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Effect of Spacing and Training on Vegetative Growth Characteristics and Yield of Tomato (*Solanum lycopersicum* L.) Grown in Polyhouse

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An experiment was carried out to study the effect of spacing and training on vegetative growth characteristics and yield of tomato under polyhouse. The experiment was comprised of four levels of spacing and three levels of training with Factorial Completely Randomized Design. The experimental results revealed that maximum plant height (241.18 cm), stem diameter (7.42 cm), number of branches per plant (26.67), leaf area (325.84 cm^2), number of clusters per plant (18.63), number of fruits per cluster (6.31), number of fruits per plant (112.44), fruit weight (106.93 g), volume of fruit (110.70 cc), specific gravity (0.97gcm^3) and yield per plant (12.07 kg) were recorded on wider spacing S_4 (60 x 60 cm). The maximum stem diameter (7.36 cm), number of branches per plant (24.53), number of clusters per plant (15.93), total yield per plant (8.48 kg) and yield per square meter (20.96 kg) were exhibited by T_3 (triple stem training). The maximum yield per square meter was observed in interaction S_2T_3 (45 x 45 cm, triple stem). while number of branches per plant (30.33), number of clusters per plant (19.67), number of fruits per cluster (6.77), number of fruits per plant (125.87) and total yield per plant (12.88 kg) were observed in treatment combination S_4T_2 (60 x 60 cm, double stem training).

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops in the India. It belongs to family Solanaceae with diploid chromosome number (2n=24) and is a typical self-pollinated day neutral plant. Tomato has originated from South America (Mexico and Peru). In tomato there are two types of growth habit have been found *viz.*, determinate (generally grown under open field condition) and indeterminate (normally grown under poly house condition). It is cultivated in both temperate and tropical regions of the world. It is consumed in a various ways like fresh in salads and sandwiches, cooked or processed in ketchup, sauces, paste, puree, juices or dried powder. Tomato plays an important role in human nutrition by providing essential amino acids, vitamins and minerals (Sainju *et al.*, 2003) and it is considered a protective food because of its particular nutritive value, as it provides important nutrients such as lycopene, beta-carotene, flavonoids, vitamin 'C' and hydroxycinnamic acid derivatives. Furthermore, this crop has achieved tremendous popularity especially in recent

years with the discovery of lycopene's anti-oxidative activities and anti-cancer functions (Wu *et al.,* 2011; Raiola *et al.,* 2014). Edible portion of tomato contains energy 18 kcal, protein 0.95 g, fat 0.11 g, carbohydrate 4.01 g, total sugar 2.49 g, Ca 11.0 mg, Fe 0.68 mg, Mg 9.0 mg, P 28.0 mg, K 218.0 mg, Na 11.0 mg, Zn 0.14 mg, thiamin 0.036 mg, riboflavin 0.022 mg, carotene (Vit. A) 320 IU, vitamin B 60.079 mg, ascorbic acid 31mg per 100 g pulp of fruit. The cultivation of vegetables under polyhouse is increasing in the state. In polyhouse, microclimate surrounding the plant is controlled partially or fully, as per the requirement of the plant species (Mishra *et al.,* 2010). In this study the main emphasis was given on appropriate cultural practices such as plant densities and training systems in order to enhance the production per unit area by utilizing the available space and utilization of the resources.

Materials and Methods

To assess effect of spacing and training on vegetative growth characteristics and yield of tomato grown under polyhouse an experiment was laid out at Hi-Tech Horticulture Unit, Department of Horticulture, Rajasthan College of Agriculture, Udaipur (Rajasthan) during August, 2015 to March, 2016. The size of the polyhouse was 28 m × 32 m (896sq.m) covered with aluminate sheet and ultra violet stabilized low density polyethylene sheet having 200 micron thickness. The experiment was comprised of four levels of spacing, *i.e*., 45 cm × 30 cm (S_1), 45 cm × 45 cm (S_2), 45 cm× 60 cm (S_3) and 60 cm × 60 cm (S_4) and three levels of training, *viz*., single stem (T_1), double stem (T_2), triple stem (T_3). The seedlings were raised on soil-less media (mixture of vermiculite, perlite and cocopit) in plug tray having cells of 2" in size. Four week old seedlings at 4-5 true leaf stage were transplanted at 45 x 30 cm, 45 x 45 cm, 45 x 60 cm and 60 x 60 cm according to different treatment combinations. Beds were irrigated when necessary during the growing season. Fertilizers were applied @ 200: 120: 120 kg NPK ha^{-1}, respectively along with micronutrient for raising healthy crop. All the management practices including hoeing; weeding and other horticultural operation were performed. Insecticide and fungicide spray were applied whenever it appeared necessary throughout the growing season. Plants were vertically trained with single stem (T_1), double stem (T_2), triple stem (T_3) per plants as per treatment combinations. The observations on plant height (cm), stem diameter (cm), number of branches per plant, leaf area (cm^2), days to first harvesting, number of clusters per plant, number of fruits per cluster, number of fruits per plant, fruit weight (g), fruit diameter (cm), volume of fruit (cc), specific gravity (g/cm^3), total yield per plant (kg) and yield per square meter (kg) were recorded from five randomly selected plants of each replication.

The plant height was measured in centimeter from the ground level to extreme growing tip of the main stem with the help of meter scale at the time of final harvest. Stem diameter was measured in centimeter at 2 cm above the ground level of plant and diameter of stem was measured with the help of vernier calipers at the stage of final harvesting. Total number of branches of individual plants was counted at the stage of final harvesting. Leaf area per plant was determined using leaf area meter, LICOR-3100 USA. Leaf area was measured at the time of final harvesting and expressed as cm^2. The days from the date of transplanting to the date of first harvesting in each treatment were recorded. The difference of the date of transplanting and date of first harvesting was calculated for the number of days required for harvesting. Total number of clusters per plant was counted on plants and averages were computed. Total number of fruits per cluster was counted from randomly

selected 10 clusters on all the five tagged plant and average was calculated. The number of fruits was counted separately on the five randomly selected plants on each date of harvest till all the fruits were harvested. Then average number of fruits per plant was calculated after dividing total number of fruit by five. Randomly selected five fruits in each treatment were weighed with the help of digital balance and the mean weight of fruit was calculated and expressed in gram. Same five fruits were used for measuring fruit diameter. The diameter of the fruit was measured with the help of vernier callipers in centimeter and average was calculated. Same five fruits which were used for recording weight of fruits were used for measuring fruit volume. Volume was measured by water displacement method. For this purpose, fruits were dipped in a full filled jar of water and the water displaced by the fruits was collected and measured by graduated glass jar and average volume of fruit was calculated. **S**pecific gravity of the fruit was worked out by dividing the weight of the fruit by the volume of the same fruit and was expressed as gram per cubic centimeter. The fruits harvested from five tagged plants were weighed separately with the help of digital balance on each harvest and sum total of each harvesting was computed for getting total yield per plant and expressed in kg. The yield of fruits per square meter was calculated by multiplying the average yield of plant and number of plants per square meter and expressed in kilogram per square meter.

Results and Discussion

Data (Table-1) reveled that maximum plant height (241.18 cm), stem diameter (7.42 cm), number of branches per plant (26.67) and leaf area (325.84 cm^2) were recorded at widest spacing *i.e.* treatment S_4 (60 cm x 60 cm) compared to others. This may be due to the availability of more space for individual plant growth, more leaf area, ample sun light and aeration under wider spacing. These findings were in conformity with the work of Bhattarai *et al.,* (2015) and Singh and Kumar (2005) in cherry tomato. Among the method of training, the maximum stem diameter (7.36 cm) and number of branches per plant (24.53) were recorded in treatment T_3 (triple stem training). These results are in accordance with the findings of Jovicich *et al.,* (1998) in sweet pepper grown in polyhouse. While maximum leaf area (319.72 cm^2) was recorded in treatment T_1 (single stem), the lowest day to first harvesting was also recorded in treatment T_1 (single stem). The present results are supported by the findings of Hesami *et al.,* (2012) in semi determinate tomato. Among the treatment combinations, maximum number of branches per plant (30.33) was observed in S_4T_3 (60 cm × 60 cm and triple stem), while lowest days to first harvesting (83.00) was observed in S_1T_1 (45 cm × 30 cm and single stem). Similar results were also recorded by Ara *et al.,* (2007) in tomato.

The plant spacing significantly influenced yield attributed characters in tomato. Data (Table-2) revealed that maximum number of clusters per plant (18.63) and number of fruits per plant (112.44) was reported at widest spacing, S_4 (60 cm × 60 cm) as compared to lowest in S_1 (45 cm × 30 cm). This might be due to more fruit set, more photosynthesis as it produces more plant height at wider spacing. Similar trend was observed by Mantur and Patil (2008), Bhattarai *et al.,* (2015) and Rajendra *et al.,* (2013) in tomato. Maximum number of fruits per cluster (6.31) at wider spacing S_4 (60 cm x 60 cm) and minimum in close spacing (45 cm x 30 cm). These findings are in accordance with the findings of Rajendra *et al.,* (2013) in tomato and Singh and Kumar (2005) in cherry tomato. The maximum fruit weight (106.93 g) and yield per plant (12.07 kg) was observed at widest spacing treatment, S_4 (60 cm x 60 cm).

Table.1 Effect of spacing and training on plant height, stem diameter, number of branches per plant, leaf area, days to first harvesting in polyhouse grown tomato

Treatment	Plant height (cm)	Stem diameter (cm)	Number of branches per plant	Leaf area (cm^2)	Days to first harvesting
Spacing (S)					
S_1 (45x30 cm)	188.38	6.86	16.64	302.23	84.56
S_2 (45x45 cm)	217.70	7.14	21.16	313.09	86.33
S_3 (45x60 cm)	235.90	7.25	24.02	318.07	85.11
S_4 (60x60 cm)	241.18	7.42	26.67	325.84	85.78
SEm±	5.197	0.062	0.144	1.449	0.617
CD at 5%	15.169	0.180	0.421	4.229	NS
Training (T)					
T_1	229.06	6.97	18.63	319.72	84.33
T_2	215.83	7.18	23.20	317.25	86.25
T_3	217.48	7.36	24.53	307.46	85.75
SEm±	4.501	0.053	0.125	1.255	0.534
CD at 5%	NS	0.156	0.364	3.663	1.560
Interaction (S x T					
S_1T_1	202.54	6.55	15.00	306.71	83.00
S_1T_2	166.11	6.79	17.07	304.07	86.00
S_1T_3	196.50	7.23	17.87	295.92	84.67
S_2T_1	226.67	6.99	18.80	316.69	87.00
S_2T_2	218.74	7.19	21.73	315.86	86.00
S_2T_3	207.67	7.26	22.93	306.71	86.00
S_3T_1	240.65	7.08	20.07	323.28	84.33
S_3T_2	234.97	7.32	25.00	318.09	84.00
S_3T_3	232.08	7.36	27.00	312.83	87.00
S_4T_1	246.40	7.26	20.67	332.18	83.00
S_4T_2	243.48	7.42	29.00	330.97	89.00
S_4T_3	233.67	7.59	30.33	314.38	85.33
SEm±	9.001	0.107	0.250	2.510	1.069
CD at 5%	NS	NS	0.7290	NS	3.1202

Table.2 Effect of spacing and training on number of clusters per plant, number of fruits per cluster, number of fruits per, fruit weight, fruit diameter, volume of fruit, specific gravity, total yield per plant and yield per square meter in polyhouse grown tomato

Treatment	Number of clusters per plant	Number of fruits per cluster	Number of fruits per plant	Fruit weight (g)	Fruit diameter (cm)	Volume of fruit (cc)	Specific gravity (g/cm^3)	Total yield per plant (kg)	Yield per square meter (kg)
Spacing (S)									
S_1(45x30cm)	12.28	3.79	46.10	80.09	10.70	84.13	0.95	3.50	15.54
S_2(45x45 cm)	15.08	5.22	76.13	93.85	11.26	97.93	0.96	6.89	20.42
S_3(45x60 cm)	16.37	5.68	90.03	98.11	12.41	102.16	0.96	9.61	21.35
S_4(60x60 cm)	18.63	6.31	112.44	106.93	11.99	110.70	0.97	12.07	20.11
SEm±	0.167	0.136	1.003	0.308	0.106	0.399	0.003	0.104	0.228
CD at 5%	0.488	0.397	2.927	0.899	0.310	1.164	0.009	0.302	0.667
Training(T)									
T_1	14.94	4.95	72.15	96.91	11.67	100.52	0.96	7.14	16.97
T_2	15.89	5.50	86.59	94.84	11.65	99.18	0.96	8.43	20.13
T_3	15.93	5.30	84.78	92.48	11.46	96.49	0.96	8.48	20.96
SEm±	0.145	0.118	0.868	0.267	0.092	0.345	0.003	0.090	0.198
CD at 5%	0.423	0.344	2.535	0.779	NS	1.008	NS	0.262	0.578
Interaction (S x T)									
S_1T_1	12.53	3.10	37.65	82.11	11.50	85.04	0.97	3.15	14.00
S_1T_2	12.33	3.67	45.27	79.60	10.42	84.27	0.94	3.30	14.68
S_1T_3	11.97	4.60	55.37	78.55	10.19	83.08	0.95	4.04	17.95
S_2T_1	14.03	5.03	64.93	95.52	11.25	99.35	0.96	5.49	16.25
S_2T_2	14.93	5.43	79.49	93.93	11.28	98.33	0.96	7.27	21.54
S_2T_3	16.27	5.20	83.97	92.09	11.25	96.10	0.96	7.92	23.46
S_3T_1	15.83	5.17	78.28	101.67	12.09	105.43	0.96	8.02	17.82
S_3T_2	16.63	6.13	95.75	99.67	12.63	104.52	0.95	10.28	22.84
S_3T_3	16.63	5.73	96.06	93.00	12.52	96.54	0.96	10.52	23.38
S_4T_1	17.37	6.50	107.73	108.33	11.83	112.28	0.96	11.89	19.80
S_4T_2	19.67	6.77	125.87	106.17	12.25	109.57	0.97	12.88	21.46
S_4T_3	18.87	5.67	103.73	106.29	11.90	110.24	0.96	11.44	19.07
SEm±	0.290	0.236	1.737	0.533	0.184	0.690	0.005	0.179	0.396
CD at 5%	0.8456	0.6881	5.0692	1.5571	0.5361	2.0153	NS	0.5237	1.1551

The similar findings were reported by Biradar *et al.*, (2014) in capsicum, Harish and Patil (2011) and Sharma *et al.*, (2011) in tomato. Maximum average fruit diameter (12.41 cm) was observed in wider spacing, S_3 (45 cm x 60 cm). Similar results were obtained in tomato by Bhahadur and Singh (2005). The highest yield per m^2 (21.35 kg) was obtained in treatment S_3 (45 cm × 60 cm) followed by 20.42 kg per m^2 in treatment S_2 (45 cm × 45 cm). It might be due to effective utilization of land, nutrients and sunlight. The results are in conformity with findings of Mantur and Patil (2008), Dasgan and Abak (2003) and Cebula (1995). The maximum specific gravity (0.97 g/cm^3) and volume of fruit (110.70 cc) were recorded in wider spacing *i.e.* S_4 (60 cm x 60 cm). The present results are supported by the findings of Muhammad and Singh (2007) in tomato.

Among the method of training, the maximum number of clusters per plant (15.93), total yield per plant (8.48 kg) was observed in T_3 (triple stem) and lowest (7.14 kg) in T_1 (single stem), whereas maximum fruit weight (96.91g) in T_1 (single stem) this observation was in close conformity with the results of Khoshkam *et al.,* (2014) and Razzak *et al.,* (2013) in tomato and Lal *et al.,* (2014) in capsicum. The maximum number of fruits per plant (86.59) and number of fruits per clusters (5.50) was observed in T_2 (double stem), these findings of the present investigation are in conformity with findings of Dasgan and Abak (2003) in bell peppers. The fruit diameter and specific gravity showed non-significance results. But the volume of fruit was significantly affected by training level with maximum volume of fruit (100.52 cc) in T_1 (single stem). The present results are supported by the findings of Muhammad and Singh *et al.,* (2007) in tomato. Maximum yield per square meter (20.96 kg) was observed in T_3 (triple stem), which was at par with T_2 (double stem). The present results are supported by the finding of Mazed *et al.,* (2015) and Alsadon *et al.,* (2013) in tomato. Among all the treatment combinations, S_4T_2 (60 cm x 60 cm and double stem) showed maximum number of clusters per plant (19.67), number of fruits per cluster (6.77) and total yield per plant (12.88 kg), while S_4T_1 (60 cm x 60 cm and single stem) showed maximum fruit weight (108.33 g) and maximum fruit diameter (12.63 cm) was reported in S_3T_2 (60 cm x 45 cm and double stem). Similar results were also recorded by Mantur and Patil (2008) in tomato, Dasgan and Abak (2003) in peppers, Lal *et al.,* (2014) in capsicum, Charlo *et al.,* (2007) in cherry tomato, Ara *et al.,* (2007) in indeterminate tomato. Maximum number of fruits per plant (125.87) was noticed in S_4T_2 (60 cm x 60 cm and double stem) treatment combination and minimum (37.65) in S_1T_1 (45 cm x 30 cm and single stem) treatment combination. Similar results were reported by Kumar and Chandra (2014) in capsicum. The maximum volume of fruit (112.28 cc) observed in S_4T_1 (60 cm x 60 cm and single stem) treatment combination. Similar finding was quoted by Ameta *et al.,* (2014) in capsicum. The maximum yield per square meter (23.46 kg) was recorded in S_2T_3 (45 cm x 45 cm and triple stem), this trend of interaction effect was also reported by Maniutiu *et al.,* (2010).

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