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GROWTH DYNAMICS AND COTTON YIELD UNDER VARIABLE THERMAL REGIMES IN SOUTH-WESTERN PUNJAB

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ABSTRACT

A study was carried out during 2020 and 2021 to examine the growth dynamics and cotton yield under various thermal regimes in south western Punjab. The experiment was planned in a factorial randomized complete block design with four sowing dates and two cultivars and replicated thrice. There was a significant decline in growth and yield attributes of tested cultivars with each successive delay in sowing from April 01. Early sown crop recorded higher seed cotton yield (2223-2956 kg ha^{-1}), which was 4-5% higher than April 20, 17-18% higher than May 10 and 36-46% higher than May 30 sown crop. This increase in seed cotton yield was due to congenial weather conditions which resulted in extended phenophases, better growth attributes like plant height and leaf area index, improved yield attributes like monopods plant^{-1}, sympods plant^{-1}, bolls plant^{-1} and boll weight that lead to higher seed cotton yield. Results also confirmed the outperformance of *Bt* hybrids in comparison to non-*Bt* genotype. The *Bt* cotton sown in the month of April was found to give higher seed cotton yield as compared to its non-*Bt* version.

Keywords: Cotton, Cultivars, Seed cotton yield, Sowing dates.

India is a global leader in terms of area under cotton cultivation as well as raw cotton production. Its cultivation provides livelihood to about 60 million people through direct and indirect cotton based activities. Here, cotton is grown on a wide range of soil types, climatic conditions ranging from arid to semi-arid to sub-humid and from rainfed (65% cotton area) to irrigated (remaining 35% cotton area) conditions. In rainfed areas, rainfall fluctuates from below 400 mm to above 900 mm coupled with erractic patterns leading to large variation in cotton production (Boopathi *et al.,* 2014). In India, cotton cultivation is mainly divided into three different zones viz. north, central and south zones. Punjab falls in the northern cotton zone of the country and represents ~20% area of this cotton zone. Being irrigated on productive soils, the productivity of this zone is higher (570 kg lint ha^{-1} compared to national average of 487 kg lint ha^{-1}) than other two zones (Anonymous, 2021). In Punjab, cotton is a second major Kharif crop after rice and a predominant cash crop of south-western zone, popularly known as cotton belt of Punjab. Cotton is also an important alternative to rice with the view of crop diversification. In this region the major constraints to cotton production are- high input costs, higher insect pest infestation, price fluctuation, etc. The situation is further aggravated by weather related constraints such as uncertain rainfall, high temperature at germination, high wind speed, etc. along with the changing climate.

Cotton growth, development and yields have been mostly affected by temperature out of many other environmental factors. Variations in temperature distresses the plant processes, resulting in differential time of squaring, anthesis and boll development (Mudassir *et al*., 2021). This type of variations in the field can be created by selecting differential sowing time. Optimum sowing time is the key management decision that determines the rate of several plant processes like phenology, accumulation of assimilates and its conversion in to sink structures and finally the economical yield (Bozbek *et al.,* 2006; Ali *et al.,* 2009). Timely sown crop experiences optimum conditions like solar radiations to produce more biomass (Arshad *et al.,* 2017). Contrarily, late sown crop which is exposed to sub-optimal and super-optimal temperatures during early vegetative and late reproductive phases (Akhter *et al.,* 2002), diseases like cotton leaf curl (Nawaz *et al.,* 2019), influences the shedding of flowers (Rahman *et al.,* 2016) and shortening of fruiting period (Mehboob *et al.,* 2020). Rahman *et al.*, (2017) reported that there was gradual decrease in time to start squaring with each 20 days delay in sowing between March 10 to June 21 in Pakistan. Timely sown crop has optimum canopy surface area (Kaur *et al.*, 2019) to efficiently accumulate dry matter for higher yield (Kaur *et al.*, 2022). Overall, sowing time is the reliable tools which are being used to evaluate the crop performance.

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For better establishment, ideal soil temperature ranges from 16-28°C and irrigation/rainfall requirement is 550-950 mm during the crop season (Datta *et al.,* 2019). Number of squares and bolls reduced considerably at a temperature above 35°C and becomes zero when temperature reaches 40°C (Hodges *et al.,* 1993). Late sowing exposed the reproductive phases of cotton against lethal temperatures. During crop maturity, marked dry season is beneficial for proper boll opening and picking. The objective of optimum sowing time is to overcome the cold shock and to reduce heat stress incidence to ensure that fruit has sufficient time to mature with better quality and optimum seed cotton yield. Considering these optimum conditions, the present study examined the yield contributing characters of two cotton genotypes under four sowing environments of south-western Punjab.

MATERIALS AND METHODS

A field experiment was conducted during 2020 and 2021 *kharif* season each at Regional Research Station, Bathinda (30°58'N, 74°18'E, 211m amsl), which is part of the Punjab Agricultural University (PAU), Ludhiana. The experiment was laid out in factorial randomized complete block design with four sowing dates (April 01, April 20, May 10 and May 30) and two cotton cultivars (F 2228 and RCH 773 BGII) in three replications. The soil of the experimental site was low in available nitrogen (186-197 kg ha^{-1}) and organic carbon (0.33-0.35 percent), medium in available phosphorus (15-17 kg ha^{-1}), medium to high in available potassium (242-282 kg ha^{-1}), slightly alkaline in pH (8.32-8.35) with sandy loam texture. Sowing of cotton was done by dibbling two seeds hill^{-1} in planting geometry of 67.5 cm ×75.0 cm. All the recommended cultural and plant protection measures were followed as per guidelines of the Punjab Agricultural University (Anonymous, 2020). Crop phenology, plant height, number of monopods, sympods and bolls plant^{-1} and boll weight were recorded from ten randomly selected plants from each plot. The attainment of a particular phenological phase was visually observed, when five out of ten tagged plants were entered into that particular stage. Leaf area index was calculated using leaf area meter from three randomly selected plants by dividing it with ground area. For this, two representative leaves from three different categories (i.e. small, medium and large size) were selected and then this average leaf area was multiplied by the total number of leaves of respective size. Number of bolls plant^{-1} was recorded at maturity from an average of ten plants. Average boll weight was calculated from randomly taking ten bolls plant^{-1} and then dividing the weight by ten. Seed cotton yield (SCY) was obtained from the total of two manual pickings on whole plot basis. Statistical analysis was performed using statistical package CPCS1 designed by the Department of Mathematics and Statistics, PAU, Ludhiana.

RESULTS AND DISCUSSION

Seasonal weather

Mean weather variations observed during the crop growing period has been presented in Figs. 1, 2 and 3. Early sown crops (April 01 and April 20) started their growth with lower maximum (1.7-4.0°C) and minimum (4.1-10.5°C) temperatures than those with late sowings (May 10 and May 30). However, the early sown crop had higher temperatures near maturity, which is beneficial for boll development while the temperatures were considerably low for the late sown crop (Fig. 1). Likewise, the early sown crop accumulated more sunshine hours (BSShrs) than the late sown crop. Total rainfall was also higher for the early sown crops, except during 2021 when April 20 and May 10 sowings received more rainfall (Fig. 3).

Table 1. Phenological calendar of cotton as affected by different treatments

Treatments	Emergence		First square		Anthesis		Boll opening		Maturity	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Sowing dates										
April 01	10.3[a]	9.3[a]	56.5[a]	55.7[a]	71.3[a]	69.7[a]	120.7[a]	120.0[a]	169.7[a]	173.3[a]
April 20	9.5[b]	9.2[a]	53.0[b]	52.3[b]	68.7[b]	67.5[b]	114.2[b]	115.8[b]	163.2[b]	166.3[b]
May 10	8.8[b]	8.5[a]	49.8[c]	50.5[c]	62.2[c]	60.8[c]	109.0[c]	112.8[c]	157.0[c]	162.0[c]
May 30	7.5[c]	6.3[b]	47.2[d]	46.5[d]	60.2[d]	59.8[c]	106.0[d]	108.2[d]	151.5[d]	156.0[d]
CD (5%)	0.71	0.86	1.22	1.50	1.59	1.81	1.61	1.53	1.01	2.26
Cultivars										
F 2228	9.8[a]	9.0[a]	54.1[a]	53.1[a]	68.0[a]	67.2[a]	114.2[a]	115.9[a]	164.7[a]	169.4[a]
RCH 773 BGII	8.3[b]	7.7[b]	49.2[b]	49.4[b]	63.2[b]	61.8[b]	110.8[b]	112.5[b]	156.0[b]	159.4[b]
CD (5%)	0.50	0.61	0.87	1.06	1.12	1.28	1.14	1.08	0.72	1.59

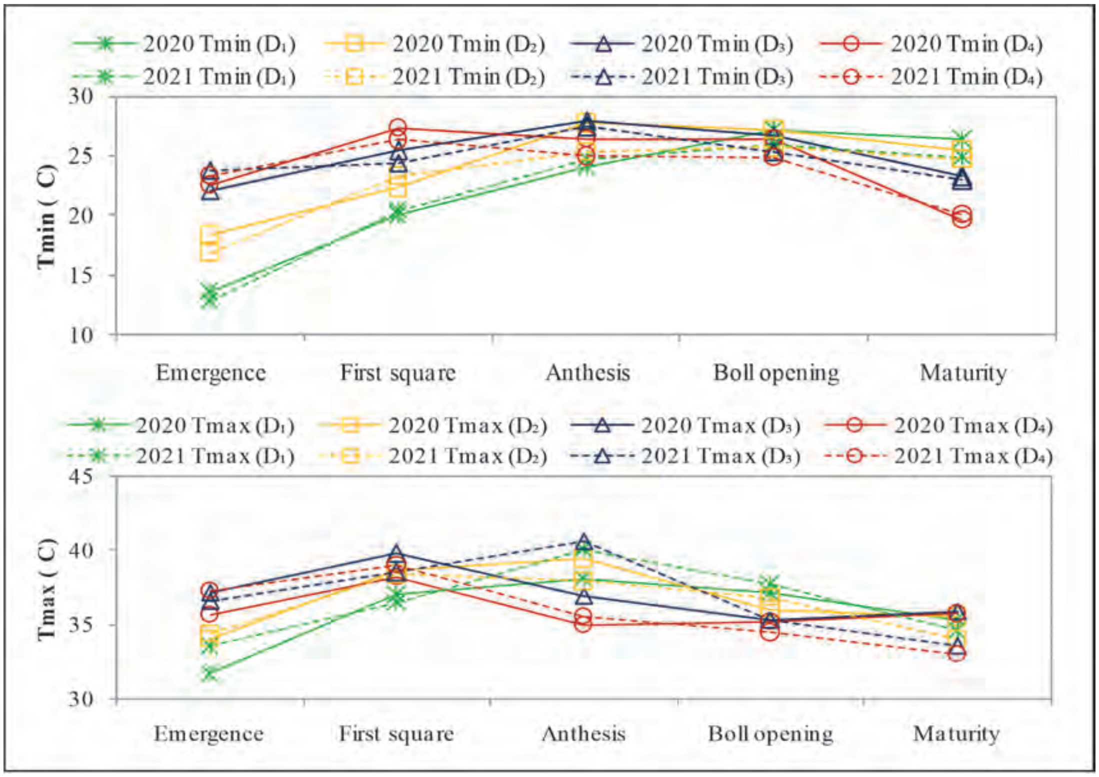

Fig. 1. Maximum temperature and minimum temperature during crop phenophases

Crop phenology

Time to emergence was significantly higher (10.3 and 9.3 days) for the April 01 sown crop and it progressively decreased for April 20 (9.5 and 9.2 days), May 10 (8.8 and 8.5 days) and May 30 (7.5 and 6.3 days) sowings during both seasons (Table 1). Late sowings exposed the seeds to higher temperatures (Fig. 1) leading to quick emergence but with lower emergence count (Kamran *et al*., 2017). The maximum days to initiate first square was observed in April 01 sowing which gradually decreased to minimum in May 30 sowing (difference of 9.2-9.3 days during both the years) in conformity with Rahman *et al.*, (2017). The opening of bolls, was also reduced by 11.8-14.7 days with delay in sowing window from April to end of May and this difference was further widened to 17.3-18.2 days near crop maturity. This difference in the occurrence of phenophases among sowing dates is due to the variations in the prevailing weather parameters (Fig. 1 and 3) especially temperature (Mehboob *et al.,* 2020). Mudassir *et al.,* (2021) also observed the phenophasic advancement in cotton by varying sowing time from March to mid-May due to least incidence of low temperature stress. Among cultivars, *Bt* cultivar RCH773 BGII took less calendar

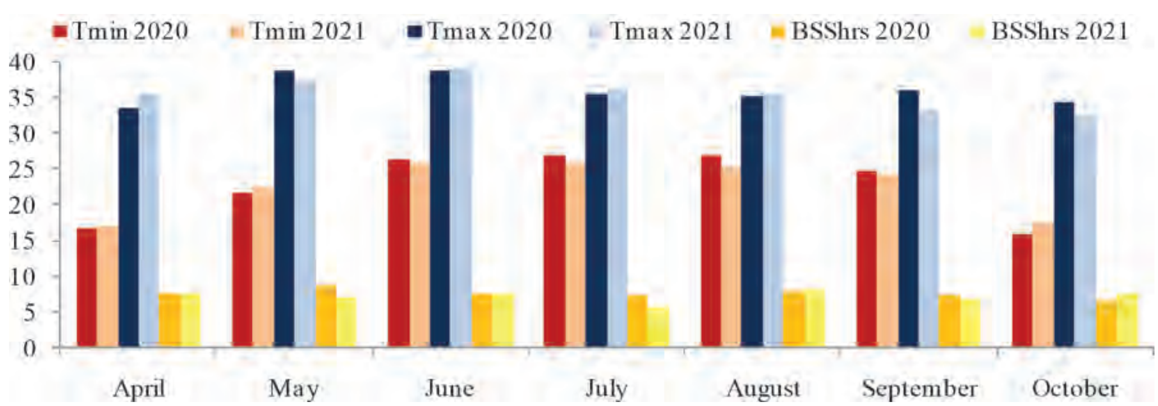

Fig. 2. Monthly weather variations during crop growing period

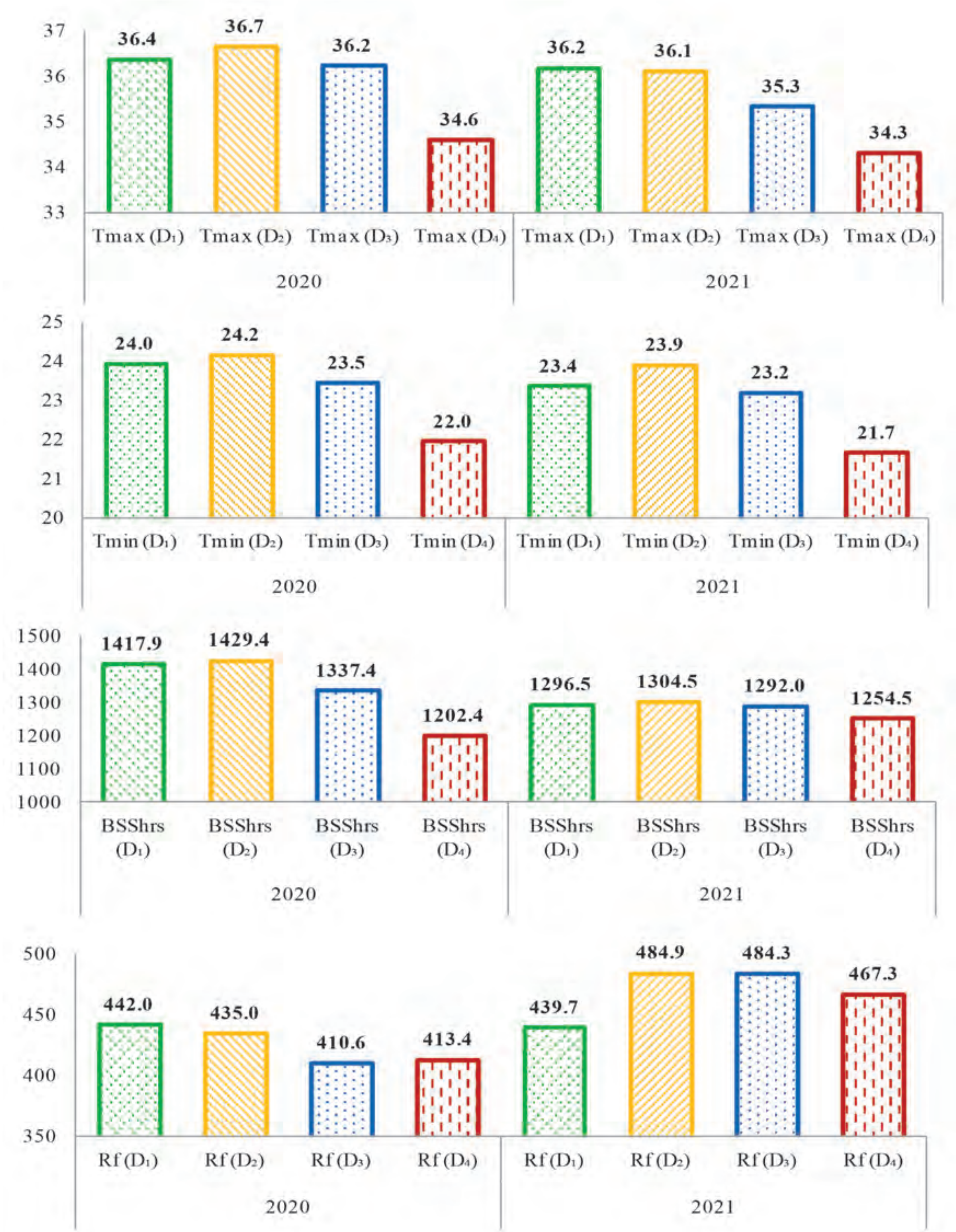

Fig. 3. Mean maximum and minimum temperature (°C), cumulative bright sunshine hours and rainfall (mm) during crop growing period

days for sowing to maturity than non-*Bt* cultivar F 2228. Earliness of *Bt* cultivars over non-*Bt* cultivars with respect to appearance of different growth stages such as first bud, first flower, first boll split and maturity has been also reported by Thakur *et al.* (2017).

Yield attributes

The favourable weather conditions, enhanced vegetative and reproductive phases, early sown crop resulted into taller plants and higher leaf area index. With each delay in sowing, leaf area index and plant

Table 2. Yield and yield attributes of cotton as affected by different treatments

Treatments	Plant height (cm)		Leaf area index		Monopods plant^{-1}		Sympods plant^{-1}		No. of bolls plant^{-1}		Boll weight (g)		Seed cotton yield (kg ha^{-1})	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Sowing dates														
April 01	189.2^{a}	186.8^{a}	5.26^{a}	5.35^{a}	4.6^{a}	4.7^{a}	28.1^{a}	27.7^{a}	65.2^{a}	51.9^{a}	3.88^{a}	3.20^{a}	2956^{a}	2224^{a}
April 20	187.2^{a}	189.8^{a}	5.16^{a}	5.24^{a}	3.8^{a}	3.9^{b}	27.8^{a}	26.7^{b}	61.3^{a}	44.6^{b}	3.93^{a}	3.05^{a}	2821^{a}	2131^{b}
May 10	157.7^{b}	160.2^{b}	4.76^{b}	4.84^{b}	2.8^{b}	2.9^{c}	22.2^{b}	21.9^{c}	49.3^{b}	39.3^{c}	3.30^{a}	2.40^{b}	2467^{b}	1834^{c}
May 30	142.7^{c}	148.7^{c}	4.32^{c}	4.41^{c}	2.3^{b}	2.4^{d}	17.3^{c}	17.7^{d}	36.0^{c}	26.6^{d}	2.78^{a}	2.15^{c}	1902^{c}	1193^{d}
CD (5%)	7.42	6.30	0.11	0.13	0.89	0.09	1.80	0.73	4.08	1.39	NS	0.07	149.89	70.40
Cultivars														
F 2228	175.6^{a}	176.4^{a}	4.97^{a}	5.06^{a}	3.0^{b}	3.1^{b}	22.6^{b}	22.6^{b}	49.8^{b}	38.5^{b}	3.04^{b}	2.50^{b}	2346^{b}	1777^{b}
RCH 773 BGII	162.8^{b}	166.3^{b}	4.77^{b}	4.86^{b}	3.7^{a}	3.8^{a}	25.0^{a}	24.4^{a}	56.1^{a}	42.7^{a}	3.91^{a}	2.90^{a}	2727^{a}	1914^{a}
CD (5%)	5.25	4.45	0.08	0.09	0.63	0.06	1.27	0.52	2.89	0.98	0.65	0.05	105.99	49.78

height gradually reduced and reported significant reduction in late sown crop that restricted canopy surface area to intercept solar radiation (Kaur *et al.*, 2019). The improved canopy size in April 01 sowing resulted in more sympods plant^{-1} (26.7-28.1), number of bolls plant^{-1} (51.9-65.2) and boll weight (3.20-3.88 g), as shown in Table 2. With further delay in sowing, the respective parameters were reduced by 1-4%, 6-14% and 1-4% in April 20 sowing. However, this reduction was further widened by 18-21%, 23-24% and 15-25% in May 10 and by 37-38%, 48-49% and 28-33% in May 30 sown crop than the April 01 sown crop. In case of late sown crop, total sunshine hours decreased (Fig. 3) that lead to progressive fall in growth attributes of cotton crop (Sankaranarayanan *et al.,* 2020). Among cultivars, *Bt* cultivar RCH 773 BGII recorded significantly higher sympods plant^{-1} (24.4-25.0), number of boll plant^{-1} (42.7-56.1) and boll weight (2.90-3.91 g) over F 2228. These differences were mainly due to the genetic makeup of cultivars. It also confirmed the superiority of *Bt* cultivars for efficient source sink mechanism, better fruiting efficiency, early maturing mechanism and higher SCY over non-*Bt* cultivars (Kaur *et al.,* 2022).

Seed cotton yield

As a result of improved growth and yield attributes, significantly higher SCY was recorded in April 01 sowing (2223-2956 kg ha^{-1}). Which was further reduced by 4-5% in April 20, 17-18% in May 10 and 36-46% in May 30 sown crops. The yield of crop during 2021 season was less (~25%) than that during the 2020 season due to attack of pink bollworm in the north western cotton zone of India. As early sown crop stays longer in the field to utilize accumulated temperature and bright sunshine hours from flowering to boll opening, it produces more photosynthates for sink structures like lint and seed (Karman *et al.,* 2017). Khan *et al.* (2017) also reported 26% higher lint yield and 45% more bolls in early sown crop owing to relatively longer cropping season that allowed greater utilization of available resources in comparison to the late sown crop. However, under late sown environments crop was subjected to earlier boll opening and also shorter duration of effective boll development caused by overlapping of vegetative and fruiting phase (Table 1). Karman *et al.* (2017) reported that extreme heat under late sown conditions lead to photosynthesis inhibition, low biomass accumulation and male sterility and finally the shedding of flowers and bolls. Similarly, Gormus and Yucel (2002) found that decreased plant height, height to node ratio, number of open bolls and fruiting branches plant^{-1} were the limiting parameters for lower SCY under late sown environments. Singh *et al.* (2020) also found that reduction in period for boll growth, poor biomass, and unfavourable environment for boll maturity lead to lesser and small bolls in late sown crop were the main reasons for low crop yield. Among cultivars, higher SCY was observed in RCH 773 cultivar (1914-2727 kg ha^{-1}) than non-*Bt* hybrid. Kaur *et al.* (2022) also documented the outperformance *Bt* genotypes with 9% more biomass in fruiting structures over the non-*Bt* cultivars.

It is concluded from the study that delayed sowing resulted in advancement of phenological stages, poor canopy structure and growth and poor yield attributes, thus leading to low yields. Whereas, early sowing provided congenial weather conditions to the crop resulting in more thermal unit accretion, improved crop growth and yield attributes and higher SCY. Thus, April sowing of cotton was found to be the best choice for higher SCY in *Bt* cotton hybrids in south western region of Punjab.

Authors' contribution

Conceptualization of research work and designing of experiments (VK, SPS, RKP, SSS, PKK); Execution of field/lab experiments and data collection (VK, RKP); Analysis of data and interpretation (VK, RKP, SSS); Preparation of manuscript (VK, SPS, RKP, JS).

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