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Influence of Plant Density *vis-à-vis* Architecture on Growth Parameters *Bt* Cotton (*Gossypium hirsutum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment entitled "Influence of plant density *vis-à-vis* architecture on *Bt* cotton (*Gossypium hirsutum* L.) yield and quality parameters" was carried out on sandy loam soil at College farm, College of Agriculture, PJTSAU, Rajendranagar, Hyderabad during 2021-22. The experiment was laid out in split plot design with three replications. Results revealed that plant densities, plants sown under planting density of 90 x 20 cm (55,555 plants ha^{-1}) recorded highest growth contributing characters such as plant height, dry matter production, first fruiting node length, internode length and height node ratio. Planting density of 90 x 30 cm (37,037 plants ha^{-1}) has recorded significantly higher number of sympodial branches and no of nodes per plant during 2021 and 2022 and pooled mean. Length of fruiting branches from node 5 to 15, length of fruiting branches from node 15 to terminal, length of all fruiting branches, distance from main stem to first boll position from node 5 to 15, distance from main stem to first boll position from node 15 to terminal, distance from main stem to first boll position of all fruiting branches, internode diameter, days to initiation of sympodial branches, days to square initiation, days to 50% flowering, days to boll formation, days to boll

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bursting stage were found to be highest in plants spaced at 90 x 60 cm (18,518 plants ha^{-1}) during two years of study and pooled mean. Interaction was found to be significant on drymatter production at 120 DAS and found highest in treatment combination of semi open plant type (Sadanand) and 90 x 20 cm (55,555 plants ha^{-1}) during 2021 and 2022 and pooled mean. Number of monopodial branches and days to initiation of monopodial branches were showed non-significant results.

Keywords: Monopodial; fruiting branches; height node; height node.

1. INTRODUCTION

Cotton crop in India provides direct livelihood to 6 million farmers and textile industry consumes 60% of country's total fibre production. India is the largest producer of cotton and occupies second position in exporting and consumption in the world. In India, Cotton is grown in three different agro - ecological zones *viz.,* Northern, Central and Southern zone. Nearly 70 per cent of the crop is cultivated under rainfed conditions in the Central and Southern regions of the country. India occupies an area of 13 m ha with production of 365 lakh bales (170 kg of each bale) and productivity being 459 kg ha^{-1}. Among the cotton growing states, Maharashtra is the largest producer with an area of 38.06 lakh ha followed by Gujarat (24 lakh ha) and Telangana (21.14 lakh ha).

Cotton production in India is caught up by low productivity due to various challenges such as rainfed conditions, small farm size, low yielding cultivars, optimum plant population, fertilizer application, increasing pests, diseases etc. Planting density and choice of cultivar are important agronomic practices that have the potential to optimize the canopy photosynthetic rate and crop productivity of any cropping system [1]. Plant canopy architectural attributes such as size, shape, and orientation of shoot components are of major agronomic importance and greatly influence crop resistance to pests and diseases, adaptability, plant density requirements, ease of harvest, and yield potential [2]. Differences in canopy architectural attributes among varieties impact cotton growth, lint yield and management.

The response of varieties with contrasting plant architecture to planting densities has important implications to cotton crop management decisions such as seeding rates. Reductions in seeding rates are gaining traction due to high seed costs and technology fees associated with transgenic cotton varieties coupled with increased adoption of seed treatments for disease, insect, and nematode control [3]. The consequent reduction in plant density may have implications for variety selection and crop management due to modifications in plant architectural traits. Cotton plant architecture is a hereditary character that can be modified by selection [4]. However, agronomic studies on the effects of the wide ranging plant architectural attributes on cotton growth, yield potential, and crop management are limited [5]. Manipulations of planting density in cotton have significant impacts on biomass partitioning, nutrient uptake, boll distribution, boll weight, lint yield, changes in the light spectrum, and crop production, which can influence yield of cotton. Thus productivity can be increased by increasing plant population per hectare *i.e* high density planting. Plants at high density can minimize evaporation and irrigation frequency, as well as increase the utilization of irrigation water. Optimal plant density can ensure healthy plant development by maintaining a core population of plants synchronizing boll number and fibre quality to achieve optimal yield [6]. Farmers in Telangana state cultivate cotton hybrids with spacing of either 90×60cm or 90×30cm without exploring full potential of suitable plant architect based density, which is essentially an important low cost agro production strategy to enhance cotton yields. To assess the optimal planting density combined with plant canopy variations an attempt has been made to study influence of cotton plant densities *vis-a vis* plant architectural traits on growth and yield potential in telangana region.

2. MATERIALS AND METHODS

The experiment on "Influence of plant density *vis-à-vis* architecture on *Bt* cotton (*Gossypium hirsutum* L.) yield and quality parameters" was conducted during *kharif* season of two consecutive years (2021 and 2022) to find out the influence of various plant densities and different plant types of *Bt* cotton on yield and quality at college farm, Professor Jayashankar Telangana State Agricultural University, College of Agriculture, Rajendranagar, Hyderabad situated at an altitude of 542.3 m above mean sea level at 17°19' N latitude and 78°23' E longitude. It is in the Southern Telangana agro-climatic zone of Telangana state. The soil analysis resulted that the texture of the soil is sandy loam with slightly alkaline in nature and having organic carbon upto 0.52 during 2021 and 0.51 during 2022.The initial soil analysis resulted that available nitrogen is low (201.9 kg ha^{-1}), available phosphorous is high (20.5 kg ha^{-1}) and available potassium is medium (370.5 kg ha^{-1}) during the year 2021. Whereas, during 2022 the available nitrogen is low (197 kg ha^{-1}), available phosphorous is high (21.2 kg ha^{-1}) and available potassium is medium (361.2 kg ha^{-1}).The average weekly maximum temperature during crop growing period was 29.4°C (2021) and 29.4°C (2022). The weekly mean minimum temperature was 19.9°C (2021) and 18.6°C (2022). Total rainfall of 504.6 mm was received during 2021 in 30 rainy days and 673.2 mm during 2022 in 40 rainy days, respectively.

The statistical design adopted for the experimentation was Split Plot design, with four replications and nine treatment combinations. The main plots were three plant types *viz.,* P_1: Compact type *Bt* cotton with Siri (Nuziveedu) hybrid; P_2: Open type *Bt* cotton with RCH 659 hybrid and P_3: Semi Open type *Bt* cotton with Sadanand hybrid. Each of these main plots were divided into three sub-plots. The sub-plots consisted of three plant densities *viz.,* D_1: 55,555 plants ha^{-1} with a spacing of 90× 20 cm; D_2: 37,037 plants ha^{-1} with a spacing of 90× 30 cm and D_3: 18,518 plants ha^{-1} with a spacing of 90×60 cm as detailed in the Fig.1. The experiment was repeated on the same site for two consecutive years in the same field during *kharif* 2021 and 2022.

3. RESULTS AND DISCUSSION

3.1 Plant Height (cm)

Plant height was an important morphological character in cotton which provides sites for nodes and internodes on which monopodial and sympodial branches emerge. Sympodial branches play an important role in determining the crop canopy spread and morphological frame work relating to productivity. The data recorded on plant height at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest as influenced by different plant types and plant densities during 2021 and 2022 were presented in Table 1 and depicted graphically in Fig.1. Crop growth was slow up to 60 DAS and complete canopy was reached at 90 DAS during both the years of study.

The plant height at 30 DAS was not significantly influenced by plant types. However, numerically taller plants (22.8 and 22.8 cm during 2021 and 2022, respectively) were observed with the semi open type (Sadanand) and the lowest height (21.0 and 20.8 cm during 2021 and 2022, respectively) was recorded with the compact type of plant growth (Siri).The plant height at 60 DAS, 90 DAS, 120 DAS and at harvest, maximum plant height of 78.4, 102.4, 118.2 and 129.0 cm (2021); 78.5, 102.4, 119.7 and 132.5 cm (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, were recorded with semi open type (Sadanand) which was significantly superior to open type (RCH-659) and compact type (Siri) plants. While, minimum plant height (71.0, 89.9, 107.3 and 114.9 cm (2021); 72.2, 91.8, 110.2 and 117.8 cm (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) was observed with compact growth of plant type (Siri).Significant differences were observed among plant types due to the genotypic growth potential of sadanand plant type might have caused the variation in plant height. The ability of sadanand hybrid having to grow taller might be due to more sunlight utilization which resulted in increased plant height. These results are in agreement with the findings of An et al. [7] and Chen et al. [8] who have reported that various genotypes show differences in plant height.

The plant height at 30 DAS, the plant height was observed to be non-significant indicating that there is no effect of plant densities on plant height at 30 DAS. Numerically, the taller plants 22.8 and 22.8 cm during 2021 and 2022, respectively, were observed with plant density of 90 x 20 cm (55,555 plants ha^{-1}) followed by 90 x 30 cm (37,037 plants ha^{-1}). While, dwarfest plants (21.2 and 20.8 cm during 2021 and 2022, respectively) were recorded with plant density of 90 x 60 cm (18,518 plants ha^{-1}).At 60 DAS, 90 DAS, 120 DAS and at harvest, plant height was significantly influenced by plant densities during both the years of study. Highest plant height of 80.9, 102.6, 117.3 and 126.6 cm (2021); 81.2, 103.4, 119.2 and 130.4 cm (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded with density of 90 x 20 cm (55,555 plants ha^{-1}) and found significantly superior to 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}). While, least plant height was recorded in planting density of 90 x 60 cm (18,518 plants ha^{-1}) (69.2, 90.1, 108.4 and 117.9 cm (2021); 69.8, 91.1, 110.3 and 119.5 cm (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively). The interaction effect of plant types and planting densities at various growth stages of *Bt* cotton on plant height (cm) was not significant during both the years of study.

This increased height at high densities and lower plant height at low densities might be due to the fact that in high densities there is a competition for nutrients, water and solar radiation. Taller plants were mainly due to expansion of inter nodal length caused by overcrowding of the plant population. This is because higher than the optimum plant population per unit area results the plant to enter into competition for light resulting in tall and thin growth. The narrow plant spacing might have provided insufficient space for spread or low plant canopy area and energy diverted upward, increasing height instead of spreading due to lower space available to each plant and hence increase in height at high densities. These results are in agreement with Jagtap and Bhale [9], Devi et al. [10] and Kavya et al. [11].

3.2 Number of Monopodial Branches per Plant

Data presented in Table 2 on number of monopodial branches per plant was not influenced by plant types, plant densities and interaction during both the years of study and pooled mean.With respect to plant types, number of monopodial branches per plant is not statistically influenced by plant types. However, numerically the highest number of monopodial branches per plant were 3.68 during 2021 and 3.69 during 2022 which was observed in semi open type (Sadanand) and open type (RCH-659). Whereas, compact growth of plant type (Siri) recorded lowest number of monopodial branches per plant being 2.50 during 2021 and 2.51 during 2022. Among plant densities, number of monopodial branches per plant were observed to be non-significant in *Bt* cotton during both the years of study. Numerically, the highest number of monopodial branches per plant were recorded in planting density of 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}) (3.65 and 3.66 during 2021 and 2022, respectively).While, the least number of monopodial branches per plant were observed in 90 x 20 cm (55,555 plants ha^{-1}) (2.37 and 2.38 during 2021 and 2022, respectively). These results are in line with the findings of Tuppad [12] and Kaggwa et al. [13].

The pooled mean and interaction effect of plant types and planting densities on number of monopodial branches per plant of *Bt* cotton was non-significant during both the years of study.

3.3 Number of Sympodial Branches per Plant

Sympodial branches form an important part on structure of cotton plant to which the fruiting bodies develop and contribute to the productivity. Data pertaining to number of sympodial branches per plant as influenced by plant types and planting densities are presented in Table 3 for 2021 and 2022.

Scrutiny of data reveals that the various plant types has significantly influenced the number of sympodial branches per plant during 2021 and 2022. Significantly, the higher number of sympodial branches per plant were recorded in semi open type (Sadanand) (11.48 and 11.69 during 2021 and 2022, respectively) which was statistically significant to open type (RCH-659) and compact type (Siri) plants. Whereas, the lower number of sympodial branches per plant were reported in compact growth of plant type (Siri) (10.05 and 10.34 during 2021 and 2022, respectively).Various plant types showed significant differences in number of sympodial branches. Open type sadanand resulted with higher branches due to maximum height obtained by the sadanand hybrid which favoured for higher number of sympodial branches. The results are in accordance with the findings of Zhao et al. [14] and Khan et al. [15].

Data shows that number of sympodial branches per plant differed significantly among the plant densities. An increased in number of sympodial branches were observed in higher plant densities during 2021 and 2022. Higher no. of sympodial branches per plant (11.27 during 2021 and 11.52 during 2022) were recorded with plant population of 37,037 plants ha^{-1} (90 x 30 cm) which was significantly superior to 18,518 plants ha^{-1} (90 x 60 cm) and 55,555 plants ha^{-1} (90 x 20 cm). While, significantly lower number of sympodial branches per plant (10.20 during 2021 and 10.52 during 2022) were noticed under plants sowing with 55,555 plants ha^{-1} (90 x 20 cm).Optimum plant densities resulted in higher number of sympodial branches which might be due to higher height obtained by the plant compared to low density planting. Compared to very high density planting of cotton optimum density provided more space for lateral expansion of branches and chance to enhance auxiliary buds of plants as compared to very closely spaced plants. These results are in conformity with the findings of Tuppad [12], Maheswari et al. [16] and Kavya et al. [11].

The interaction effect of plant types and planting densities on number of sympodial branches per plant of *Bt* cotton were non-significant during both the years of study.

3.4 Dry Matter Production (kg ha^{-1})

Data on drymatter production (kg ha^{-1}) at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest as influenced by plant types and plant densities are presented in Table 4 and Fig. 2 for both the years of study. Perusal of the data reveals that the drymatter production of *Bt* cotton, increased progressively with the advancement of the crop stage. Dry matter production (kg ha^{-1}) at 30 DAS was not significantly influenced by plant types. However, numerically drymatter production of 142 and 143 kg ha^{-1} during 2021 and 2022 respectively, was observed with the treatment semi open type (Sadanand) and the least drymatter production (121 and 123 kg ha^{-1} during 2021 and 2022 respectively, was recorded with compact type (Siri) plants.

Maximum dry matter production of 419 kg ha^{-1} (2021) and 443 kg ha^{-1} (2022) was recorded with semi open type (Sadanand) which was on par with open type (RCH-659) and significantly superior to compact type (Siri) plants. Least drymatter production of 298 kg ha^{-1} (2021) and 317 kg ha^{-1} (2022) at 60 DAS was observed with compact growth of plant type (Siri).Maximum drymatter production of 4312, 7104 and 8720 kg ha^{-1} (2021); 4321, 7645 and 8705 kg ha^{-1} (2022) at At 90 DAS, 120 DAS and at harvest,, respectively, was recorded with semi open type (Sadanand) which was significantly superior to open type (RCH-659) and compact type (Siri) plants. While, least drymatter production (2617, 4835 and 5638 kg ha^{-1} (2021); 2633, 4857 and 6119 kg ha^{-1} (2022) at 90 DAS, 120 DAS and at harvest, respectively) was observed with compact growth of plant type (Siri).The superiority of the semi open type hybrid sadanand in the drymatter accumulation may be attributed to having the tallest and thickest plants, and as well the highest area of photosynthetic leaves and this in turn increased the capacity of drymatter accumulation in the different plant parts [17].

At 30 DAS, the drymatter production was observed to be non-significant indicating that there is no effect of plant densities on drymatter production (kg ha^{-1}). Numerically, the drymatter production 142 and 144 kg ha^{-1} during 2021 and 2022, respectively, were observed with plant density of 90 x 20 cm (55,555 plants ha^{-1}) followed by 90 x 30 cm (37,037 plants ha^{-1}). While, drymatter production of 119 and 120 kg ha^{-1} during 2021 and 2022, respectively, was recorded with plant density of 90 x 60 cm (18,518 plants ha^{-1}).Highest drymatter production of 477, 4359, 7373 and 8565 kg ha^{-1} (2021); 487, 4381, 7400 and 8581 kg ha^{-1} (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded when *Bt* cotton was sown under planting density of 90 x 20 cm (55,555 plants ha^{-1}) and found significantly superior to 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}).Results revealed that high plant densities have higher drymatter production and low plant densities have least drymatter production. At high plant densities, even though the drymatter produced plant^{-1} was low due to inter plant competition, higher densities resulted in higher total drymatter production per unit area. However, at low plant densities, due to more availability of space, light, moisture and nutrients, the drymatter production per plant is maximum but total drymatter yield was low due to less population per unit area. These are in line with Tuppad [12], Devi et al. [10], Chen et al. [8] and Kavya et al. [11] who observed that the partitioning of assimilates to reproductive parts was lower in narrow row high plant density systems.

The interaction effect of plant types and planting densities on drymatter production (kg ha^{-1}) at various growth stages of *Bt* cotton was significant at 120 DAS during both the years of study and pooled mean.

3.5 Main Stem Diameter (mm)

Data on main stem diameter as influenced by various plant types and plant densities are presented in 4.Perusal of the data reveals that, main stem diameter was significantly affected by the plant types and plant densities tried in the field experiment at all growth stages except at 30 DAS and interaction.

Table 1. Plant height (cm) of *Bt* cotton at 30DAS, 60DAS, 90DAS, 120DAS and at harvest as influenced by varied plant types and plant densities

Treatments	30 DAS			60 DAS			90 DAS			120 DAS			At harvest		
	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean
Main plot: Plant types															
P_1- Siri (Compact)	21.0	20.8	20.9	71.0	72.2	71.6	89.9	91.8	90.9	107.3	110.2	108.7	114.9	117.8	116.3
P_2- RCH 659 (Open)	21.9	21.8	21.9	75.3	75.3	75.3	96.7	97.4	97.0	113.1	114.5	113.8	121.9	125.0	123.5
P_3- Sadanand (Semi Open)	22.8	22.8	22.8	78.4	78.5	78.4	102.4	102.4	102.4	118.2	119.7	119.0	129.0	132.5	130.8
SE(m)±	0.3	0.3	0.3	0.7	0.7	0.7	1.4	1.3	1.3	1.3	1.0	1.1	1.5	1.7	1.5
CD (p=0.05)	NS	NS	NS	2.7	2.7	2.7	5.4	4.9	5.2	5.0	3.9	4.2	5.7	6.6	6.1
Sub plot treatments: Plant densities															
D_1- 90× 20cm (55,555 plants ha^{-1})	22.8	22.8	22.8	80.9	81.2	81.1	102.6	103.4	103.0	117.3	119.2	118.2	126.6	130.4	128.5
D_2- 90× 30cm (37,037plants ha^{-1})	21.7	21.9	21.8	74.6	75.0	74.8	96.3	97.1	96.7	112.8	114.9	113.8	121.3	125.4	123.4
D_3- 90× 60cm (18,518 plants ha^{-1})	21.2	20.8	21.0	69.2	69.8	69.5	90.1	91.1	90.6	108.4	110.3	109.4	117.9	119.5	118.7
SE(m)±	0.3	0.3	0.3	1.7	1.7	1.7	1.7	1.9	1.8	1.2	1.3	1.2	1.0	1.6	1.3
CD (p=0.05)	NS	NS	NS	5.3	5.2	5.2	5.2	5.8	5.5	3.8	4.1	3.8	3.2	4.8	3.9
Interaction															
P×D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D×P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

P×D: For two subplot means at same level of main plot means; D×P: For two mainplot means at same level of sub plot means

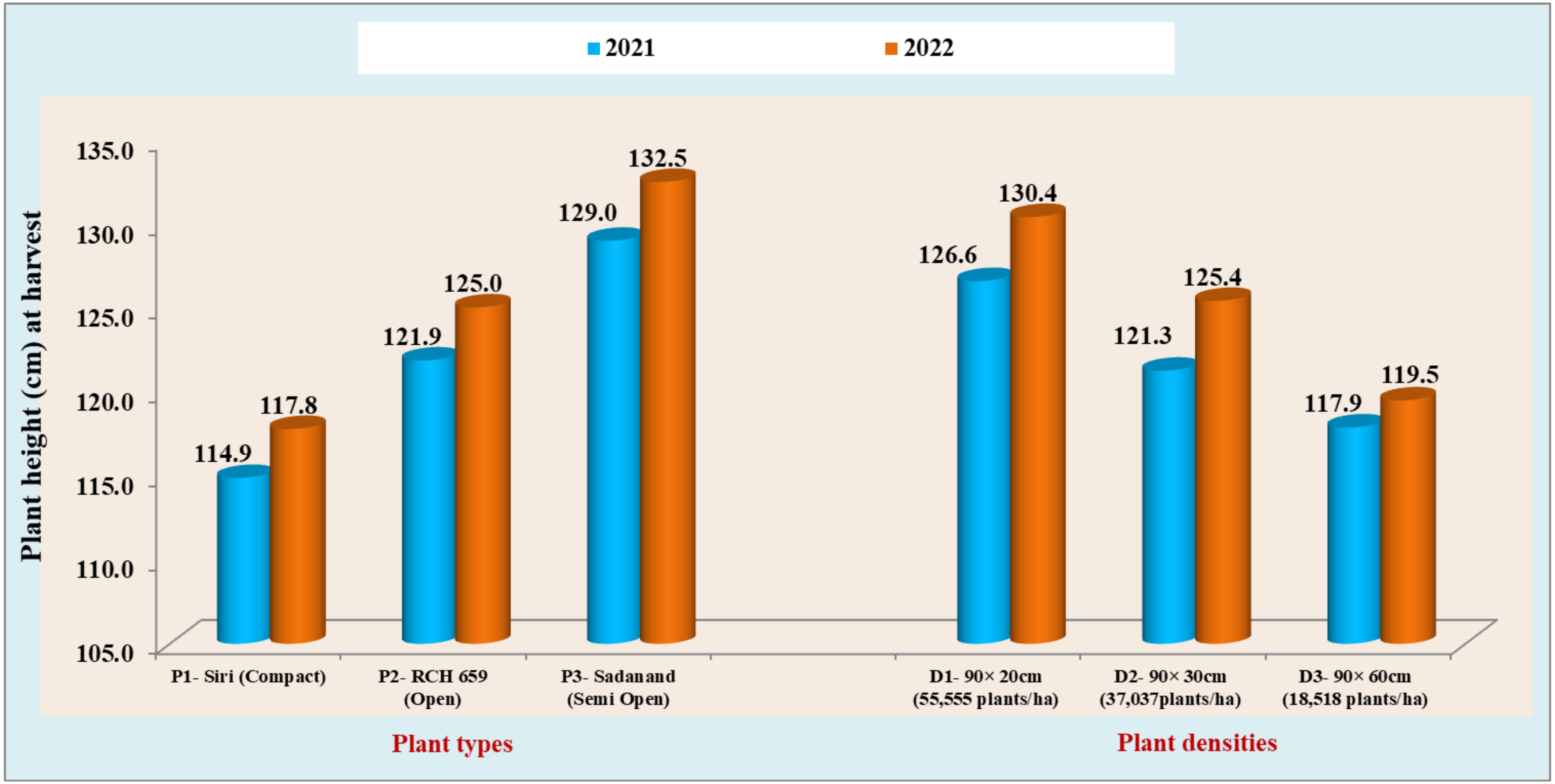

Fig. 1. Plant height (cm) of *Bt* cotton at harvesting stage as influenced by varied plant types and plant densities

Table 2. No. of monopodial branches per plant and sympodial branches per plant of *Bt* cotton as influenced by varied plant types and plant densities

Treatments	No. of monopodial branches plant^{-1}			No. of sympodial branches plant^{-1}		
	2021	**2022**	**Pooled Mean**	**2021**	**2022**	**Pooled Mean**
Main plot: Plant types						
P_1- Siri (Compact)	2.50	2.51	2.51	10.05	10.34	10.20
P_2- RCH 659 (Open)	3.68	3.69	3.69	10.66	11.02	10.84
P_3- Sadanand (Semi Open)	3.68	3.69	3.69	11.48	11.69	11.58
SE(m)±	1.80	1.80	1.80	0.14	0.16	0.15
CD (p=0.05)	NS	NS	NS	0.57	0.62	0.57
Sub plot treatments: Plant densities						
D_1- 90× 20cm (55,555 plants ha^{-1})	2.37	2.38	2.38	10.20	10.52	10.36
D_2- 90× 30cm (37,037plants ha^{-1})	3.65	3.66	3.66	11.27	11.52	11.40
D_3- 90× 60cm (18,518 plants ha^{-1})	3.65	3.66	3.66	10.72	11.01	10.86
SE(m)±	1.95	1.96	1.96	0.15	0.16	0.14
CD (p=0.05)	NS	NS	NS	0.45	0.48	0.44
Interaction						
P×D	NS	NS	NS	NS	NS	NS
D×P	NS	NS	NS	NS	NS	NS

P×D: For two subplot means at same level of main plot means; D×P: For two mainplot means at same level of sub plot means

Table 3. Dry matter production (kg ha^{-1}) of leaf, stem and reproductive structures of *Bt* cotton at 30DAS, 60DAS, 90DAS, 120DAS and at harvest as influenced by varied plant types and plant densities

Treatments	30 DAS			60 DAS			90 DAS			120 DAS			At harvest		
	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean
Main plot: Plant types															
P_1- Siri (Compact)	121	123	122	298	317	307	2617	2633	2625	4835	4857	4846	5638	6119	5248
P_2- RCH 659 (Open)	128	129	129	379	402	390	3541	3596	3568	5779	5786	5783	7016	7275	6401
P_3- Sadanand (Semi Open)	142	143	142	419	443	431	4312	4321	4316	7104	7645	7270	8720	8705	8078
SE(m)±	2	3	3	16	19	17	108	147	128	311	300	305	222	184	256
CD (p=0.05)	NS	NS	NS	65	75	68	425	580	502	1223	1178	1198	875	725	1004
Sub plot treatments: Plant densities															
D_1- 90× 20cm (55,555 plants ha^{-1})	142	144	143	477	487	482	4359	4381	4370	7373	7400	7387	8555	8581	7977
D_2- 90× 30cm (37,037plants ha^{-1})	130	131	130	337	378	358	3720	3757	3739	6066	6004	6035	7132	7387	6568
D_3- 90× 60cm (18,518 plants ha^{-1})	119	120	119	281	297	289	2390	2413	2401	4279	4675	4477	5688	6131	5182
SE(m)±	2	3	3	17	23	20	107	127	116	246	267	237	364	346	309
CD (p=0.05)	NS	NS	NS	53	71	61	330	393	359	759	824	730	1123	1068	952
Interaction															
P×D	NS	NS	NS	NS	NS	NS	NS	NS	NS	1316	1428	1265	NS	NS	NS
D×P	NS	NS	NS	NS	NS	NS	NS	NS	NS	1462	1499	1419	NS	NS	NS

P×D: For two subplot means at same level of main plot means; D×P: For two mainplot means at same level of sub plot means

Table 4. Interaction between plant types and plant densities on drymatter production (kg ha^{-1}) in *Bt* cotton for 120 DAS

Treatments	2021				2022				Pooled mean			
	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean	D_1	D_2	D_3	Mean
P_1	5727	5984	2795	4835	6045	5705	2820	4857	5886	5845	2807	4846
P_2	7960	5563	3816	5779	7615	5905	3838	5786	7787	5734	3827	5783
P_3	8434	6652	6226	7104	8538	6403	7368	7645	8486	6528	6797	7270
Mean	7373	6066	4279		7400	6004	4675		7387	6035	4477	

	SE(m)±	CD (p=0.05)	CV (%)	SE(m)±	CD (p=0.05)	CV (%)	SE(m)±	CD (p=0.05)	CV (%)
P	312	1223	18	300	1178	17	305	1198	18
D	247	760	14	268	825	15	237	730	14
P×D	427	1316		464	1429		411	1265	
D×P	468	1462		483	1500		453	1419	

Table 5. Main stem diameter (mm) of *Bt* cotton at 30DAS, 60DAS, 90DAS and 120DAS as influenced by varied plant types and plant densities

Treatments	30 DAS			60 DAS			90 DAS			120 DAS		
	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean	2021	2022	Pooled Mean
Main plot: Plant types												
P_1- Siri (Compact)	6.31	6.33	6.32	18.60	18.97	18.78	26.22	26.40	26.31	35.75	36.06	35.91
P_2- RCH 659 (Open)	5.64	5.65	5.64	11.22	11.48	11.35	24.03	24.12	24.07	30.18	30.35	30.27
P_3- Sadanand (Semi Open)	5.72	5.73	5.73	16.05	16.37	16.21	25.06	25.23	25.15	33.83	34.01	33.92
SE(m)±	0.12	0.12	0.12	0.70	0.98	0.87	0.34	0.35	0.34	0.57	0.59	0.57
CD (p=0.05)	NS	NS	NS	2.75	4.13	3.43	1.32	1.37	1.33	2.22	2.30	2.25
Sub plot treatments: Plant densities												
D_1- 90×20cm (55,555plants ha^{-1})	5.28	5.28	5.28	13.03	13.21	13.12	23.26	23.47	23.36	30.99	31.06	31.02
D_2- 90×30cm (37,037plants ha^{-1})	6.05	6.08	6.06	15.14	15.63	15.38	25.11	25.27	25.19	33.28	33.44	33.36
D_3- 90×60cm (18,518plants ha^{-1})	6.34	6.37	6.35	17.69	17.97	17.83	26.93	27.02	26.97	35.49	35.93	35.71
SE(m)±	0.24	0.24	0.24	0.64	0.74	0.69	0.52	0.50	0.51	0.59	0.76	0.68
CD (p=0.05)	NS	NS	NS	1.97	2.28	2.12	1.60	1.54	1.56	1.83	2.35	2.09
Interaction												
P×D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
D×P	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

P×D: For two subplot means at same level of main plot means; D×P: For two mainplot means at same level of sub plot means

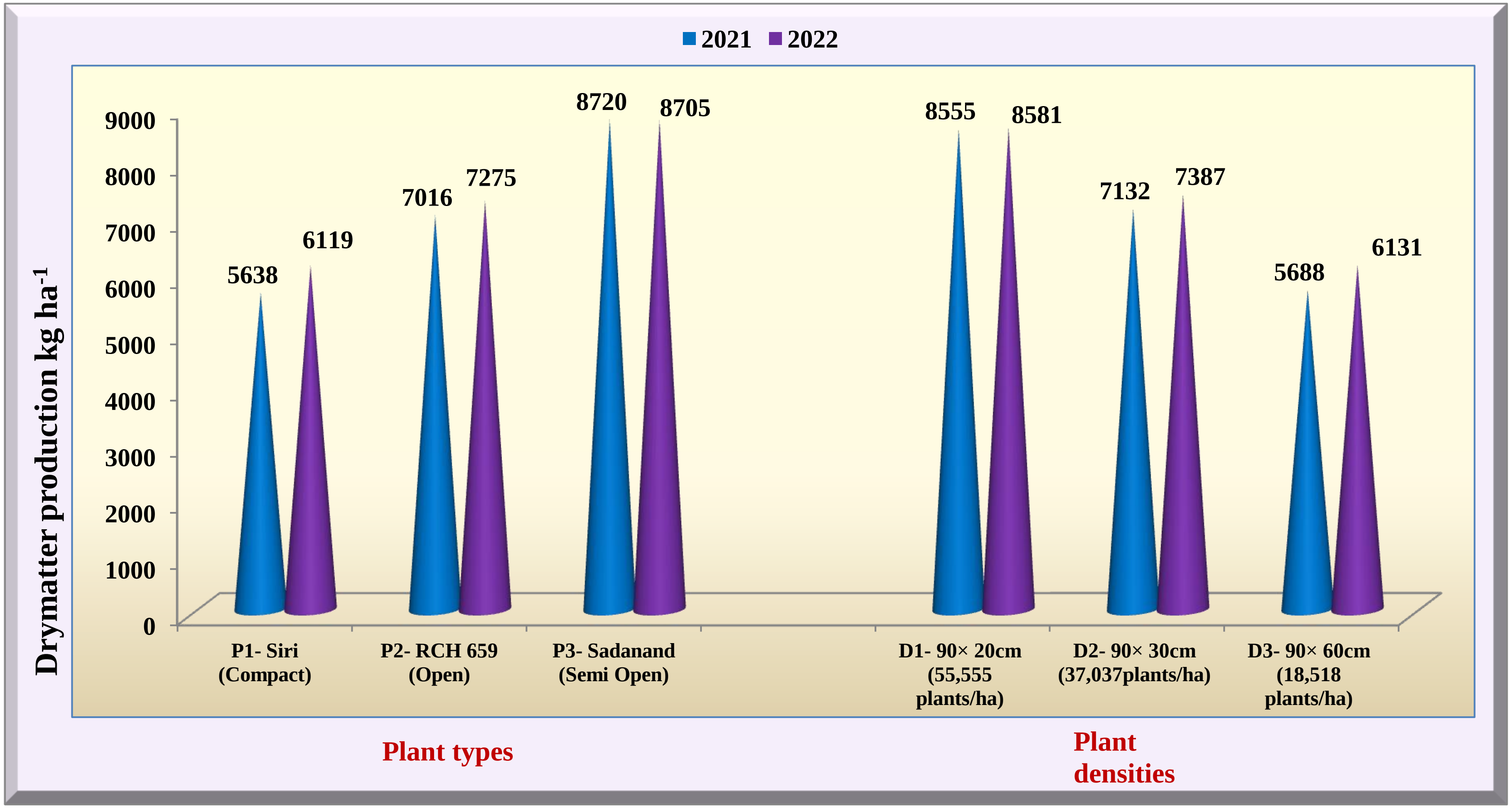

Fig. 2. Interaction between plant types and plant densities on drymatter production (kg ha-1) in Bt cotton for 120 DAS

Data reveals that main stem diameter at 30 DAS was not-significantly influenced by treatments. However, numerically the higher main stem diameter of 6.31 and 6.33 mm during 2021 and 2022 respectively, was observed with compact growth type (Siri) and the lower main stem diameter of 5.64 and 5.65 mm during 2021 and 2022 respectively, was recorded with the open type growth of plant type (RCH 659).Main stem diameter at 60 DAS, 90 DAS and 120 DAS was maximum of 18.60, 26.22 and 35.75 mm (2021); 18.97, 26.40 and 36.06 mm (2022) at 60 DAS, 90 DAS and 120 DAS, respectively, was recorded with compact type (Siri) growth of plant type, which was statistically on par with semi open type (Sadanand) and significantly superior to open type (RCH 659) cotton plants. While, least main stem diameter (11.22, 24.03 and 30.18 mm (2021); 11.48, 24.12 and 30.35 mm (2022) at 60 DAS, 90 DAS and 120 DAS, respectively) was observed with open type (RCH 659) cotton plants. Highest main stem diameter was observed with siri plant type due to the genotypic growth potential of compact plant type which is having dwarf growth compared to open type plant growth might have caused the variation in main stem diameter. These results are in agreement with Zhao et al. [14] who have reported that various genotypes show differences in plant height.

Data on main stem diameter at 30 DAS, the main stem diameter was observed to be non-significant inferring that there is no effect of plant densities on main stem diameter. Numerically, the highest main stem diameter 6.34 and 6.37 mm during 2021 and 2022, respectively, was observed with plant density of 90 x 60 cm (18,518 plants ha^{-1}) followed by 90 x 30 cm (37,037 plants ha^{-1}). While, lowest main stem diameter (5.28 and 5.28 mm during 2021 and 2022, respectively) was noticed with plant density of 90 x 20 cm (55,555 plants ha^{-1}). Data on main stem diameter reveals that at 60 DAS, 90 DAS and 120 DAS, main stem diameter was significantly influenced by plant densities during both the years of study. Highest main stem diameter of 17.69, 26.93 and 35.49 mm (2021); 17.97, 27.02 and 35.93 mm (2022) at 60 DAS, 90 DAS and 120 DAS, respectively, was recorded with density of 90 x 60 cm (18,518 plants ha^{-1}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 20 cm (55,555 plants ha^{-1}). While, least main stem diameter was found in planting density of 90 x 20 cm (55,555 plants ha^{-1}) (13.03, 23.26 and 30.99 (2021); 13.21, 23.47 and 31.06 (2022) at 60 DAS, 90 DAS and 120 DAS, respectively).Therefore, results revealed that main stem diameter increased in wider spacing with less plant population. Increase in the plant population reduced the stem diameter. It is due to the etiolation caused by a high competition for light at high plant density. Whereas, at low plant population wider spacing's provided high availability of nutrients, moisture, light favoured high leaf area index. This enables more photosynthates production and might have been distributed in the stem which is dwarfer at low plant population. This well distribution of photosynthates in stem could be the possible reason for the increased stem diameter at low densities. Similar observations were also evidenced by previous researchers Chen et al. [8] and Kavya et al. [11].

The interaction effect of plant types and plant densities at various growth stages of *Bt* cotton on main stem diameter was non-significant.

4. CONCLUSIONS

The data recorded on plant height among various plant types were found to be significant at all the growth stages of crop except at 30 DAS during the first year (2021), second year of study (2022) and pooled mean. At 60 DAS, 90 DAS, 120 DAS and at harvest, maximum plant height was recorded with semi open type (Sadanand) which was significantly superior to open type (RCH-659) and compact type (Siri) plants. While, minimum plant height was observed with compact growth of plant type (Siri). With respect to densities at 30 DAS, the plant height was observed to be non-significant indicating that there is no effect of plant densities on plant height at 30 DAS. At 60 DAS, 90 DAS, 120 DAS and at harvest, highest plant height was recorded with density of 90 x 20 cm (55,555 plants ha^{-1}) and found significantly superior to 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}). While, least plant height was recorded in planting density of 90 x 60 cm (18,518 plants ha^{-1}).

Number of monopodial branches per plant is not statistically influenced by plant types and planting densities during 2021 and 2022 and pooled mean.

Scrutiny of data reveals that the various plant types and planting densities have significantly influenced the number of sympodial branches per plant during 2021 and 2022. Significantly, the higher number of sympodial branches per plant were recorded in semi open type (Sadanand) compared to open type (RCH-659) and compact type (Siri) plants. An increased in number of sympodial branches were observed in higher plant densities during 2021 and 2022 and pooled mean. Higher no. of sympodial branches per plant were recorded with plant population of 37,037 plants ha^{-1} (90 x 30 cm) which was significantly superior to 18,518 plants ha^{-1} (90 x 60 cm) and 55,555 plants ha^{-1} (90 x 20 cm). While, significantly lower number of sympodial branches per plant were noticed under plants sowing with 55,555 plants ha^{-1} (90 x 20 cm).

A perusal of the data reveals that the drymatter production of *Bt* cotton, increased progressively with the advancement of the crop stage. Drymatter production during different growth stages were significantly influenced by various plant types except at 30 DAS during 2021 and 2022 and pooled mean. At 60 DAS, maximum drymatter production was recorded with semi open type (Sadanand) which was on par with open type (RCH-659) and significantly superior to compact type (Siri) plants. At 90 DAS, 120 DAS and at harvest, maximum drymatter production was recorded with semi open type (Sadanand) which was significantly superior to open type (RCH-659) and compact type (Siri) plants. While, least drymatter production was observed with compact growth of plant type (Siri) at all the growth stages. Various plant densities tested in the experiment have significantly influenced the drymatter production at all the growth stages of *Bt* cotton except at 30 DAS during 2021 and 2022. Drymatter production behaved similarly at 60 DAS, 90 DAS, 120 DAS and at harvest during both the years of study and pooled mean. Highest drymatter production was recorded when *Bt* cotton was sown under planting density of 90 x 20 cm (55,555 plants ha^{-1}) and found significantly superior to 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}). While, least drymatter production was observed in planting density of 90 x 60 cm (18,518 plants ha^{-1}) at all growth stages. The interaction effect of plant types and planting densities on drymatter production (kg ha^{-1}) at various growth stages of *Bt* cotton was significant at 120 DAS during both the years of study and pooled mean.

Data on main stem diameter as influenced by various plant types and plant densities reveals that, main stem diameter was significantly affected by the plant types and plant densities tried in the field experiment at all growth stages except at 30 DAS and interaction during two years of study. At 60 DAS, 90 DAS and 120 DAS maximum main stem diameter was recorded with compact type (Siri) growth of plant type, which was statistically on par with semi open type (Sadanand) and significantly superior to open type (RCH 659) cotton plants. Among plant densities highest main stem diameter was recorded with density of 90 x 60 cm (18,518 plants ha^{-1}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 20 cm (55,555 plants ha^{-1}). While, least main stem diameter was found in planting density of 90 x 20 cm (55,555 plants ha^{-1}). The interaction effect of plant types and planting densities at various growth stages of *Bt* cotton on main stem diameter was non-significant during both the years of study and pooled mean.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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