Evaluation and Characterization of Tomato (*Solanum lycopersicum* L.) Genotypes Using Path Coefficient, GGE Biplot and Cluster Analyses Under Natural Heat Stress

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Abstract
Tomato grown during late winter in plains of Nepal suffers from high temperature stress which causes severe reduction in fruit yield. Thus, this study was conducted to evaluate yield potential of nine tomato genotypes under seasonal heat stress condition of Chitwan, Nepal during dry summer seasons of 2018 and 2019. Analysis of variance showed significant differences (*p* ≤ 0.05) among all genotypes for growth, yield and yield attributing traits. The highest mean marketable fruit yield of 101.6 t ha⁻¹ was recorded in genotype TO-1057 and the lowest (32.9 t ha⁻¹) in AVTO-9802. The highest positive direct effect of marketable fruit per plant (0.99) on fruit yield per plant was observed followed by average fruit weight (0.795), plant height (0.392), and inflorescence per plant (0.316) and fruit diameter (0.249). Correlation analysis revealed that plant height, fruit weight and diameter were positively associated with fruit yield. Fruit diameter showed positive and significant correlation with average fruit weight (0.983***). The GGE Biplot indicated that TO-1057, Pariposa-4102 and Srijana (check variety) were superior for fruit yield and other major yield contributing traits. These superior were grouped into one cluster having taller plants with higher marketable fruits per plant, fruit set percentage, flowers per inflorescence, marketable fruits and fruit yield per plant. Tomato genotypes with semi-determinate to indeterminate growth habit with medium sized fruits performed better in the experiment. This study suggests that the genotype TO-1057 and Srijana could be recommended for summer season cultivation in the plains of Chitwan.

Keywords  Heat stress; High temperature; Path coefficient; Tomato

Background
Tomato (*Solanum lycopersicon* L.), the most important vegetable crop of the world, is grown in both tropical and temperate regions. It thrives best in moderate climates, but can adapt to a wide range of climatic conditions. It is cultivated as winter crop in plains of Nepal (Soti, 2018), however, summer season production gets off-season market price (Paudel and Bhattarai, 2018). In the plains of Nepal, the winter and pre-monsoon maximum temperatures range between 20°C to 25°C and 30°C to 35°C, respectively, while the dry summer season temperature exceeds 40°C in some places (DHM, 2017). The optimal daily mean temperature for tomato fruit set under field conditions is between 21 to 25°C (Solankey et al., 2018), but the cultivation of this crop in subtropical regions inevitably exposed to higher day and night temperatures for successive days or even weeks during the reproductive growth phase, which can greatly hamper fruit set (Sato et al., 2006). Lack of tolerance to high temperature in most tomato cultivars presents a major limitation for tomato growers.

One of the major effects of high temperatures is the reduction of reproductive success, which commonly translates into yield loss in agricultural settings (Asseng et al., 2011). Fruit number and fruit weight are the important yield components, which are severely affected under high temperature stress and ultimately yield is markedly reduced (Solankey et al., 2018; Singh et al., 2015). Tomato fruit set reduced markedly when average maximum day temperature goes above 32°C (Hazra and Som, 2006). Due to rise in average day/night temperature (32/26°C) a decrease in the yield of tomato is a common problem (Srivastava et al., 2012). In Rampur, Chitwan (a plain area of Nepal), the average maximum daily temperature reaches 29°C in March and exceeds 32°C from April (NMRP,
2016). Therefore, the present study was under taken to screen the genotypes in respect of different quantitative traits for identification of superior heat tolerant tomato genotypes to be grown during dry summer season in plains of Nepal.

1 Results

1.1 Analysis of variance for morphological and yield traits

Tomato genotypes differed significantly for all the observed traits (Table 1). Genotype, Srijana, gained the maximum height of 176 cm at final harvest whereas AVTO-9304, the most dwarf, measured only 61.24 cm and at par with AVTO-9801 (68.5 cm). AVTO-9304 and AVTO-9801 flowered within 28 days after transplanting (DAT), Celebrity flowered at the last (34 DAT) but at par with the others except two early flowering genotypes. Similarly, early flowering genotypes provided early harvest within 74 DAT. Despite Celebrity flowered late, first harvesting duration was significantly longer in Florida-91 (85 DAT). Srijana had the longest harvest duration and the highest number of pickings.

Table 1 Yield and yield attributing characters of tomato genotypes combined over years

| Genotypes   | PH  | DFF | DFH | NH  | HD  | IN   | FPI | FIPI | FS  | FW  | FD  | MFP | YP   | YTH  |
|-------------|-----|-----|-----|-----|-----|------|-----|------|-----|-----|-----|-----|------|------|
| AVTO-9304   | 61.2ef | 28b | 74cd | 9c  | 20c | 54a  | 5.27a | 8.43a | 62.4a-d | 26.40f | 4.13d | 72.96ab | 1610.76de | 35.79de |
| AVTO-1314   | 92.6b-d | 33a | 79b | 8d  | 20c | 35cd | 3.47d | 5.25g | 66.59a-c | 61.20c | 5.2c  | 38.7c  | 1914.18de | 42.54de |
| AVTO-9801   | 68.5c  | 28b | 74d  | 8cd | 21c | 47b  | 4.42bc | 7.51b | 58.89cd | 26.20f | 4.05d | 62.47b | 1534.78de | 34.11de |
| AVTO-9802   | 83.9d  | 33a | 79b | 7d  | 20c | 46b  | 3.58d | 6.02ef | 59.69cd | 45.30de | 5.16c | 36.77c | 1484.26e | 32.98e |
| Florida-91  | 88.6cd | 33a | 85a  | 8c  | 30b | 23c  | 2.60e | 4.35h | 60.04b-d | 158.90a | 7.54a | 22.39d | 3216.26bc | 71.47bc |
| Celebrity   | 103.0bc | 34a | 79b | 9c  | 30b | 30d  | 3.09d | 5.40fg | 57.56cd | 121.70h | 6.93b | 28.77cd | 3159.28bc | 70.21bc |
| Pariposa-   | 106.0b | 33a | 79b | 11b | 33b | 39c  | 3.72cd | 6.18de | 60.08d | 61.90c | 5.29c | 68.35b | 3519.42b | 78.21b |
| TO-1057     | 104.0b | 33a | 80b | 11b | 33b | 47b  | 4.60ab | 6.73cd | 68.4ab | 58.10cd | 5.08c | 84.66a | 4572.62a | 101.62a |
| Srijana     | 176.0a | 33a | 78bc | 13a | 44a | 20e  | 4.90ab | 7.00bc | 70.22a | 40.50e | 4.96c | 58.88b | 2418.66cd | 53.74cd |
| Mean        | 98.0  | 31.78 | 78.5l | 9 | 29  | 38.04 | 3.96 | 6.32 | 62.67 | 66.70 | 5.37 | 52.66 | 2603.36 | 57.85 |
| p-value     | < 0.001 | <    | <    | <    | <    | <    | 0.035 | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| LSD (≤ 0.05) | 14.3 | 1.91 | 3.43 | 1.41 | 4.95 | 5.83 | 0.83 | 0.67 | 8.06 | 14.08 | 0.46 | 14.3 | 917.41 | 20.38 |
| CV%         | 9.05 | 3.75 | 2.72 | 6.53 | 7.34 | 9.53 | 13.09 | 6.65 | 13.72 | 13.12 | 5.36 | 16.68 | 21.9 | 21.9 |

Note: All the values are the mean. MFP = marketable fruit per plant, YP = yield (kg) per plant, FW = fruit weight, YTH = yield ton per hectare, FD = fruit diameter, IN = inflorescence number, PH = plant height, NH = number of harvest, HD = harvest duration, FPI = fruit number per inflorescence, FIPI = flower number per inflorescence, FS = fruit set percentage, DFF = days to fifty percent flowering, DFH = days to first harvesting. Means in the column followed by same letter (s) in each treatment do not differ significantly at (p ≤ 0.05) by DMRT

Tomato genotypes varied significantly for their ability to develop inflorescence, flowers and fruits. AVTO-9304 developed the highest (54) number of inflorescences per plant while Srijana had the least (20) which was at par with Florida-91 (23). Moreover, AVTO-9304 produce the highest number of flowers (8) and fruits (5) per inflorescence which is at par with TO-1057 and Srijana. Fruit setting ability was significantly higher in Srijana which was at par with TO-1057, AVTO-9304 and AVTO-1314.

Fruit diameter (cm), fruit weight (g) and fruit yield per plant (kg plant⁻¹) differed significantly among tomato genotypes (Table 1). Celebrity had the biggest fruit size of 7.54 cm diameter and its individual fruit weighed 158.94 g. Fruit size of AVTO-9801 and AVTO-9304 were small having diameter of 4.05 and 4.13 cm, respectively. TO-1057 produced the highest fruit yield of 101.62 t ha⁻¹ whereas AVTO-9802 provided the lowest fruit yield of 32.98 t ha⁻¹ combined over years.

1.2 Path Coefficient Analysis

Path coefficient analysis (Figure 1; Table 2) revealed that the high positive direct effect on yield per plant was noted for marketable fruit per plant (0.99) and average fruit weight (0.795) followed by plant height (0.392).
Inflorescences per plant also had direct positive (0.316) effect to yield per plant, however, it showed significant negative correlation. It was also observed that the negative direct effect were exerted by number of flowers (-0.185) and fruits (-0.115) per inflorescence. Some traits like fruit diameter, number of inflorescences per plant and marketable fruits per plant showed positive indirect effect via fruit diameter.

Table 2 Path coefficient showing direct (diagonal) and indirect effect (off diagonal) of different characters on fruit yield in tomato

| Traits | FW | FD | IN | PH | FPI | FPI | MFP | YP (r) |
|--------|----|----|----|----|-----|-----|-----|-------|
| FW     | 0.795 | 0.239 | -0.179 | 0.012 | 0.080 | 0.142 | -0.629 | 0.473 |
| FD     | 0.763 | 0.249 | -0.191 | 0.057 | 0.079 | 0.140 | -0.655 | 0.467 |
| IN     | -0.451 | -0.150 | 0.316 | -0.240 | -0.046 | -0.098 | 0.491 | -0.244*** |
| PH     | 0.025 | 0.036 | -0.194 | 0.392 | -0.015 | 0.016 | 0.035 | 0.315 |
| FPI    | -0.557 | -0.171 | 0.126 | 0.050 | -0.115 | -0.148 | 0.698 | -0.251 |
| FPI    | -0.609 | -0.163 | 0.155 | 0.014 | -0.080 | -0.185 | 0.713 | -0.332* |
| MFP    | -0.500 | -0.163 | 0.155 | 0.014 | -0.080 | -0.132 | 1.000 | 0.203 |

Note: Significance level for correlations: * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001

Table 3 Genotypic and phenotypic correlation coefficients (r values) among reproductive traits

| Traits | Cor. | MFP | YP | FW | FD | IN | PH | NH | HD | FPI | FPI | DFF |
|--------|-----|-----|----|----|----|----|----|----|----|-----|-----|-----|
| YP     | rg  | 0.203 |      |     |     |     |     |     |     |     |     |     |
|        | rp  | 0.292* | 0.473 |     |     |     |     |     |     |     |     |     |
| FW     | rg  | -0.708* |      | 0.461*** |     |     |     |     |     |     |     |     |
|        | rp  | -0.629*** | -0.679*** | 0.985*** |     |     |     |     |     |     |     |     |
| FD     | rg  | -0.750* |      | 0.467 |     | 0.629*** | 0.960*** |     |     |     |     |     |
|        | rp  | -0.655*** | -0.576*** | 0.443*** | -0.601*** | 0.856*** |     |     |     |     |     |     |
| IN     | rg  | 0.572 |      | -0.244 | -0.617 |     | -0.674* |     |     |     |     |     |
|        | rp  | 0.491*** | -0.178 | -0.567*** | -0.603*** |     |     |     |     |     |     |     |
| PH     | rg  | 0.046 |      | 0.315 | 0.022 | 0.136 | -0.709* |     |     |     |     |     |
|        | rp  | 0.035 | 0.295* | 0.032 | 0.144 |     | -0.463*** |     |     |     |     |     |
| NH     | rg  | 0.506 |      | 0.504 | -0.119 | -0.707 | -0.361 | 0.810*** |     |     |     |     |
|        | rp  | 0.466*** | 0.444*** | -0.114 | -0.070 | -0.339** | 0.749*** |     |     |     |     |     |
| HD     | rg  | 0.148 |      | 0.622 | 0.233 | 0.297 | -0.668 | 0.902*** | 0.914*** |     |     |     |
|        | rp  | 0.140 | 0.557*** | 0.231* | 0.284** | -0.619*** | 0.838*** | 0.877*** |     |     |     |     |
| FPI    | rg  | 0.866*** | -0.251 | -0.900*** | -0.915*** | 0.505 | 0.135 | 0.508 | 0.093 |     |     |     |
|        | rp  | 0.698*** | -0.117 | -0.709*** | -0.685*** | 0.397*** | 0.129 | 0.417*** | 0.073 |     |     |     |
| FPI    | rg  | 0.807*** | -0.332 | -0.843*** | -0.879*** | 0.641 | -0.102 | 0.294 | -0.115 | 1.000*** |     |     |
|        | rp  | 0.713*** | -0.229* | -0.766*** | -0.755*** | 0.529*** | -0.088 | 0.282* | -0.075 | 0.798*** |     |     |
| DFF    | rg  | -0.475 |      | 0.602 | 0.714* | -0.634 | 0.549 | 0.176 | 0.502 | -0.663** | -0.808** |     |
|        | rp  | -0.368*** | 0.437*** | 0.506*** | 0.610*** | -0.437*** | 0.504*** | 0.134 | 0.406*** | -0.487*** | -0.676*** | 0.736*** |
| DFH    | rg  | -0.518 |      | 0.610 | 0.852** | 0.877** | -0.578 | 0.185 | -0.007 | 0.341 | -0.791* | -0.886** | 0.874** |
|        | rp  | -0.433*** | 0.428*** | 0.685*** | 0.679*** | -0.376*** | 0.238* | -0.024 | 0.242* | -0.500*** | -0.685*** | 0.681*** |

Note: Significance level for correlations: * P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001; rg = genotypic correlation coefficient and rp = phenotypic correlation coefficient
1.4 GGE biplot for genotype-by-trait relationship

GGE biplot analysis for the discriminating and representativeness of traits (Figure 2) was carried out to find out more informative traits for the selection of genotypes. The analysis explained 80.74% of the total variation of the standardized data. It reflects the moderate complexity of the relationships among the measured traits. The first two principal components (PC1 and PC2) explained 49.70% and 31.04% of total variations, respectively. The polygon view of the GGE biplot (Figure 3) helps to identify genotypes with the highest values for one or more traits. The biplot in Figure 3 presents the data of nine genotypes in 13 different traits and the following information can be obtained: the vertex genotypes in this analysis are Srijana, Florida-91, AVTO-9802, AVTO-9801 and AVTO-9304. Treatments in the vertex are the best or the unsuitable treatments in some or all of the traits since they had the longest distance from the origin of biplot (Sabaghnia and Janmohammadi, 2016). Here, major yield traits NH, FS, PH, HD YTH and MFP are in that sector of the polygone where Srijana (vertex genotype), TO-1057 and Pariposa-4102 are exist. The vertex treatment Florida-91 was suitable for FW and FD while the vertex genotype AVTO-9801 was represented by IN and the other vertex genotypes were not represented by any traits. The arrow “Average environment axis” (Figure 2) showed that fruit setting percentage, number of harvest, plant height, harvest duration and yield t ha⁻¹ were more representative and traits like marketable fruits per plant and days to first flowering were less representative. Traits like inflorescence per plant and average fruit weight were least representative. A test environment that has a smaller angle with the AEA is more representative (Yan and Tinker, 2006).

Figure 1 Path diagram for the relationships between seven variables with yield per plant. X1 (FW), X2(FD), X3(IN), X4(PH), X5(FPI), X6(FIPI), X7(MFP) and Y (Yield per plant)

Figure 2 The discrimination and representation view of the GGE biplot to show the discriminating ability and representativeness of the traits
When biplot describes a sufficient amount of the total variation (here, 81%), the correlation coefficient between any two traits is approximated by the cosine of the angle between their vectors (Yan and Rajcan, 2002). The correlation coefficients among the traits indicate that the biplot currently shows relationship among the traits that had relatively large loading on both PC1 and PC2. Therefore, the most prominent relations by Figure 2 are: a strong positive correlation between FPI and MFP; between FS and NH; and between PH and HD; and between FD and FW; and between FPI and MFP as indicated by the acute angles between their vectors ($r = \cos 0 = +1$). The correlations between NH and DFH; FS and DFF were near zero (Figure 2) as indicated by the near perpendicular vectors ($r = \cos 90 = 0$). There was a negative correlation between MFP and FW, and between IN and YTH as indicated by obtuse angle. Most of the mentioned results can be verified using original correlation coefficients (Table 2).

### 1.5 Clustering of genotypes

The cluster analysis grouped nine genotypes into four clusters (Figure 4; Table 4). Cluster-IV comprised of three genotypes and other three clusters comprised of two genotypes each. The genotypes in cluster-I were observed with short stature, higher number of cluster/plant, number of flowers/cluster, earlier in flowering and first harvest as compared to all other genotypes of cluster-II, III and IV (Table 4). The genotypes with low vegetative growth are early ripening. The genotypes of second group had average values for all studied traits. The genotypes in cluster-III had bigger fruits with higher fruit weight. The genotypes of Cluster-IV were taller plants, more flowers per inflorescence, higher fruit set percentage with higher marketable fruits per plant contributing more yield per plant and per unit area.
Table 4 Mean comparison of different characters of tomato genotypes in cluster analysis

| Cluster | MFP  | YP    | FW    | YTH   | FD   | IN   | PH   | NH   | HD   | FPI  | FIPI | FS   | DFF  | DFH  |
|---------|------|-------|-------|-------|------|------|------|------|------|------|------|------|------|------|
| 1       | 67.7 | 1572.8| 26.3  | 35.0  | 4.1  | 51   | 64.9 | 8    | 21   | 5    | 8    | 60.7 | 28   | 74   |
| 2       | 37.7 | 1699.2| 53.3  | 37.8  | 5.2  | 41   | 88.2 | 7    | 20   | 4    | 6    | 63.1 | 33   | 79   |
| 3       | 25.6 | 3187.8| 140.3 | 70.8  | 7.2  | 27   | 95.8 | 9    | 31   | 3    | 5    | 58.8 | 33   | 82   |
| 4       | 70.6 | 3503.6| 53.5  | 77.9  | 5.1  | 35   | 128.7| 11   | 37   | 4    | 7    | 66.2 | 33   | 79   |

2 Discussion

Yield is complex character controlled by many interrelated factors with negative and positive effects that contributes to marketable yield (Mohamed et al., 2012; Walia et al., 2018). In this study, genotype TO-1057 stood out among the others for having a higher estimated fruit production per plant and area. This genotype had the highest number of marketable fruits per plant. It also in the group of genotypes that had higher number of fruits per inflorescence along with AVTO-9304 and Srijana. Marketable fruits per plant is a major contributing traits for yield per plant in tomato. Florida-91 and Celebirty had bigger sized fruits but they did not produced the highest yield because of fewer number of fruits per plant. In contrast, Genotype AVTO-9304 had the highest number of inflorescence per plant, flowers and fruits per inflorescence, did not have the highest yield. It might be attributed to smaller fruit size. Flowers per inflorescence was significantly and positively associated with fruits per inflorescence but negatively associated with fruit weight, fruit diameter and locule number per fruit (Ullah et al., 2015). The results of the present study clearly indicated that to maximize the yield we have to select genotypes with higher marketable fruits with medium sized fruits. In contrast to our result, a study conducted in Rajasthan, India reported TO-1057 produced only 2.62 kg plant⁻¹ marketable yield from poly-house condition (Singh et al., 2020). It strongly recommends for the environment specific genotype selection. Additionally, TO-1057 is one of the least preferred genotypes by white fly (Rehman et al., 2020).

Fruit set percentage is one of the major traits for selection of genotypes under heat stress. It is observed that anthesis that took place after 3rd week of March affected by high temperature (Figure 1). Srijana, TO-1057, AVTO-9304 and AVTO-1314 had higher fruit set percentage. Besides having higher number of inflorescences per plant and fruit set percentage, determinate varieties did not produce high yield. Xu (2017) reported that long term moderate heat stress affects pollen viability, fruit set, flower number per inflorescence but number of inflorescences per plant remain unaffected. Based on the fruit set percentage and corresponding yield per plant, TO-1057 and Srijana were tolerant to high temperature.

Results of path coefficient analysis suggested that marketable fruits per plant and average fruit weight were major contributing traits for yield per plant. In our study, TO-1057 produced the highest yield because of more marketable fruits per plant. Path analysis indicated number of fruits per plant and single fruit weight had the highest positive direct effect on yield and direct selection for these traits is possible (Bojarian et al., 2019).

In most of the cases genotypic and phenotypic correlation coefficients were of the same directions but the former were slightly higher in magnitude indicating low influence of environments that enhanced the acceptance of these findings (Sharmin et al., 2019). The correlation study revealed that MFP is important to increase the productivity of tomato genotypes. TO-1057 produced significantly highest fruit yield had the highest number of marketable fruits per plant with medium sized fruits (Table 1). The positive correlation of FW and FD with YP but negative correlation with MFP indicates that number of fruits per plant decreased when the size of the fruits increased. In our study, Florida-91 and Celebrity had large fruit size but they ranked 3rd and 4th positions, respectively for yield per plant. Based on the correlation and ANOVA results, genotypes with medium size fruits could be suitable for maximum productivity under Chitwan, condition of Nepal. This result is in accordance with earlier findings (Reddy et al., 2013; Rajolli et al., 2017; Bojarian et al., 2019). We had used only one indeterminate genotype which was pruned to two stem system that did not let to produce many inflorescences.

Harvest duration had strong positive correlation with yield per plant. Low productivity among Asian Vegetable Research and Development Centre (AVRDC) genotypes could be due to short harvest duration. IN, FIPI and FPI
had positive correlation with YP but negatively associated with MFP was due to the only consideration of MFP rather than total fruits per plant. FlPI and FPI had positive correlation with IN but negatively correlated with fruit set percentage indicates that high ambient temperature might have affected the fruit set.

GGE biplot analysis suggested that genotype Srijana is one of the important genotype for consideration. The traits like number of harvest, plant height and harvest duration had high discriminating power and genotype Srijana on the vertex of the polygon. The result of which-won-where indicates that Srijana is suitable genotypes because genotypes located on the vertices of the polygon performed either best or the poorest in one or more environments (Yan and Tinker, 2006). The cumulative effect of number of harvest, plant height and harvest duration along with fruit setting percentage was observed in Srijana, TO-1057, Pariposa-4102. These traits shares smaller angle with ‘the Average-Environment Axis’. Yan and Tinker (2006) reported that a test environment that has smaller angle with the AEA is more representative and discriminating but non-representative test environments are useful for selecting specifically adapted genotypes if the target environments can be divided into mega-environments (Yan and Tinker, 2006).

The result of clustering of morphological traits grouped these nine genotypes according to their origin. Group I and II were originated in Taiwan, Group III in the USA and, in group IV, Srijana was developed in Nepal while TO-1057 and Pariposa-4021 were developed in India. Moreover, these three genotypes developed in the similar geographical region. Clustering of genotypes suggested that TO-1057, Pariposa-4102 and Srijana are suitable genotypes for cultivation in summer season. These three genotype also shares geographical similarities in their origin.

Yield is the major criteria for genotype selection. It is even more important when farmers are cultivating crops in heat stress condition. TO-1057 produced the highest marketable fruit yield therefore, it could the first choice for cultivation. The cumulative effect of traits suggests that the genotype Srijana is another potential genotype. Srijana is indeterminate genotype and we kept two stems in Srijana to manage its growth habit while other genotypes kept unpruned. It is expected that the more the branch number in a plant, such plant would be able to produce more fruits resulting in more fruit weight (Singh and Raj, 2004). Negative association of fruit yield with flower and fruit per inflorescence and positive correlation with fruit diameter and plant height indicates that genotypes with medium sized fruit with semi-determinate or indeterminate growth habits are suitable under natural heat stress conditions of Nepal.

3 Materials and Methods
3.1 Site description
This study was conducted during dry summer seasons of 2018 and 2019 at the research field of Department of Horticulture, Agriculture and Forestry University (27°39'23.6"N, 84°21'26.8"E) Nepal (Figure 5) at an altitude of 256 meter above sea level. Climatically the site is characterized by sub-tropical conditions with an annual precipitation of 1372.70 mm, a mean annual temperature 24.6°C and mean relative humidity of 84.9 %. The maximum daily ambient temperature rose above 20°C which reached to critical temperature point of 32°C in third week of March (Figure 6). Later, in 3rd week of April onward, it was around 35°C., however, the optimum temperature for growth and yield in tomato is 21~24 °C (Table 5). The recorded rainfall during the crop period was 445.25 mm. The soil of the experimental area was sandy loam in texture having good fertility with 5.46 pH. Soil of the experimental plot was solarized with 100 gauge white plastic for two months.

3.2 Experimental material and design
The experiment comprised of nine tomato genotypes. Of them, three were determinate type (AVTO-9304, AVTO-9801, and AVTO-9802) while five were semi-determinate type (Florida-91, Celebrity, Pariposa-4102, AVTO-1314, and TO-1057) and one standard check (Srijana) was indeterminate. The experiments was carried out in a Randomized Complete Block Design (RCBD) with four replications. Seedlings were raised in plug trays filled with potting mixture. Seedlings of 34 days old were transplanted in the 1st week of February at the spacing of 75 cm x 60 cm for consecutive years of 2018 and 2019.
Figure 5 Location of experimental area (A = Map of Nepal, B= Province-3, C= Chitwan District, D= AFU, Rampur, E = Department of Horticulture)

Figure 6 Mean ambient temperature (°C) during crop growing season

Table 5 The effect of temperature on flowering, pollination, fruit set and colour development in tomato

| Temperature (°C) | Effect on flowering, pollination, fruit set and colour development |
|------------------|---------------------------------------------------------------|
| Below 10°C       | Fruits are unable to develop red colour                      |
| 10°C - 20°C      | Optimum for good colour development                          |
| Below 18°C day and 12°C night | Chilling injury and low fruit setting                      |
| 21°C             | Optimum for pollination                                     |
| 25°C day and 18°C night | Best for flowering and fruit setting                   |
| Above 30°C       | Red colour start to disappear and fruits become yellowish red colour |
| Above 32°C day and 22°C night | Affect fruit set adversely                          |
| Above 40°C       | Lycopene is completely destroyed                             |

Note: Adapted from Solankey et al. (2018)

The recommended dose of farm yard manure (FYM) i.e. 30 t ha\(^{-1}\) and 150:100:100 N:P\(_2\)O\(_5\):K\(_2\)O kg ha\(^{-1}\) was applied. Half dose of N and full dose of P\(_2\)O\(_5\) and K\(_2\)O along with Borax 10 kg ha\(^{-1}\) and Zinc Sulphate 50 kg ha\(^{-1}\), respectively was applied as basal dose. The half of recommended dose of nitrogen was applied in two split doses as top dressings on 30 and 60 days after transplanting. Nitrogen and phosphorus was supplied through Di-Ammonium Phosphate (DAP) containing 18%N and 46%P\(_2\)O\(_5\), remaining dose of nitrogen was supplied through urea containing 46%N and
potash was supplied through Muriate of Potash (MoP) containing 60% K₂O. Weeding was carried out manually and irrigation was applied as per crop requirement.

3.3 Data collection and analysis
The data of each genotype were taken as per DUS guidelines of tomato from the middle 5 plants leaving plants on either ends of the row to avoid the border effects. Individual plants as well as plot base data were collected for plant height, flowering and fruiting traits and final yield. Analysis of variance for the pooled data of evaluated traits were carried out using Statistical Tool for Agricultural Research (STAR, Version 2.0.1, 2014) software. The level of significance used in 'F' test was $p \leq 0.05$. When the treatment effects were found significant, means were separated using Duncan’s Multiple Range Test (DMRT). Major seven variables; FW-fruit weight (g/fruit), FD-fruit diameter (cm), IN-inflorescence number, PH-plant height (cm), FPI-number of fruits per inflorescence, FIPI-number of flowers per inflorescence, MFP-marketable fruits per plant, YP-yield per plant (kg/plant) were considered for path analysis. Direct effect and indirect effect via fruit weight and indirect effects of all variables on yield was calculated using (LISREL 8.80 Student Edition, 2006). Genotypic correlation coefficient was measured for different traits for detecting the intensity and direction of association among the characters using META-R (Version 6.0, CIMMYT, 2016). GGE Biplot was developed using RStudio (Version 1.3.1056 © 2009-2020 RStudio, PBC, Open source). Cluster analysis was done for grouping genotypes using the Ward’s method by Microsoft Excel, XLSTAT Version 2020.1.10 (http://www.xlstat.com).

4 Conclusion
Higher fruit yield than the national average productivity of tomato (19.3 t ha⁻¹) concluded that the tested genotypes possess the heat tolerant ability. Likewise, in terms of productivity, TO-1057 showed the highest level of heat tolerance. Srijana was identified as heat tolerant genotype because of its highest fruit setting percentage. Due to longer harvest duration and continuous growth habit, Srijana would be suitable for dry summer season. Therefore, TO-1057 and Srijana are recommended for plains of Chitwan. It is concluded that with high temperature tolerance genotypes, tomato production under natural heat stress is possible in plains of Chitwan. However, genotype selection is a continuous process, so further research including more heat tolerant genotypes is recommended.

Authors' contributions
T. R. Chapagain designed and carried the experiment in the field. He completed data analysis and the writing of the first draft of the paper. A. K. Shrestha is the key person who guide the experiment, data analysis and paper writing. M. D. Sharma, A. Srivastav and K. M. Tripathi guided during experiment and revision. All authors read and approved the final manuscript.

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