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INFLUENCE OF DIFFERENT PLANT DENSITIES ON PHYSIOLOGICAL PARAMETERS *VIS-À-VIS* ARCHITECTURE ON *BT* COTTON (*Gossypium Hirsutum L.*)

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ABSTRACT

A field experiment was conducted on "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 2021-23. The experiment was laid out in split plot design with three replications. Results revealed that physiological parameters *viz.,* significant on leaf area index and light interception rate were record highest in semi open type. Specific leaf weight was found to be highest in compact type of plant canopy. Among plant densities, leaf area index and light interception rate were observed to be highest in plants planted under 90 x 20 cm (55,555 plants ha^{-1}), while highest specific leaf weight was noticed highest in plant spacing of 90 x 60 cm (18,518 plants ha^{-1}) during two years of study and pooled mean. Non-significant statistical differences were observed among canopy temperature and SPAD readings (chlorophyll content in leaves).

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 witnessed 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 (Yao *et al.* 2016). 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 (Stewart, 2005). 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 (Siebert and Stewart, 2006). 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 (Morgen, 1917). However, agronomic studies on the effects of the wide

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ranging plant architectural attributes on cotton growth, yield potential, and crop management are limited (Saeed *et al.* 2011). 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 (Dong *et al.* 2010). 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.

MATERIAL 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.3.2. The experiment was repeated on the same site for two consecutive years in the same field during *kharif* 2021 and 2022.

RESULTS AND DISCUSSION

PHYSIOLOGICAL PARAMETERS

1. Leaf Area Index

Data on Leaf Area Index (LAI) as influenced by various plant types and plant densities are presented in Table 1. A perusal of the data reveals that, LAI was significantly affected by the plant types and plant densities tried in the experiment at all growth stages except at 30 DAS and interaction.

1.1. Leaf area index as influenced by plant types

The data in Table 4.12 reveals that LAI at 30 DAS was not-significantly influenced by plant types. However, numerically the highest LAI of 0.63 and 0.64 during 2021 and 2022 respectively, was observed with semi open growth type (Sadanand) and the lower LAI of 0.55 and 0.55 during 2021 and 2022 respectively was recorded with the compact type (Siri).

Highest leaf area index at being 1.93, 3.20, 4.29 and 3.74 (2021); 1.91, 3.11, 4.39 and 3.75 (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded with semi open type (Sadanand), which was statistically on par with open

type (RCH-659) and significantly superior to compact type (Siri) plants. While, minimum LAI (1.51, 2.58, 3.72 and 3.14 (2021); 1.51, 2.48, 3.71 and 3.15 (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) was observed with compact growth of plant type (Siri).

In annuals the initial leaf area development from seedlings is less for much of the early growth phases and may not be significant differences. As leaf area develops the leaf surfaces get expanded for capture of more sunlight. Semi open type growth of cotton plant where leaf is arranged at a certain angled to capture the photosynthetically active radiation at a higher rate and minimize the shading effect on lower leaves. Compared to compact type where erectophile canopy is structured (Less leaf area is exposed to direct sunlight) and open type plants where planophile canopy is available for capturing the sunlight (Shading of lower leaves was observed). The semi open type architecture in sadanand *Bt* cotton hybrid, has higher light interception allowing more light to penetrate to the bottom part of canopy increases the leaf area resulting production of more assimilates which is distributed to the reproductive structures and obtaining more yields. The results are in concurrent with the findings of Chapepa *et al.* (2013), Long *et al.* (2017), Chen *et al.* (2021), Chen *et al.* (2022), Sultana *et al.* (2023).

1.2 Leaf area index as influenced by plant densities

Leaf area index in respect to plant densities were observed to be significant at 60 DAS, 90 DAS, 120 DAS and at harvest except at 30 DAS of *Bt* cotton during the first year and second year of study (Table 1).

At 30 DAS, the LAI was observed to be non-significant indicating that there is no effect of plant densities on LAI. Numerically, the highest LAI 0.65 and 0.66 during 2021 and 2022, respectively, was 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, lowest LAI (0.55 and 0.55 during 2021 and 2022, respectively) was recorded with plant density of 90 x 60 (18,518 plants ha^{-1}).

Data on LAI revealed that at 60 DAS, 90 DAS, 120 DAS and at harvest, LAI was significantly influenced by plant densities during both the years of study. Highest LAI of 1.98, 3.25, 4.32 and 3.73 (2021); 1.99, 3.18, 4.43 and 3.77 (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}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 (18,518 plants ha^{-1}). While, least LAI was found in planting density of 90 x 60 (18,518 plants ha^{-1}) (1.43, 2.40, 3.67, 3.07 (2021); 1.40, 2.38, 3.69, 3.13 (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

This highest leaf area index at higher plant densities might be due to higher leaf area per unit area. Narrow row spaced plants covers more leaf area per unit ground area significantly increasing the leaf area index. Earlier finding of Chapepa *et al.* (2013), Long *et al.* (2017), Chen *et al.* (2021), Chen *et al.* (2022), Sultana *et al.* (2023) confirm the current finding.

1.3 Effect of interaction

The interaction effect of plant types and planting densities on leaf area index at various growth stages of *Bt* cotton was significant at 120 DAS during both the years of study and pooled mean.

In respect of interaction, data presented in Table 2 inferred that significantly highest leaf area index was recorded with semi open type (Sadanand) with plant densities 90 x 20 cm (55,555 plants ha^{-1}) (P_3D_1 – 4.51 during 2021, 4.67 during 2022 and 4.59 in pooled mean) which is significantly superior to P_1D_1, P_1D_2 and P_1D_3 during both the years. Least leaf area index was noticed with compact type (Siri) combined with 90 x 60 cm (18,518 plants ha^{-1}) (P_1D_3 – 3.26 during 2021, 3.23 during 2022 and 3.25 in pooled mean). This indicates that semi open type (Sadanand) when planted under plant density of 90 x 20 cm resulted with highest leaf area index. Similar results were also obtained from the field experiments of Mao *et al.* (2014), Chen *et al.* (2022) and Sultana *et al.* (2023).

2. Specific leaf weight (mg cm^{-2})

Data pertaining to specific leaf weight (mg cm^{-2}) as influenced by various plant types and plant densities are tabulated in Table 3 shows that specific leaf weight was significantly affected by the plant types and plant densities at all growth stages except at 30 DAS and interaction.

Table 1: Leaf Area Index 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)	0.55	0.55	0.55	1.51	1.51	1.51	2.58	2.48	2.53	3.72	3.71	3.71	3.14	3.15	3.15
P_2- RCH 659 (Open)	0.60	0.61	0.60	1.68	1.69	1.68	2.71	2.73	2.72	3.92	4.08	4.01	3.34	3.45	3.40
P_3- Sadanand (Semi Open)	0.63	0.64	0.63	1.93	1.91	1.92	3.20	3.11	3.15	4.29	4.39	4.34	3.74	3.75	3.75
SE(m)±	0.03	0.03	0.03	0.06	0.06	0.06	0.10	0.10	0.10	0.09	0.10	0.10	0.08	0.09	0.08
CD (p=0.05)	NS	NS	NS	0.24	0.22	0.23	0.41	0.38	0.40	0.36	0.38	0.37	0.30	0.34	0.32
Sub plot treatments: Plant densities															
D_1- 90×20cm (55,555 plants ha^{-1})	0.65	0.66	0.65	1.98	1.99	1.98	3.25	3.18	3.22	4.32	4.43	4.38	3.73	3.77	3.75
D_2- 90×30cm (37,037plants ha^{-1})	0.58	0.58	0.58	1.71	1.72	1.71	2.83	2.76	2.80	3.96	4.06	4.01	3.41	3.45	3.43
D_3- 90×60cm (18,518 plants ha^{-1})	0.55	0.55	0.55	1.43	1.40	1.41	2.40	2.38	2.39	3.67	3.69	3.68	3.07	3.13	3.10
SE(m)±	0.03	0.03	0.03	0.08	0.08	0.08	0.12	0.12	0.12	0.08	0.08	0.08	0.08	0.08	0.08
CD (p=0.05)	NS	NS	NS	0.25	0.25	0.25	0.38	0.37	0.38	0.24	0.24	0.24	0.23	0.24	0.24
Interaction															
P×D	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.44	0.42	0.41	NS	NS	NS
D×P	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.41	0.46	0.45	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 2: Interaction between plant types and plant densities on Leaf Area Index in *Bt* cotton at 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 Siri (Compact)	3.99	3.91	3.26	3.72	3.98	3.91	3.23	3.71	3.99	3.91	3.25	3.71
P_2 RCH 659 (Open)	4.47	3.97	3.41	3.92	4.64	4.10	3.44	4.08	4.55	4.07	3.42	4.01
P_3 Sadanand (Semi Open)	4.51	4.00	4.35	4.29	4.67	4.17	4.39	4.39	4.59	4.05	4.37	4.34
Mean	4.32	3.96	3.67		4.43	4.06	3.69		4.38	4.01	3.68	

	SE(m)±	CD (p=0.05)	CV (%)	SE(m)±	CD (p=0.05)	CV (%)	SE(m)±	CD (p=0.05)	CV (%)
P (Plant types)	0.09	0.36	7.93	0.10	0.38	8.29	0.09	0.37	8.11
D (Plant densities)	0.08	0.24	6.67	0.08	0.24	6.72	0.08	0.24	6.68
PXD	0.14	0.44		0.14	0.42		0.13	0.41	
DXP	0.13	0.41		0.15	0.46		0.14	0.45	

Table 3: Specific leaf weight (mg cm^{-2}) of *Bt* cotton at 30 DAS, 60 DAS, 90 DAS, 120 DAS 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)	1.34	1.36	1.35	2.06	2.17	2.12	2.45	2.55	2.50	2.58	2.60	2.59	2.64	2.65	2.65
P_2- RCH 659 (Open)	1.33	1.35	1.34	1.82	1.83	1.82	2.30	2.29	2.30	2.37	2.38	2.38	2.61	2.43	2.52
P_3- Sadanand (Semi Open)	0.85	0.85	0.85	1.62	1.61	1.61	1.84	1.83	1.84	1.96	1.96	1.96	1.98	1.97	1.98
SE(m)±	0.09	0.10	0.09	0.06	0.09	0.06	0.10	0.11	0.10	0.11	0.11	0.11	0.11	0.11	0.11
CD (p=0.05)	NS	NS	NS	0.23	0.37	0.25	0.40	0.43	0.40	0.42	0.41	0.41	0.42	0.42	0.42
Sub plot treatments: Plant densities															
D_1- 90×20cm (55,555 plants ha^{-1})	1.05	1.05	1.05	1.51	1.57	1.54	1.95	1.86	1.90	2.01	2.00	2.01	2.09	2.08	2.09
D_2- 90×30cm (37,037plants ha^{-1})	1.11	1.12	1.12	1.85	1.88	1.87	2.19	2.22	2.21	2.33	2.33	2.33	2.34	2.34	2.34
D_3- 90×60cm (18,518 plants ha^{-1})	1.36	1.39	1.38	2.14	2.16	2.15	2.45	2.59	2.52	2.60	2.67	2.64	2.65	2.69	2.67
SE(m)±	0.08	0.09	0.09	0.09	0.09	0.06	0.08	0.12	0.09	0.10	0.10	0.10	0.08	0.08	0.08
CD (p=0.05)	NS	NS	NS	0.27	0.27	0.18	0.22	0.36	0.28	0.31	0.31	0.31	0.24	0.24	0.24
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

2.1 Specific leaf weight as influenced by plant types

The data in Table 3 reveals that specific leaf weight at 30 DAS was not-significantly influenced by treatments. However, numerically the highest specific leaf weight of 1.34 and 1.36 mg cm^{-2} during 2021 and 2022 respectively, was observed with compact type (Siri) and the lower specific leaf weight of 0.85 and 0.85 mg cm^{-2} during 2021 and 2022 respectively was noticed with the semi open growth type (Sadanand).

Specific leaf weight at 60 DAS, 90 DAS, 120 DAS and at harvest followed the similar trend during both years. Maximum specific leaf weight of 2.06, 2.45, 2.58 and 2.64 mg cm^{-2} (2021); 2.17, 2.55, 2.60 and 2.65 mg cm^{-2} (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded with compact growth of plant type (Siri), which was statistically on par with open type (RCH-659) and significantly superior to semi open type (Sadanand). While, minimum specific leaf weight (1.62, 1.84, 1.96 and 1.98 mg cm^{-2} (2021); 1.61, 1.83, 1.96 and 1.97 mg cm^{-2} (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) was observed with semi open type (Sadanand).

Specific leaf weight is the derivation of leaf weight and leaf area. Hence, more leaf area the specific leaf weight is less. Semi open type growth of cotton plant where leaf is arranged at a certain angled to capture the photosynthetically active radiation at a higher rate producing more leaf area has less specific leaf weight. Compared to compact type where erectophile canopy is structured (Less leaf area is exposed to direct sunlight) and open type plants where planophile canopy is available for capturing the sunlight and has less leaf area and resulting higher specific leaf weight. The results are in conformity with the findings of Long *et al.* (2017), Mao *et al.* (2014) and Sultana *et al.* (2023).

2.2 Specific leaf weight as influenced by plant densities

Specific leaf weight in respect to densities were observed to be significant at 60 DAS, 90 DAS, 120 DAS and at harvest except at 30 DAS of *Bt* cotton during the first year (2021) and second year of study (2022). A perusal of data presented in Table 4.13 indicates that, at 30 DAS, the specific leaf weight was observed to be non-significant inferring that there is no effect of plant densities on specific leaf weight. Numerically, the highest specific leaf weight 1.36 and 1.39 mg cm^{-2} during 2021 and 2022, respectively, were 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 specific leaf weight (1.05 and 1.05 mg cm^{-2} during 2021 and 2022, respectively) was recorded with plant density of 90 x 20 cm (55,555 plants ha^{-1}).

Data on specific leaf weight revealed that at 60 DAS, 90 DAS, 120 DAS and at harvest, highest specific leaf weight of 2.14, 2.45, 2.60 and 2.65 mg cm^{-2} (2021); 2.16, 2.59, 2.67 and 2.69 mg cm^{-2} (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, 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 specific leaf weight was found in planting density of 90 x 20 cm (55,555 plants ha^{-1}) (1.51, 1.95, 2.01 and 2.09 mg cm^{-2} (2021); 1.57, 1.86, 2.00 and 2.08 mg cm^{-2} (2022) at 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

This highest specific leaf weight at lower plant densities might be due to sufficient availability of nutrients, space, sunlight and soil moisture which lead to thicker leaves resulting in higher leaf specific weight. The higher plant densities recorded less leaf weight due to lower production of photosynthates since competition exists for nutrient, light and moisture. Earlier findings of Long *et al.* (2017), Mao *et al.* (2014) and Sultana *et al.* (2023) confirm the current findings.

2.3 Effect of interaction

The interaction effect of plant types and planting densities on specific leaf weight at various growth stages of *Bt* cotton was non-significant during both the years of study.

3. Light interception rate (%)

Data pertaining to light interception rate (%) as influenced by various plant types and plant densities are tabulated in Table 4 reveals that light interception rate was significantly affected by the plant types and plant densities at all growth stages. Whereas, interaction between the plant types and densities found non-significant.

3.1 Light interception rate (%) as influenced by plant types

The data presented in Table 4 reveals that light interception rate at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest followed the similar trend during both the years of study.

Maximum light interception rate of 24.96, 77.11, 104.45, 113.04 and 103.82 % (2021); 25.59, 77.95, 104.99, 110.01 and 101.68 (2022) at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded with semi open type (Sadanand), which was found statistically on par with open type growth of *Bt* cotton plants (RCH-659) and significantly superior to compact type (Siri) plants. While, minimum light interception rate of 18.38, 54.84, 75.16, 80.86 and 73.84 % was recorded during 2021 and 18.55, 55.31, 74.25, 78.91 and 73.06 % was observed during 2022 at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) with compact growth of plant type (Siri).

As leaf area develops the leaf surfaces get expanded for higher interception of radiant energy capture of more sunlight and significant differences can be observed on light interception rate. Semi open type growth of cotton plant where leaf is arranged at a certain angled to capture the photo synthetically active radiation at a higher rate causes more light interception and minimize the shading effect on lower leaves. Compared to compact type where erectophile canopy is structured (Less leaf area is exposed to direct sunlight) and open type plants where planophile canopy is available for capturing the sunlight (Shading of lower leaves was observed). The semi open type architecture in sadanand *Bt* cotton hybrid, has higher light interception allowing more light to penetrate to the bottom part of canopy increases the leaf area resulting production of more assimilates which is distributed to the reproductive structures and obtaining more yields. The results are in concurrent with the findings of Chapepa *et al.* (2013), Long *et al.* (2017), Chen *et al.* (2021), Chen *et al.* (2022), Sultana *et al.* (2023).

3.2 Light interception rate (%) as influenced by plant densities

Light interception rate in respect to densities were observed to be significant at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest of *Bt* cotton during 2021 and 2022. Data on light interception rate presented in Table 4 shows that, at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, highest light interception rate of 26.79, 78.41, 102.48, 110.01 and 100.90 (2021); 26.83, 78.83, 102.90, 108.46 and 99.21 (2022) at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively, was recorded with density of 90 x 20 cm (55,555 plants ha^{-1}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}). While, least light interception rate was found in planting density of 90 x 60 cm (18,518 plants ha^{-1}) (17.10, 53.32, 76.44, 81.30 and 75.92 (2021); 18.47, 53.95, 76.50, 80.41 and 75.22 (2022) at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

This higher light interception rate at high plant densities might be due to more leaf area available for interception of radiant energy. The low plant densities recorded lower number of leaves per unit area results in less interception rate. Similar findings were also reported by previous researchers. Chapepa *et al.* (2013), Long *et al.* (2017), Chen *et al.* (2021), Chen *et al.* (2022), Sultana *et al.* (2023).

3.3 Effect of interaction

The interaction effect of plant types and planting densities on light interception rate at various growth stages of *Bt* cotton was non-significant during both the years of study.

4. Canopy temperature (°C)

Data pertaining to canopy temperature as influenced by plant types and plant densities at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest during 2021 and 2022 are presented in Table 5. Non-significant differences were observed in *Bt* cotton among plant types and planting densities and their interaction at all the phenological stages of crop during two years of study.

Numerically, compact type growing cotton hybrids was found with high canopy temperature (29.28, 30.94, 33.09, 34.75 and 35.44 °C during 2021 and 29.29, 30.98, 33.11, 34.77 and 35.47 °C during 2022 and 29.28, 30.96, 33.10, 34.76 and 35.46 °C in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) compared to open type of growing cotton hybrids (26.06, 27.52, 30.36, 31.88 and 32.52 °C during 2021; 26.15, 27.59, 30.45, 31.91 and 32.58 °C during 2022 and 26.10, 27.56, 30.41,

Table 4: Light interception rate (%) of *Bt* cotton at 30 DAS, 60 DAS, 90 DAS, 120 DAS 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)	18.38	18.55	18.47	54.84	55.31	55.08	75.16	74.25	74.70	80.86	78.91	79.89	73.84	73.06	73.45
P_2- RCH 659 (Open)	21.64	22.36	22.00	65.52	66.13	65.82	88.24	88.83	88.54	95.34	94.32	94.83	87.76	87.11	87.44
P_3- Sadanand (Semi Open)	24.96	25.59	25.28	77.11	77.95	77.53	104.45	104.99	104.72	113.04	110.01	111.52	103.82	101.68	102.75
SE(m)±	0.88	0.94	0.91	3.41	3.47	3.44	4.73	4.41	4.57	5.15	4.30	4.72	4.57	3.73	4.15
CD (p=0.05)	3.46	3.71	3.58	13.39	13.61	13.50	18.59	17.33	17.96	20.21	16.87	18.54	17.93	14.66	16.30
Sub plot treatments: Plant densities															
D_1- 90×20cm (55,555 plants ha^{-1})	26.79	26.83	26.81	78.41	78.83	78.62	102.48	102.90	102.69	110.01	108.46	109.24	100.90	99.21	100.06
D_2- 90×30cm (37,037plants ha^{-1})	21.18	21.20	21.19	65.74	68.61	67.17	88.93	88.68	88.80	97.93	94.37	96.15	88.61	87.41	88.01
D_3- 90×60cm (18,518 plants ha^{-1})	17.10	18.47	17.74	53.32	53.95	53.63	76.44	76.50	76.47	81.30	80.41	80.85	75.92	75.22	75.57
SE(m)±	1.32	1.36	1.34	3.75	3.80	3.78	3.94	4.55	4.23	3.81	4.50	4.16	3.92	3.82	3.87
CD (p=0.05)	4.07	4.20	4.13	11.56	11.70	11.63	12.13	14.01	13.07	11.74	13.86	12.80	12.07	11.77	11.92
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

Table 5: Canopy temperature (^{0}C) of *Bt* cotton at 30 DAS, 60 DAS, 90 DAS, 120 DAS 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)	29.28	29.29	29.28	30.94	30.98	30.96	33.09	33.11	33.10	34.75	34.77	34.76	35.44	35.47	35.46
P_2- RCH 659 (Open)	26.06	26.15	26.10	27.52	27.59	27.56	30.36	30.45	30.41	31.88	31.91	31.89	32.52	32.58	32.55
P_3- Sadanand (Semi Open)	27.87	27.93	27.90	29.44	29.48	29.46	30.60	30.68	30.64	32.13	32.24	32.19	32.78	32.81	32.79
SE(m)±	0.55	0.57	0.56	0.59	0.62	0.61	0.50	0.54	0.52	0.52	0.57	0.55	0.53	0.56	0.55
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub plot treatments: Plant densities															
D_1- 90×20cm (55,555 plants ha^{-1})	28.57	28.59	28.58	30.13	30.17	30.15	31.85	31.87	31.86	33.45	33.47	33.46	34.12	34.14	34.13
D_2- 90×30cm (37,037plants ha^{-1})	28.40	28.49	28.44	29.79	29.85	29.82	31.48	31.55	31.51	33.05	33.16	33.10	33.71	33.75	33.73
D_3- 90×60cm (18,518 plants ha^{-1})	27.23	27.29	27.26	27.98	28.02	28.00	30.72	30.82	30.77	32.26	32.29	32.28	32.91	32.97	32.94
SE(m)±	0.45	0.46	0.46	0.51	0.53	0.52	0.34	0.38	0.36	0.36	0.39	0.38	0.36	0.38	0.37
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
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

31.89 and 32.55 °c in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

With respect to plant densities, high density planting provided higher canopy temperature (28.57, 30.13, 31.85, 33.45 and 34.12 °C during 2021 and 28.59, 30.17, 31.87, 33.47 and 34.14 °C during 2022 and 28.58, 30.15, 31.86, 33.46 and 34.13 °C in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) at all the stages when compared to high density planting (27.23, 27.98, 30.72, 32.26 and 32.91 °C during 2021 and 27.29, 28.02, 30.82, 32.29 and 32.97 °C during 2022 and 27.26, 28.00, 30.77, 32.28 and 32.94 °c at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

Similar reports of non-significant influence of plant types and planting densities on canopy temperature was reported by the previous workers Santosh *et al.* (2019) and Maheswari and Krishnaswamy (2019).

5. SPAD readings (chlorophyll content in leaves)

A perusal of data pertaining to SPAD readings as influenced by plant types and plant densities at 30 DAS, 60 DAS, 90 DAS, and 120 DAS and at harvest during 2021 and 2022 are presented in Table 6. The chlorophyll content determines the photosynthetic capacity and influence the rate of photosynthesis, drymatter production and yield. SPAD readings (chlorophyll content in leaves) increased up to 120 DAS and thereafter it declined till harvest. *Bt* cotton as influenced by plant types and planting densities and their interaction did not differ significantly with respect to chlorophyll content in leaves at all growth stages of cotton crop during two years of study.

Canopy temperature was not influenced by plant type and densities of open type growing cotton hybrids was found with high chlorophyll content in leaves (32.90, 34.88, 40.81, 44.07 and 36.14 during 2021 and 33.08, 34.94, 40.90, 44.11 and 36.07 during 2022 and 32.99, 34.91, 40.86, 44.09 and 36.11 in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) compared to compact type of growing cotton hybrids (31.44, 33.33, 38.99, 42.11 and 34.53 during 2021 and 31.61, 33.36, 39.09, 42.18 and 34.68 during 2022 and 31.53, 33.35, 39.04, 42.15 and 34.61 in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively).

With respect to plant densities low density planting provided higher chlorophyll content values (32.30, 34.24, 40.06, 43.27 and 35.48 during 2021 and 32.48, 34.31, 40.16, 43.31 and 35.41 during 2022 and 32.39, 34.28, 40.11, 43.29 and 35.45 in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) at all the stages when compared to high density planting (31.99, 33.91, 39.67, 42.85 and 35.13 during 2021 and 32.07, 34.01, 39.76, 42.86 and 35.22 during 2022 and 32.03, 33.96, 39.72, 42.86 and 35.18 in pooled mean at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest, respectively) this is due to the fact that, low plant densities are provided with all the natural resources required for their growth and attributed in better performance of individual plant.

Similar reports of non-significant influence of plant types and planting densities on canopy temperature was reported by Yang *et al.* (2014).

CONCLUSION

Leaf Area Index (LAI) was significantly influenced by various plant types and plant densities at all growth stages except at 30 DAS and interaction during 2021 and 2022 and pooled mean. Highest leaf area index at 60 DAS, 90 DAS, 120 DAS and at harvest was recorded with semi open type (Sadanand), which was statistically on par with open type (RCH-659) and significantly superior to compact type (Siri) plants. Among plant densities LAI revealed that at 60 DAS, 90 DAS, 120 DAS and at harvest significantly highest LAI was found in planting density of 90 x 20 cm (55,555 plants ha^{-1}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}). While, least LAI was found in planting density of 90 x 60 (18,518 plants ha^{-1}).

Data pertaining to specific leaf weight (mg cm^{-2}) shows that specific leaf weight was significantly affected by the plant types and plant densities at all growth stages except at 30 DAS and interaction. Specific leaf weight at 60 DAS, 90 DAS, 120 DAS and at harvest followed the similar trend during both years and pooled mean. Maximum specific leaf weight was recorded with compact type (Siri) plants which was statistically on par with open type (RCH-659) and significantly superior to semi open type (Sadanand). While, minimum specific leaf weight was observed with semi open type (Sadanand). Specific

Table 6: SPAD Chlorophyll meter readings of *Bt* cotton at 30 DAS, 60 DAS, 90 DAS, 120 DAS 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)	31.44	31.61	31.53	33.33	33.36	33.35	38.99	39.09	39.04	42.11	42.18	42.15	34.53	34.68	34.61
P_2- RCH 659 (Open)	32.24	32.32	32.28	34.17	34.27	34.22	39.98	40.07	40.03	43.18	43.19	43.19	35.41	35.5	35.46
P_3- Sadanand (Semi Open)	32.90	33.08	32.99	34.88	34.94	34.91	40.81	40.90	40.86	44.07	44.11	44.09	36.14	36.07	36.11
SE(m)±	0.78	0.66	0.72	0.83	0.80	0.82	0.97	0.97	0.97	1.05	1.05	1.05	0.86	0.87	0.87
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub plot treatments: Plant densities															
D_1- 90×20cm (55,555 plants ha^{-1})	31.99	32.07	32.03	33.91	34.01	33.96	39.67	39.76	39.72	42.85	42.86	42.86	35.13	35.22	35.18
D_2- 90×30cm (37,037plants ha^{-1})	32.29	32.46	32.38	34.23	34.26	34.25	40.05	40.15	40.10	43.25	43.32	43.29	35.47	35.62	35.55
D_3- 90×60cm (18,518 plants ha^{-1})	32.30	32.48	32.39	34.24	34.31	34.28	40.06	40.16	40.11	43.27	43.31	43.29	35.48	35.41	35.45
SE(m)±	0.50	0.58	0.54	0.53	0.57	0.55	0.62	0.68	0.65	0.67	0.7	0.69	0.55	0.49	0.52
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
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

leaf weight in respect to densities were observed to be significant at 60 DAS, 90 DAS, 120 DAS and at harvest and highest was found in 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 specific leaf weight was found in planting density of 90 x 20 cm (55,555 plants ha^{-1}) at 60 DAS, 90 DAS, 120 DAS and at harvest during 2021, 2022 and pooled mean.

Data pertaining to light interception rate (%) reveals that light interception rate was significantly affected by the plant types and plant densities at all growth stages. Whereas, interaction between the plant types and densities found non-significant. Significantly highest light interception rate at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest followed the similar trend during both the years of study and pooled mean. Maximum light interception rate at all growth stages were recorded with semi open type (Sadanand), which was found statistically on par with open type growth of *Bt* cotton plants (RCH-659) and significantly superior to compact type (Siri) plants. With regard to plant densities highest light interception rate was recorded with density of 90 x 20 cm (55,555 plants ha^{-1}) which was significantly superior to other plant densities *viz.,* 90 x 30 cm (37,037 plants ha^{-1}) and 90 x 60 cm (18,518 plants ha^{-1}) at 30 DAS, 60 DAS, 90 DAS, 120 DAS and at harvest.

Data pertaining to canopy temperature and SPAD readings (chlorophyll content in leaves) were not significantly influenced by canopy architectures and plant densities at 30 DAS, 60 DAS, 90 DAS,120 DAS and at harvest during 2021 and 2022 and pooled mean.

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