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Optimization of sowing time to mitigate heat stress in spring maize (*Zea mays*) in Indo-Gangetic plains of India

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ABSTRACT

In spring maize (*Zea mays* L.) prone to heat stress, especially at terminal stages, understanding the impact of sowing time on important genotypes for heat stress tolerance is crucial to optimize yield. An experiment was conducted during 2020 and 2021 at the Research farm of ICAR-Indian Institute of Maize Research, Ludhiana, Punjab to study the effect of sowing time and genotype interactions on yield and heat stress in spring maize. The experiment was laid out in a split-plot design (SPD) comprised of 4 different sowing dates, viz. 15th February; 25th February; 5th March; and 15th March, and 4 maize genotypes, viz. PMH1; PMH10; CoH(M)6; and CoH(M)8, replicated thrice. Spring maize sown on 15th February gave a higher grain yield (8.5 t/ha). Successive delays of 10, 20, and 30 days in sowing of spring maize caused significant yield penalties of 15%, 24%, and 29%, respectively. Heat stress at flowering was observed with delayed sowing (5th and 15th March), leading to a ~20% yield decline compared to non-stressed conditions (15th February). Furthermore, sowing beyond 15 February resulted in a shortening of vegetative (4–15 days) and reproductive (3–8 days) periods. Spring maize sown on 15 February gave higher water productivity (16–34%) compared to delayed sowings. Among genotypes, PMH 1 recorded a higher yield (8.2 t/ha) under non-stressed conditions with early sowing on 15th February. However, under heat stress, PMH 10 gave a higher yield (6.5 t/ha) sown on 25th February. Overall, it could be concluded that spring maize sowing up to 15th February is the optimum time to avoid heat stress at the flowering stage to achieve higher yield in north-western regions of India.

Keywords: Anthesis-silking interval, Heat stress, Spring maize, Staggered sowing, Water productivity

Maize (*Zea mays* L.) is one of the world's leading cereals having a global annual production of >1 billion tonnes (Sharma and Dass 2012, FAO 2023). In India, maize is grown throughout the year, having accounts in *kharif* (83%) and *rabi* (17%) seasons, and it shares about 9% of the national food grain production and also provides quality feed for poultry and animals as well as raw material for industry (Dass *et al.* 2015, Ghosh *et al.* 2016 and Kumari *et al.* 2017). The recent rise of demand in the poultry sector and bioethanol production from maize has generated an additional demand of 17 million tonnes by 2025 (GOI 2022). In northern India, the area under spring maize has expanded considerably in Punjab and Haryana owing to the best-suited option after the harvest of *toria*, sugarcane, potato, and pea in February. Additionally, spring maize has a high grain (6–8 t/ha) and biomass (11–13 t/ha) yield potential fetching 60–80,000 ₹/ha within 120–130 duration days (February–June)(Ordonez *et al.* 2015). Heat stress during the reproductive stage has become one of the prime abiotic stresses for crop production in the semi-arid tropics of India.

In India, about 50–60% of the maize growing area faces heat stress (>35°C) during the pre-monsoon hot season from April to June (Zaidi *et al.* 2016). It is predicted that annual mean maximum temperatures may rise by 1.4–1.8°C in 2030 and 2.1–2.6°C by 2050 (Tesfaye *et al.* 2017) may cause yield loss owing to heat stress sensitivity at the reproductive stages (T. max >35°C and T. min >23°C, relative humidity <40%) (Chen *et al.* 2012). Optimal sowing date provides appropriate environmental conditions like rainfall, less fluctuation of temperature, sunshine, etc. during the entire crop cycle that helps in achieving crop yield potential (Sepat *et al.* 2019). An increase in every 2°C temperature above the normal temperature may cause an 8–13% yield reduction in maize (Lobell *et al.* 2011). In maize, genotype suitability is another critical factor for obtaining higher productivity. The selection of early maturing maize genotypes may avoid high temperature stress from the anthesis to grain filling stage

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owing to the completion of the life cycle from February–June during pre-monsoon hot seasons. It was presumed that a combination of optimal sowing time and suitable maize early maturing genotypes could be the best adaptation strategy for protecting maize from adverse weather conditions without having any yield penalty. Therefore, a study was planned to investigate the influence of sowing time and genotype interactions on yield and heat stress in spring maize.

MATERIALS AND METHODS

The experiment was conducted during 2020 and 2021 at the Research farm of ICAR-Indian Institute of Maize Research, Ludhiana, Punjab. The climate of the site is semi-arid tropical having maximum and minimum temperatures varied from 17–43°C in 2020 and 10–40°C in 2021. The average rainfall during the growing season (February–June) was 148 mm and 168 mm in 2020 and 2021, respectively. During the crop growth, heat stress (>38°C) was noticed in the 5^{th} week which coincided with flowering in sowing on 5 March and 15 March. The soil was sandy loam in texture with a *p*H of 8.3 and having 150 kg/ha, 11 kg/ha, and 280 kg/ha available N, P and K, respectively. The experiment was laid out in a split-plot design (SPD) with three replications. In main plots, 4 planting dates, viz. 15 February; 25 February; 5 March; and 15 March, while in sub-plots 4 maize genotypes, viz. PMH 1; PMH 10; CoH(M) 6; and CoH(M) 8 were taken. PMH 1 is recommended for cultivation in irrigated Punjab and north-western Plains Zone (NWPZ) while PMH 10 matures in 120 days with a yield potential of 6.5–7 t/ha. The maize varieties, viz. CoH(M) 6 and CoH(M) 8 are late (105–110 days) and medium maturing (100–105 days) respectively. Both of them are suitable for irrigated (7.5–8.0 t/ha) and rainfed (5.0–5.5 t/ha) regions. Before sowing, seed treatment was done with imidachloropid 70 ws @10 g/kg of seed to protect the crop from stem borer incidence. Maize was sown on the ridge with a distance of 67.5 cm row × row and 20 cm plant × plant using 20 kg/ha seed. Irrigation was applied as per the crop requirement. The recommended dose of 180 kg N, 60 kg P_2O_5 and 40 kg K_2O through urea, di-ammonium phosphate, and muriate of potash, respectively was applied. A full amount P_2O_5 and K_2O was applied at sowing time while N was given in three equal splits at sowing, knee height (45 DAS), and tasseling stage (80 DAS). Pendimethalin (PE) followed by hand weeding at 35 DAS was done for effective weed control. Fall armyworm incidence was controlled by the spray of chlorantraniliprole 18.5 SC at 15 and 25 DAS. The crop was harvested during the second fortnight of June for 15 February and 25 February while during the first fortnight of July for 5 March and 15 March in both years. The phonological data such as days to 50% silking, tasseling, anthesis-silking interval (ASI), and days to physiological maturity were recorded as per the standard procedure. Data for plant height and cobs/plant were taken at the harvesting stage from 10 tagged plants in respective plot. Likewise, yield attributes, viz. cob length, kernel rows/cob, kernels/row and prolificacy were recorded after harvest. The grain yield was recorded at 14% grain moisture content and expressed as t/ha. Water productivity was computed by dividing the grain yield (kg/ha) with irrigation water applied (mm) and expressed in kg/m^3.

Statistical analysis: Analysis of variance was computed by using SAS version 9.4 software. For treatment mean comparison, the least significant difference values were obtained at a 95% confidence interval.

RESULTS AND DISCUSSION

Thermal environment and crop phenology: Staggered sowing was significantly influenced by thermal environments for spring maize (Table 1). Here, based on temperature and relative humidity (RH) the thermal environments were categorized into two groups, viz. normal and heat-stressed to assess the impact of heat stress on spring maize at the flowering stage. Late sowing on 5 March and 15 March was affected by heat stress (mean maximum temperature >38°C, mean minimum temperature >23°C and <36% RH) at the flowering stage in spring maize. On the other hand, early sowing on 15 February and 25 February escaped heat stress as maximum (35°C) and minimum temperatures (21°C) remained below the threshold limits at the flowering stage. This highlights that early sowing on 15 February and 25 February escaped heat stress at the flowering stage and it was found more favourable for maize production compared to late sowing on 5 March and 15 March. The prevailing

Table 1 Effect of sowing time on phenology of maize (mean of two years)

Sowing date	Days to 50% tasseling	Days to 50% silking	Anthesis-silking interval (days)	Vegetative period (days)	Reproductive period (days)	Physiological maturity (days)
15 February	88 (13 May)	91 (16 May)	3	82	33	123
25 February	83 (18 May)	87 (22 May)	4	78	30	117
5 March	78 (23 May)	84 (29 May)	6	74	25	109
15 March	71 (26 May)	77 (1 June)	6	67	27	104
LSD (*P*=0.05)	6.1	8.5	1.2	5.3	3.8	5.6

Data in parenthesis indicating the date of 50% tasseling or silking.

weather conditions influenced the growth and development of maize as the temperature varied with staggered dates of sowing (Zaidi *et al.* 2016). Therefore, days to 50% tasseling and days to 50% silking in spring maize varied across different sowing dates. Days to 50% tasseling commenced between 13–18 May with 15 and 25 February whereas, 50% silking occurred during 16–20 May. In spring maize, it was observed that early sowing took more days for 50% tasseling (83–88 days) and silking (87–91 days) compared to late sowing. It is worth mentioning that more days taken for the anthesis-silking interval (ASI) have a negative influence on kernel formation. It was prolonged under late sowing as the crop faced heat stress and a longer ASI (6 days) was noticed as compared to 15 February and 25 February (3–4 days). This phenomenon ascribed to heat stress at the flowering stage decreased ear length more than tassel growth, which extended ASI. Sowing on 15 February recorded a prolonged vegetative period (4–15 days) and reproductive period (3–8 days) compared to other sowing dates. Sowing on 5 March and 15 March recorded less reproductive period (25 and 27 days, respectively) duration compared to 15 February (33 days). All the selected genotypes, viz. CoH(M) 6, PMH 10, PMH 1 and CoH(M) 8 belong to the same maturity group (120 days) with similar phenology for days taken to 50% tasseling and 50% silking.

Growth and yield parameters: In spring maize, delayed sowing on 5 and 15 March recorded a negative impact on plant height as compared to 15 and 25 February (Table 2). Early sowing on 15 February recorded the highest plant height (208 cm), while late sowing maize on 5 March (198 cm) and 15 March (195 cm) recorded shortest height in both years. The high temperature faced on 5 March and 15 March shortened the elongation of stem inter-node, leading to restricted plant height (Yang *et al.* 2018). Sowing dates significantly influenced ear length, no. of kernels/row, and prolificacy in spring maize. The longest ear (19.1 cm) length was observed on 15 February, while the shorter ear (17.1 cm) on 15 March. In this case, heat-stressed conditions affected the formulation of photosynthates and altered the synthesis of hemicellulose and cellulose, resulting in poor cob expansion (Sharma *et al.* 2014). Sowing on 25 March recorded low kernels/ row (29.6) while higher kernels/row (33.5) on 15 February. The duration between pollination and fertilization plays a role in determining kernels and reduction in kernel/row was noticed owing to heat stress with 5 and 15 March. Heat stress, in particular, can lead to drying of pollen and reduced viability, resulting in lower fertilization of ovaries and ultimately fewer grains being set in the maize cob (Chen *et al.* 2012). Therefore, a significant decline in prolificacy was observed with late sowing (0.81) while 15 February showed maximum prolificacy (0.96). PMH 10 recorded higher kernel rows/cob (14.6), kernels/row (32.7) and prolificacy (1.09) among the maize genotypes in 2020 and 2021.

Yield, harvest index and correlation studies: The grain and biomass yield of maize was significantly influenced by sowing and genotypes (Table 2). Sowing on 15 February recorded the highest grain yield (8.5 t/ha) followed by 25 February (7.2 t/ha) and 5 March (6.4 t/ha). Sowing on 15 March recorded the lowest grain yield (6 t/ha). A decrease in grain yield (15–29%) was registered on 15 March as compared to 15 February. The adverse impact of heat stress on anthesis-silking interval and phenology led to a decline in grain yield with delayed planting (Rattalino-Edreira and Otegui 2012). Moreover, heat stress during the flowering stage led to kernel abortion, significantly influencing pollination and grain yield in spring maize (Sepat *et al.* 2024). High temperatures (>35°C) caused degeneration of starch synthesis enzymes and starch deposition in kernels with low kernel weight and yield (Zaidi *et al.* 2016). In

Table 2 Effect of sowing dates and varieties on growth and yield parameters of spring maize during 2020 and 2021

Treatment	Plant height (cm)		Cob length (cm)		Kernel rows/ cob		Kernels/ row		Cobs/plant (prolificacy)		Grain yield (t/ha)		Biomass yield (t/ha)		Harvest Index	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Sowing date																
15 February	208	214	19.1	20.2	16.8	16.8	33.5	34.8	1.09	1.07	7.27	8.00	15.57	17.11	46.7	46.8
25 February	204	209	18.0	19.8	16.2	16.2	32.9	32.7	1.07	0.98	6.99	7.58	14.99	16.20	46.6	46.8
5 March	199	205	17.6	17.6	14.8	14.8	31.6	30.2	0.82	0.82	6.00	6.40	13.10	13.93	45.8	45.9
15 March	196	201	17.1	16.9	14.0	14.0	29.6	28.2	0.81	0.76	5.15	5.12	11.35	11.44	45.4	44.8
SEm±	3.67	3.08	0.33	0.88	0.49	0.59	0.60	0.73	0.04	0.05	0.34	0.38	0.73	0.93	0.31	0.34
LSD (P=0.05)	11.74	9.87	1.05	2.80	1.58	1.89	1.91	2.32	0.14	0.16	1.10	1.21	2.34	2.99	0.99	1.10
Genotype																
PMH1	202	207	18.0	19.0	16.1	16.1	32.9	34.0	0.99	0.98	6.68	7.32	14.40	15.76	46.4	46.4
PMH10	200	210	18.4	19.0	16.0	16.0	32.7	33.6	0.97	0.95	6.49	7.29	14.02	15.65	46.3	46.6
CoH(M)6	201	208	17.8	18.5	14.9	14.9	30.9	30.1	0.92	0.86	6.22	6.50	13.52	14.12	46.0	46.0
CoH(M)8	200	204	17.6	18.0	14.8	14.8	31.1	28.2	0.90	0.86	6.00	6.00	13.04	13.17	46.0	45.6
SEm±	2.86	1.65	0.28	0.40	0.38	0.46	0.40	0.58	0.04	0.04	0.18	0.31	0.40	0.59	0.18	0.32
LSD (P=0.05)	NS	5.28	0.90	1.27	1.22	1.47	1.27	1.87	0.12	0.13	0.58	0.98	1.29	1.89	NS	1.02

Table 3 Correlation between yield and growth, development and yield parameters in spring maize

	ASI	PH	CL	KR	KPR	PR	BM	HI	GY
ASI	1	-0.72*	-0.53	-0.217	-0.209	-0.598	-0.560	-0.519	-0.591*
PH		1	0.564*	0.524	0.693	0.318	0.859**	0.208	0.879**
CL			1	0.338*	0.825*	0.604	0.491	0.564**	0.962**
KR				1	0.088	0.357	0.666	0.640	0.729*
KPR					1	0.370	0.789*	0.721*	0.845**
PR						1	0.362	0.592	0.507
BM							1	0.632	0.912**
HI								1	0.893**
GY									1

ASI, Anthesis-silking interval; PH, Plant height; CL, Cob length; KR, Number of kernel rows; KPR, Number of kernels/row; PR, Prolificacy; BM, Biomass; HI, Harvest index; GY, Grain yield.

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2- tailed).

addition, a short physiological maturity period (104–109 days) associated with late sowing reduced the period of photosynthate formation. It is well established that the effect of heat stress is highly dependent on the genetic aspect of maize varieties (Tesfaye *et al.* 2017). PMH 10 (7.3 t/ha) and PMH 1 recorded higher grain yield (7.2 t/ha). CoH(M) 8 (6.9 t/ha) and CoH(M) 6 (6.6 t/ha) produced low yield, irrespective of sowing dates. Under a stressed environment, PMH 10 outperformed other varieties, while PMH 1 recorded the highest yield under a non-stress environment (15 and 25 February). A yield reduction of 18-32% and 9-30% in PMH 1 and CoH(M) 6, respectively was with late sowing compared to 15th February (Fig. 1). CoH(M) 8 (13-25%) and PMH 10 (19-26%) exhibited comparatively lower yield decline across the sowing environments, indicating their stability in adverse conditions. In maize, high and low amount of biomass was observed on 15 February (22 t/ha) and 15 March (18.8 t/ha), respectively. Late sowing recorded a reduction in biomass ranging from 2.07–3.17 t/ha as compared to 15th February. PMH 1 (20.8 t/ha) and CoH(M) 8 (20.5 t/ha) gave higher biomass followed by PMH 10 (19.9 t/ha) and CoH(M) 8 (18.8 t/ha). PMH 10 recorded least decline in biomass under heat-stress environments (>38°C) (3.89%) compared to others varieties. The decrease in biomass is mainly linked to grain yield reduction, which was caused by modifications in source-sink capacity of maize (Bana *et al.* 2013). The negative effect of heat stress on the photosynthetic apparatus and rubisco activation are the main reasons for the decrease in biomass under heat stress (Lobell *et al.* 2011). In spring maize, the harvest index (HI) ranged between 33–39% in both the years. HI was higher with early sowing maize varieties (36–39%) compared to late sowing (33–34%) as late sowing faced the heat stress at flowering. CoH(M) 6 recorded the lowest (34%) while PMH 10 had the highest (37%) HI. On average, maize varieties recorded 7–14% decreases in HI under a heat-stress environment compared to a non-stress environment. A significant negative correlation (r = -0.591) was found between the anthesis-silking interval and grain yield (Table 3). This indicates that a larger interval between anthesis and silking is undesirable for achieving high grain yield. On the other hand, the duration between ASI is required to achieve optimum yield under a heat-stress environment (Yang *et al.* 2018). Plant height showed a significant positive correlation (r = 0.879) with grain yield. A taller plant height was associated with the accumulation of higher dry matter and photosynthate with a significant impact on grain yield (Sepat *et al.* 2013). Among the yield parameters, cob length (r = 0.962), number of kernels/ row (r = 0.729), and number of kernels/row (r = 0.845) were positively correlated with the formation of grain yield during both years in spring maize.

Irrigation water use and water use efficiency: The hot and dry weather conditions from April to June resulted in a high evapotranspiration demand (ET) for the spring maize, ranging from 8.4–12.3 mm/day. Therefore, the number of irrigations increased consequently with late sowing; 15 February (12 irrigation) <25 February (13 irrigation) <15 March (14 irrigation) <5 March (16 Irrigation). The trend for water use was 15 February (811 mm) <25 February (840 mm) <15 March (897 mm) <5 March (900 mm) (Fig. 2). The high vapour pressure deficit caused by elevated temperatures and low relative humidity increases the water requirement in late sown conditions (Sepat *et al.* 2019). A low ET

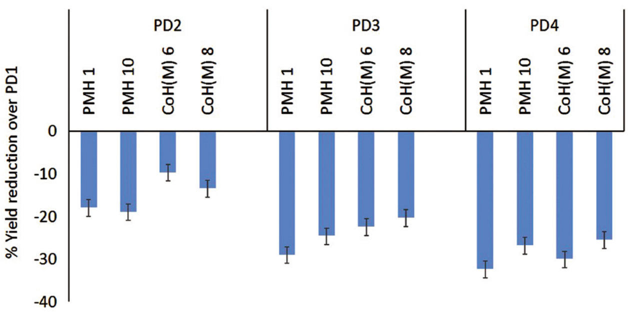

Fig. 1 Per cent grain yield reduction in the genotypes over 15 February (mean of two years).
PD1, 15 February; PD2, 25 February; PD3, 5 March; PD4, 15 March.

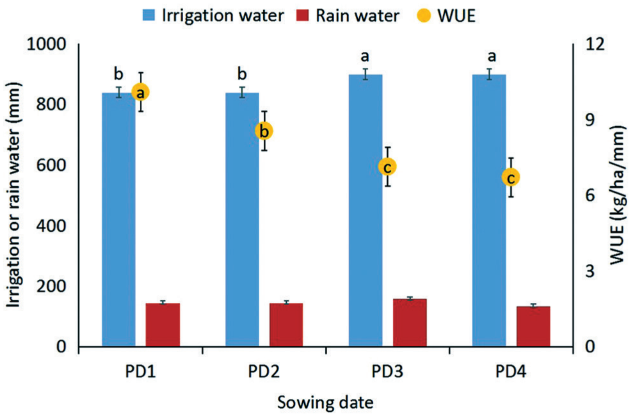

Fig. 2 Effect of planting dates on irrigation water need and water use efficiency (mean of two years).
WUE, Water use efficiency; PD1, 15 February; PD2, 25 February; PD3, 5 March; PD4, 15 March. Values with the same letter are not significantly different (P< 0.05).

demand during the vegetative growth stage in early sowing resulted in less frequent irrigations. The distributions of rainfall during the growing season varied between 134.6 and 158.2 mm, and 5 March received the highest rainfall and 15 March obtained lowest rainfall. Water productivity showed a declining trend with delayed sowing of spring maize. A higher water productivity observed with early sowing attributed to higher dry matter formation at low ET. Sowing on 15 February enhanced the water productivity (10.1 kg/m^3) followed by 25 February (8.5 kg/m^3) and 5 March (7.1 kg/m^3). Sowing on 15 March recorded the lowest water productivity (6.7 kg/m^3).

Based on the 2-years study, it can be concluded that a fluctuation in temperature at the flowering stage has a negative impact on the grain yield of spring maize. In spring maize, heat stress can be minimized by using a staggered sowing approach and the selection of maize varieties with late sowing is required to achieve higher yield in spring maize. Overall, sowing on 15th February with PMH 10 maize variety is ideal to achieve higher productivity and water-use efficiency in spring maize for Punjab and Haryana, and other parts of Indo-Gangetic Plains.

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