended for upright growth habit and high yield under application of 50 kg $ha^{-1}$ of N:P:K 15:15:15 fertilizer.

Stem diameter variation along the height of tomato plants is important to the upright growth habit of tomato cultivars. Improved tomato cultivars however varied in their susceptibility to prostration at maturity. The robustness of the aerial stem diameter, the thin nature of the basal stem as well as WPF at harvest are some of the factors responsible for this growth habit. Cultivars with robust basal stem combined with reduced variation in stem diameter and appreciable yield will be a promising cultivar for producing fresh tomato fruits in future. Application of 50 kg $ha^{-1}$ of NPK 15:15:15 fertilizer can also reduce the susceptibility of the crop to prostrate growth at maturity. Studies that consider reducing the spacing of the identified cultivar to achieve optimum yield $ha^{-1}$ in comparison with others with higher yield and PGH is suggested to justify the reduced yield that upright growth of stem could cause. The growing of the tomato cultivars in locations with different agroecology is recommended for a better varietal selection.

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