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IMPACT OF CLIMATIC VARIABLE INDUCED ABIOTIC STRESS ON FLOWERING PATTERN IN BG-II COTTON (*G. HIRSUTUM*) HYBRIDS

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ABSTRACT

The flowering pattern significantly influences the behavior of any hybrid or varieties. The flowering phase of a genotype play a crucial role in deciding optimal sowing window, hybridization timing and time of crop termination. Hybrids with early flowering tendency are suitable for late sowing, while late-flowering ones are recommended for early sowing. Describing cotton hybrids as early, timely, or late based on flowering initiation to termination is challenging due to the indeterminate growth habit. The 50% flowering stage serves as a crucial parameter to determine the dominant fruiting phase and overall duration of a hybrid. An investigation during 2018 to 2022 was undertaken to access the influence of climatic variables on the flowering patterns of cotton hybrids. Based on 50% flowering data recorded for 454 hybrids across five study years, hybrids were categorized considering 50% flowering duration vis-à-vis corresponding Standard Meteorological Week (SMW). The 50% flowering window for BG-II cotton hybrids ranged from 43 DAS to 90 DAS (25 SMW to 31 SMW) wherein 60 DAS to 83 DAS (27 to 30 SMW) recorded as prominent 50 % flowering window observed across the years and hybrids. In 2018, out of 100 BG-II hybrids, 28 hybrids (28%) reached 50% flowering at 69 DAS, while 41 hybrids (41%) achieved the same at 83 DAS. For 2019, out of 96 hybrids, around 32% flowered at 70 DAS and approximately 64% at 77 DAS. Moving to 2022, around 51% and 46% of 43 hybrids flowered at 73 DAS and 80 DAS (29 SMW), respectively. The time required for 50% flowering showed a positive correlation ($p<0.05$) with cumulative rainfall and T_{min} (minimum temperature) throughout the study period. Conversely, a negative correlation ($p<0.01$) was observed with $T_{difference}$; indicated lower cumulative rainfall and higher $T_{difference}$ may led to stressful conditions resulting early 50% flowering.

Key words : 50% flowering, BG-II hybrids, Cotton, Days after sowing (DAS), Standard Meteorological Weeks (SMW).

Introduction

India is the largest producer of cotton in the world with 312 lakh bale production in an area of 12.37 million hectare with productivity of 428.4 kg lint/ha as per the estimates of Directorate of Economics and Statistics, Ministry of Agriculture & Farmers' Welfare, 2021-22. Bollgard-II (BG-II) cotton is the only GM crop approved by Genetic Engineering Appraisal Committee (GEAC) for commercial cultivation in India during the year 2005 and it occupies more than 95% of total area under cotton cultivation (Verma *et al*., 2021). In 2020-21, India's cotton production has declined by 2.31 % to 352.48 lakh bales as compared to 360.65 lakh bales in 2019-20 as per the estimates of Directorate of Economics and Statistics; while it again reduce by 12.33 % in 2021-22 (312.03 lakh bales) compared to 2020-21 (DES, Ministry of Agriculture & Farmers' Welfare, 2021-22). The overall yield of a genotype in cotton is the output of total good opened bolls, a product of flowering wherein variations in climate have an impact on the flowering patterns of plants in terrestrial ecosystems (Rosenzweig *et al*., 2007; Khan *et al*., 2018; Wang *et al*., 2018). Multiple research investigations have shown that temperature significantly affects the reproductive phase of different plant species (Wang *et al*., 2018). However, it was shown that the response of temperature variation and effect on phenological stages is not uniform in nature as there were geographic variations in temperature (Vashistha *et al*., 2009). To describe a hybrid as early, timely or late based on initiation of flowering to termination is very difficult in cotton due to its indeterminate growth habit. The time (from days to sowing), when 50 percent of the plants have started flowering is described as 50% flowering time (Franks *et al*., 2007). So 50% flowering is a parameter for dominant fruiting phase as well as duration of the particular variety or hybrid. Each particular hybrid has a different level of productivity, depending on the female parent's yielding ability, synchronization of female and male flowering (Tiwari *et al*., 2022). Understanding the proper time of hybridization, harvesting time and optimal sowing windows may play an important role in increasing the yield of cotton hybrids. Flowering pattern is an important parameter by which breeder can determine the earliness as well as proper time of crossing for particular hybrid (Majeed *et al*., 2021). In general 50% flowering time is estimated to examine the flowering behavior of a particular variety/hybrid (Lal *et al*., 2023). Flowering pattern may successfully indicate the proper time of hybridization, crop termination and optimum sowing window for a particular crop (Waghmare, 2022). For instance, if a hybrid is early flowering in nature that may be recommended for late sowing where as if a hybrid showed late 50% flowering that may be recommended for early sowing. Accessing the flowering pattern sometimes also aids in managing issues like Pink Bollworm (PBW) and Cotton Leaf Curl Disease (CLCuD) (Ali *et al*., 2003). Extended flowering periods contribute to PBW inoculums development, whereas completing flowering early reduces susceptibility to CLCuD as at later growth stages it showed less yield losses in cotton (Monga and Sain, 2021).

Materials and Methods

The present experiment was undertaken during 2018 to 2022 at ICAR-Central Institute for Cotton Research, Regional Station, Sirsa, Haryana to know the influence of climatic variables on flowering patterns in different sets of coded cotton hybrids received from seed companies. The general agronomic and cultural practices were uniform for all the hybrids starting from sowing to nutrition and pest management. The 50% flowering data was recorded for all the hybrids for each study year and were grouped into various categories according to number of days (DAS) required to reach at 50% flowering simultaneously the corresponding Standard Meteorological Week (SMW) was also recorded. The SMW designation of the weeks was represented as supplementary Table 1. A total of 454 BG-II hybrids (100 in 2018, 96 in 2019, 90 in 2020, 89 in 2021 and 84 in 2022) were evaluated to study the flowering pattern. In each study years the hybrids were categorized according to the time required to reach at 50% flowering described as days after sowing (DAS) and number of hybrids falling under a particular SMW (in terms of DAS) was recorded. The weather parameters were recorded from the Agro-meteorological observatory, ICAR-CICR, Regional Station, Sirsa. The difference in minimum and maximum temperature was expressed as $T_{difference}$ and the difference in minimum/morning and evening /minimum Relative humidity was expressed as RH_{diff}. The statistical analysis was performed in SAS Statistical programming software (SAS Institute Inc. 2016. SAS® 9.4 Language Reference: Concepts, Sixth Edition. Cary, NC: SAS Institute Inc.).

Supplementary Table 1 : Standard Meteorological Weeks.

Week No.	Dates	Week No.	Dates
1	01 Jan–07 Jan	27	02 Jul–08 Jul
2	08 Jan–14 Jan	28	09 Jul–15 Jul
3	15 Jan–21 Jan	29	16 Jul–22 Jul
4	22 Jan–28 Jan	30	23 Jul–29 Jul
5	29 Jan–04 Feb	31	30 Jul–05 Aug
6	05 Feb–11 Feb	32	06 Aug–12 Aug
7	12 Feb–18 Feb	33	13 Aug–19 Aug
8	19 Feb–25 Feb	34	20 Aug–26 Aug
9*	26 Feb–04 Mar	35	27 Aug–02 Sep
10	05 Mar–11 Mar	36	03 Sep–09 Sep
11	12 Mar–18 Mar	37	10 Sep–16 Sep
12	19 Mar–25 Mar	38	17 Sep–23 Sep
13	26 Mar–01 Apr	39	24 Sep–30 Sep
14	02 Apr–08 Apr	40	01 Oct–07 Oct
15	09 Apr–15 Apr	41	08 Oct–14 Oct
16	16 Apr–22 Apr	42	15 Oct–21 Oct
17	23 Apr–29 Apr	43	22 Oct–28 Oct
18	30 Apr–06 May	44	29 Oct–04 Nov
19	07 May–13 May	45	05 Nov–11 Nov
20	14 May–20 May	46	12 Nov–18 Nov
21	21 May–27 May	47	19 Nov–25 Nov
22	28 May–03 Jun	48	26 Nov–02 Dec
23	04 Jun–10 Jun	49	03 Dec–09 Dec
24	11 Jun–17 Jun	50	10 Dec–16 Dec
25	18 Jun–24 Jun	51	17 Dec–23 Dec
26	25 Jun–01 Jul	52**	24 Dec–31 Dec

*Week No.9 will be 8 days during leap year; **Week No. 52 will always have 8 days.

Results and Discussion

Flowering behavior of the hybrids during 2018 to 2022

The main idea of the study was to have information regarding the flowering behavior of the hybrid to decide its suitable time during sowing window. In Northern cotton

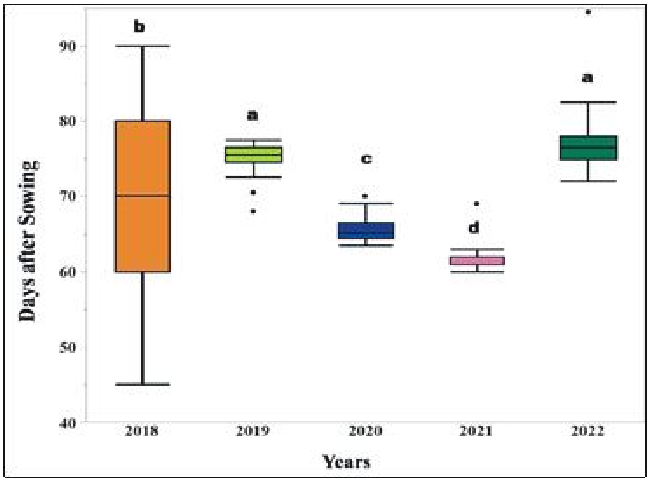

Fig. 1 : Variation in 50 % flowering time among the hybrids during 2018 to 2022. *Different letters up-on each box plot showed significant difference ($p<0.05$).

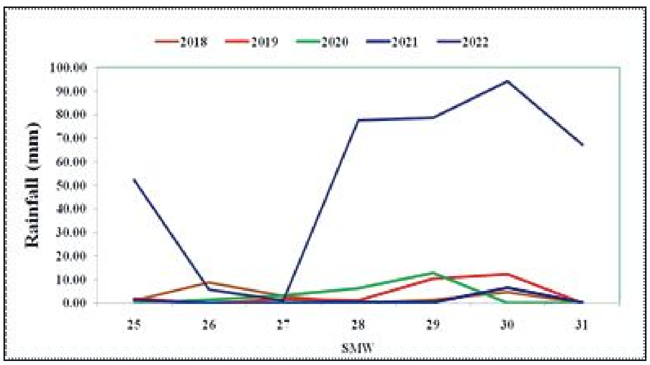

Fig. 2 : Standard Meteorological Week (SMW) wise rainfall pattern during 2018 to 2022.

growing zone of India, cotton crop is sown under assured irrigation system and the availability of canal water decides the sowing period. In such circumstances the flowering behavior or the duration of hybrids plays an immense role. Overall based on five years data it was observed that flowering window for the BG-II cotton hybrids spanned from 43 DAS to 90 DAS (25 SMW to 31SMW) of which 60 DAS to 83 DAS (27 to 30 SMW) recorded as dominating flowering window. During this period majority of the hybrids were at 50% flowering stage over the years. These hybrids are amenable for sowing during the optimum sowing window. During 2018 the 50% flowering time among various hybrids ranged between 48 DAS to 90 DAS where as in 2019 it ranged from 63 DAS to 77 DAS. In the year 2020, 50% flowering time spanned from 63 DAS to 70 DAS, on the other hand in 2021 it varied from 60 DAS to 67 DAS. During the year 2022, flowering window ranged between 73 DAS to 87 DAS. The longest flowering window was observed in 2018, where as it was shortest during 2020 and 2021 (Fig. 1).

Grouping of hybrids with respect to average time required for 50% flowering time

In the year 2018, 28 hybrids showed 50% flowering at 69 DAS (28 SMW) constituting approximately 28% of the evaluated hybrids (100 hybrids) and 41 hybrids constituting 41% of the evaluated hybrids were at 50% flowering at 83 DAS (30 SMW). In the year 2019, out of 96 hybrids evaluated; 31 hybrids showed 50% flowering after 70 DAS (29 SMW) and 61 hybrids showed 50% flowering at 77 DAS (30 SMW). In 2020, among 90 hybrids, roughly 81% displayed late flowering, with 73 reaching 50% at 29 SMW (63 DAS) and 17, approximately 19%, at 70 DAS (30 SMW). In 2021, around 99% of 84 hybrids were at 50% flowering by 60 DAS (27 SMW). Lastly, in 2022, about 52% and 46% of 84 hybrids flowered at 73 DAS (28 SMW) and 80 DAS (29 SMW), respectively. Table 1 represents the Year wise flowering behavior of the BG-II cotton hybrids.

Prevailing climatic variables during the flowering window over the years

In the year 2018, there was a gradual decrease in $T_{difference}$ from 25 SMW to 31 SMW. The minimum temperature was also in increase trend from 25 to 28 SMW. During 69 to 83 DAS (28-30 SMW) most of the hybrids (74%) were at 50% flowering as during period having higher minimum temperature ($T_{min)}$ and lowered temperature difference ($T_{diff'}$). The difference between maximum and minimum Temperature ($T_{difference}$) is negatively correlated with 50% flowering time which may lead to late flowering during this year. The same trend was also observed during 2019 also, the major flowering window was 63 to 77 DAS (28-30 SMW). The increase in T difference during 29-30 SMW may be the reason behind the completion of 50% flowering. During 2020, 63-70 DAS (29-30 SMW) was the period when all the hybrids were at 50 % flowering. The lowered $T_{difference}$ after 25th SMW may be the reason behind the late flowering behavior of the hybrids. The year 2021 was very typical as during the flowering window there was very less rain fall, which may leads to moisture stress situation and resulted in early flowering. During 2022, there was high rainfall during 25th SMW resulting absence of moisture stress situation resulting late flowering in most of the hybrids during 2022. It is very interesting to observe that higher T_{min} was playing a crucial role in speeding up the flowering among the hybrids; whereas $T_{difference}$ may responsible for completion timing of 50% flowering among majority of the hybrids (Tables 3 and 4, Fig. 2). Majeed *et al.* (2021), Badeck *et al.* (2004), Ahas and Aasa (2006), Estrella and Menzel (2006) and Peñuelas *et al*. (2004)

Table 1 : Grouping of hybrids with respect to average time required for 50% flowering during 2018 to 2022.

Year	Date of sowing	Number of hybrid observed with 50 % flowering (SMW)							
		25 SMW	26 SMW	27 SMW	28 SMW	29 SMW	30 SMW	31 SMW	Total no. of hybrids
2018	04 May 2018	5 (48 DAS)	1 (55 DAS)	19 (62 DAS)	28 (69 DAS)	5 (76 DAS)	41 (83 DAS)	1 (90 DAS)	100
2019	09 May 2019	-	-	-	4 (63 DAS)	31 (70 DAS)	61 (77 DAS)	-	96
2020	17 May 2020	-	-	-	-	73 (63 DAS)	17 (70 DAS)	-	90
2021	06 May 2021	-	-	83 (60 DAS)	1 (67 DAS)	-	-	-	84
2022	30 April 2022	-	-		44 (73 DAS)	39 (80 DAS)	1 (87 DAS)	-	84

***SMW:** Standard Meteorological Week.

Table 2 : Correlation co-efficient between climatic variables during the flowering window and time to 50% flowering.

Climatic variables	Time to 50 % flowering (DAS)
T_{max}	**-0.18**
T_{min}	**0.49***
RH (Morning)	**0.14**
RH (Evening)	**0.37**
T_{diff}	**-0.67****
RH_{Diff}	**-0.41**
Rainfall (cumulative)	**0.53***

*significant at 5%; **significant at 1%.

which may play a important role in understanding of the dynamics of flowering time under changing climate.

Correlation between climatic variables and 50 (%) flowering time

The time required to reach the 50% flowering was positively correlated with (p< 0.05) cumulative rainfall and T_{min} whereas, it was negatively correlated with (p< 0.01) $T_{difference}$ over the study period of 2018 to 2022. Temperature was fundamental in determining the phenological response in several parts of the world with altitudinal variances (Luo *et al*., 2007; Shen *et al.*, 2015). The influence of climatic parameters on flowering time in Linseed was reported by Jain (2011). Higher the cumulative rainfall and T_{min}; time required to reach 50% flowering will also be higher. On the other hand, higher $T_{difference}$ will lead to early flowering. The Morning and evening Relative humidity also showed positively correlation with time to 50% flowering though, it was not statistically significant (Table 2). Morrison and Stewart (2002) observed heat stress induced flowering in *Brassica* spp. Similar observations that the weather factors influencing the flowering behavior were also reported by

Table 3 : Temperature variables during the flowering period from 2018 to 2022.

SMW	2018			2019			2020			2021			2022		
	T_{max}	T_{min}	T_{diff}	T_{max}	T_{min}	T_{diff}	T_{max}	T_{min}	T_{diff}	T_{max}	T_{min}	T_{diff}	T_{max}	T_{min}	T_{diff}
25	38.57	21.76	16.81	37.61	26.03	11.59	40.64	29.93	10.71	39.10	28.60	10.50	33.10	24.50	8.60
26	35.56	21.39	14.17	39.91	26.93	12.99	38.61	29.79	8.83	41.70	29.70	12.00	39.80	27.00	12.80
27	36.03	24.37	11.66	38.26	27.11	11.14	38.79	29.26	9.53	40.3	30.50	9.80	36.50	28.10	8.40
28	37.97	27.01	10.96	36.07	26.20	9.87	36.96	26.71	10.24	37.90	28.50	9.40	35.60	26.40	9.20
29	35.27	26.50	8.77	33.30	21.99	11.31	34.76	26.24	8.51	37.40	27.10	10.30	35.20	26.30	8.90
30	35.14	26.36	8.79	33.33	22.09	11.24	36.36	26.96	9.40	33.80	27.10	6.70	33.0	26.30	6.70
31	36.34	27.43	8.91	34.83	22.93	11.90	36.49	26.86	9.63	34.50	26.70	7.80	32.30	26.20	6.10

have reported the impact of various weather factors on the flowering behavior of flora species such as Euphorbia, *Brassica*, *Heliotropium*, *Acacia* and *Solanum* in the district of Jhelum, Pakistan. Jagadish *et al*. (2016) observed a complex signaling network of flowering regulation with change in ambient temperature involving different transcription factors (*PIF4, PIF5*), flowering suppressors (*hvoddsoc2*, *SVP*, *FLC*) and autonomous pathway (*FCA*, *FVE*) genes, mainly from *Arabidopsis*,

Table 4 : Variation for Relative humidity during the flowering period from 2018 to 2022.

SMW	2018			2019			2020			2021			2022		
	RH Morn	RH Even	RH diff	RH Morn	RH Even	RH diff	RH Morn	RH Even	RH diff	RH Morn	RH Even	RH diff	RH Morn	RH Even	RH diff
25	76.14	49.00	27.14	70.14	46.14	24.00	61.00	40.00	21.00	66.9	41.3	25.60	84.4	56.1	28.3
26	76.86	63.29	13.57	62.29	41.71	20.57	73.86	47.71	26.14	57.6	31.9	25.70	57.3	43.0	14.3
27	82.00	62.14	19.86	63.57	47.29	16.29	74.57	48.29	26.29	58.4	37.3	21.10	71.9	55.3	16.6
28	72.43	51.43	21.00	71.71	56.29	15.43	78.86	51.57	27.29	68.6	51.4	17.20	77.1	71.0	6.1
29	77.29	64.86	12.43	83.14	66.00	17.14	87.29	61.14	26.14	79.0	55.6	23.40	83.0	77.3	5.7
30	84.43	66.43	18.00	83.57	71.57	12.00	74.86	55.57	19.29	85.3	73.1	12.20	90.3	76.7	13.6
31	66.86	53.71	13.14	80.86	65.86	15.00	72.14	60.14	12.00	87.4	67.4	20.00	89.0	80.7	8.3

Craufurd and Wheeler (2009) in maize, Jagadish *et al*. (2016) in wheat and maize.

The present study examined how weather affects cotton flowering patterns. Over several years, we found that the timing of 50% flowering varied depending on rainfall and temperature. Cooler temperatures and more rain led to later flowering, while drier and warmer conditions caused earlier flowering. This information can help stakeholders as well as farmers to choose cotton hybrids best suited for planting times and weather conditions.

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Authors' contribution

RK, SKV, DP, AP: Conceptualization and conduct of the experiments, DP, RK: Data analysis and interpretation of the results; DP, RK, SKV and SB: writing of the manuscript; RK, DP, SKV and SB: Editing and proofreading.

Conflict of interest

The authors declare no conflict of interest.

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