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Performance of maize (*Zea mays*) parental lines under low temperature conditions during winter season

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ABSTRACT

To assess the effect of low temperatures on their vegetative growth, flowering behaviour and seed yield, a study was conducted at New Delhi, during the winter seasons of 1996–97 and 1997–98 with parental lines of 5 popular commercial hybrids, viz 'Ganga 5' [('CM 202' × 'CM 111') × ('CM 500')], ' Ganga 11' [('CM 202' × 'CM 111') × ('CM 501')], 'Ganga Safed 2' [('CM 400' × 'CM 300') × ('CM 600')], 'PHM 1' ('CM 135' × 'CM 136') and 'PHM 2' ('CM 137' × 'CM 138'). Low temperature regimes prevalent during December–February, retarded early vegetative growth (plant height), altered plant type (thickened stem and reduced internodal length) and caused various physiological damages on plant parts especially leaves (chlorosis, chlorotic bands, burning and drying). Large variability was observed among genotypes for chlorosis followed by chlorotic bands and yellowing of leaves. The low temperature injury was greater in first year when compared with second year, as the temperature was lower in the latter. All the genotypes showed varying degree of injuries but recovered by producing new flush of leaves in the second fortnight of February with onset of optimum temperatures (minimum temperature above 10^{0}C). The temperate line of maize 'CM 202' showed better tolerance when compared with tropical lines of maize ('CM 500'and'CM 501', 'CM111') which showed severe yellowing and drying of leaves. Open pollinated maize varieties, 'CM 500'and 'CM 501' were the most susceptible and exhibited severe yellowing and drying of leaves followed by 'CM 111', 'CM 138', 'CM 136', 'CM 137' and 'CM 135' (chlorotic leaves with less drying) and 'CM 300', 'CM 400', and 'CM 600' exhibited poor growth and yellowing of leaves. Inbred line, 'CM 202' showed mild yellowing with purpling of leaves. Single crosses 'CM 400' × 'CM 300' and 'CM 202' × 'CM 111' were the least susceptible among genotypes and exhibited better growth, least yellowing and drying of leaves. The low temperature had marginal effect on final plant height, leaves/plant, seed yield and 100-seed weight but greater effect on Anthesis silking interval (ASI), days to flowering and its duration.

Key words: Seed production, Maize, *Zea mays*, Parental lines, Low temperature injury

The sensitivity of a crop species to low temperature and chilling frequently restricts the environment in which it can be cultivated. Maize(*Zea mays* L.) is traditionally a monsoon crop (June–October) in India, but is extensively cultivated in large parts of eastern and southern India in winter (October–April) season (DMR, New Delhi 1998). During winter season in northern plains especially Delhi, the average temperature falls up to 15^{0}C and minimum touches 2^0–3^{0}C during December-January with frost incidence, which causes both freezing (chlorotic bands, chlorosis, drying of leaves) and non-freezing (leaves turn oily followed by drying after frost incidence) injuries. Thus the sub-optimum temperatures during sowing and post-germination phase severely disrupted the development, early seedling and vegetative growth of the crop (Ashworth and Pearce 2002). Therefore for successful cultivation of maize during winter season, the genotypes should have stable performance, low temperature tolerance besides high yield potential.

Though maize belongs to frost-sensitive group of plants, it is moderately sensitive to chilling (Miedema 1982; Pal and Nagey 2002). It is believed, that maize cannot grow where there are frosty nights and average temperature falls below 13^{0}C (Singh 1986). Innovative research on genetic amelioration and agronomic manipulations at the Punjab Agricultural University, Ludhiana confirmed possibility of cultivation of winter maize even in the areas with severe winter and frost occurrence (Brar *et al.* 1988). Thus the present study was undertaken to evaluate the performance of maize parental lines in winter and assess the effect of low temperature on their vegetative growth, flowering behaviour and seed yield.

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MATERIALS AND METHODS

The study was conducted at the Indian Agricultural Research Institute, New Delhi during the winters of 1996–97

Table 1 Low temperature injuries on maize parental lines in winter season

Genotype	December (second fortnight)		January (first fortnight)		January (second fortnight)		February (first fortnight)	
WI: Scale (1–9)	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98
'CM 202' (3–4)	Mild purpling	No symptoms	Purpling	Mild purpling	Purpling followed by drying of leaf tips	Mild purpling	Drying of tips and margins (lower leaves)	Drying of lower leaves
'CM 111' (5–6)	Mild yellowing	Green to mild yellowing	Chlorosis to chlorotic bands, drying	Mild yellowing followed by drying of leaves	Yellowing and drying of leaves	Mild yellowing drying of leaves	Drying of margins and lower leaves	Drying of leaves
'CM 500', 'CM 501' (6–7)	Mild yellowing, chlorotic patches	Pale green, mild yellowing	Yellowing, chlorotic bands, oily leaves followed by drying of margins and tips	Yellowing, chlorotic bands on leaves	Chlorotic bands, drying of leaves, burnt look	Chlorotic bands followed by drying	Drying of leaves, severe burnt look	Drying of lower leaves
'CM 300' 'CM 400', 'CM 600' (4–5)	Mild purpling-Yellowing	Yellowing	Mild purpling, Purpling	Mild purpling	Mild purple to pale green leaves with tip drying	Mild purpling, drying of leaves	Drying of tips (lower leaves)	Drying of leaf tips and margins
'CM 400' × 'CM300' (3–4)	Mild yellowing	Pale green	Yellowing on tips and margins	Dull green followed by yellowing	Tip and margin drying	Drying of leaves	Drying of lower leaves	Drying of lower leaves
'CM202' × 'CM 111' (3–4)	Pale green	Green	Yellowing	Dull green	Tip drying	Drying of leaves	Drying of lower leaves	Drying of lower leaves
'CM 135', 'CM 136','CM 137', 'CM 138' (5–6)	Chlorotic leaves	Green-Chlorotic leaves	Chlorotic bands	Chlorotic leaves followed by drying of leaves	Chlorotic bands with margin drying	Chlorotic patches and drying of leaves	Chlorotic bands with margin drying	Drying of leaves
Temperature (min.) (°C)	3.5–6.0	6.5–8.2	3.0–4.4	5.1–7.8	6.0–3.8	3.3–3.4	5.2–5.3	5.4–10.8
RH (%) range	82–35	93–68	83–36	90–42	91–39	90–41	91–33	83–29
Wind speed (km/hr)	0.1–0.8	2.6–3.2	0.3–0.7	2.9–3.9	3.0–4.9	1.8–3.4	3.6–4.4	3.1–3.4
Sunshine (hr)	4.9–6.0	0.4–0.9	5.6–6.4	3.4–5.4	5.0–5.6	4.2–6.4	5.9–7.3	3.1–4.5
Rainfall (mm)	9.00	8.60	0.00	0.00	3.00	0.00	4.00	14.00

WI, Winter injury; 1,green leaves; 2, dull green leaves; 3, light green leaves; 4, yellowish green leaves; 5, yellow leaves with chlorotic bands; 6, dark yellow leaves with chlorotic bands; 7, severe yellow and oily leaves; 8, severe yellow, oily and burnt leaves; 9, oily and burnt leaves

and 1997–98 with parental lines of 5 popular commercial hybrids, viz 'Ganga 5' [('CM 202' × 'CM 111') × ('CM 500')], 'Ganga 11' [('CM 202' × 'CM 111') × ('CM 501')], 'Ganga Safed 2' [('CM 400' × 'CM 300') × ('CM 600')], 'PHM 1' ('CM 135' × 'CM 136') and 'PHM 2' ('CM 137' × 'CM 138'). The parental lines were sown on 1 and 7 November 1996–97 and 1997–98, respectively, in randomized block design with 3 replications in plots of 5 m × 3 m (4 rows) with a spacing of 75 cm × 25 cm. The data were recorded on non-freezing injury caused by low temperature (yellowing of leaves) and freezing injury caused by frost (leaves became oily and dried) on vegetative parts on plot basis and quantified (1 to 9 scale) (Table 1). Besides intensity of yellowing or drying, number of plants and proportion of leaf area affected were also recorded while rating for yellowing and freezing injury at weekly intervals from 15 December to 15 February in both the seasons. Observations were also recorded on plant height, number of leaves, days to flowering and seed yield.

RESULTS AND DISCUSSION

Low temperature injury

The effect of low temperature on plant type depends on the stage of growth at which plant is exposed and severity and duration of cold stress. In both the seasons, the low temperature prevailed between the second fortnight of December and first fortnight of February when the minimum temperature ranged from 3.0° to 6.0°C and 3.3° to 10.8°C, respectively, in 1996–97 and 1997–98. The sub-optimum low temperatures coincided with the early vegetative growth (5–9 leaves stage) and caused various physiological damages, viz chlorosis, chlorotic bands, yellowing and drying of leaves (Fig 1) of the leaves which reduced the photosynthetic

Fig 1 Low temperature injuries on leaves. *Top left*, Chlorosis; *top right*, chlorotic bands; *bottom left*, yellowing; *bottom right*, drying of leaves

capacity. These injuries were more evident on leaves due to the presence of chloroplast and especially in the whorl region, as the tissues in cell extension zone of the leaves were more sensitive than that of full grown or meristematic tissues. Large variability was observed for chlorosis, followed by chlorotic bands and yellowing and least for freezing injury (Table1). Yellowing initially was mild which later became severe and affected more than 90% of the plants, especially in the sensitive genotypes. In the plots, 70–90% plants showed winter injury of varying degree. Usually a lower temperature is required for induction of chlorotic bands than chlorosis of leaves in the field. In the study, a combination of both the effects were observed. Exposure of parental lines to low but non-freezing temperatures (3.5^0–6.0^0C in 1996–97 and 6.5^0–8.0^0C in 1997–98) during the second fortnight of December resulted in appearance of pale green and yellow leaves which later developed transverse yellow bands (leaves forming whorl) after an exposure to severe chilling (last week of December, and first week of January). The results confirmed the findings of Janda *et al.* (1998). Few albino plants were also observed in the plots of 'CM 202' and 'CM 111'. Miedema (1982) reported that exposure of plants to a temperature range of 10^0–15^0C with high light intensity resulted in albinism due to partial loss of chlorophyll (pale green) and accumulation of carotenoids(yellowing). Few parental lines also showed mild to severe purpling of leaves which was expression of low-temperature tolerance and a mechanism for reducing light induced damage to photosynthetic system under low temperature stress (Hardcare and Eagles 1980).

During the study, frost incidence occurred only on 2 days in the first season. The leaves developed chlorotic bands, turned oily in the morning followed by drying after 3–5 days causing few patches of burnt look. Miedema (1982) reported that cool and dewy night with frost followed by clear morning caused greying and silvering of leaves. During our study, the cool nights were followed by foggy mornings (from the last week of December to January), thus these symptoms were not observed.

Low temperature injury was greater in the first year than the second as the temperature was lower in the latter. Though the leaves showed varying degree of injury but the growing point was not killed. Plants of all the genotypes recovered from this injury by producing new flush of leaves with onset of optimum temperature regimes in the second fortnight of February when the minimum and maximum temperatures rose above 10°C and 25°C respectively. Our results are in accordance with Sharma *et al.* (1985).

The genotypes with broad, horizontal leaves('CM 500'and 'CM 501') suffered more than those with narrow leaves ('CM 300', 'CM 400' and 'CM 202'). A comparison of high-yielding (single crosses) and low-yielding genotypes (parental lines) revealed that the former had lower yellowing and early vigour than that of later thus sustained lower injuries. These genotypes also differed more for yellowing than that of purpling. Genotypic variability was observed for chlorosis and freezing injury. The temperate maize line 'CM 202' showed better tolerance than tropical lines which showed severe yellowing and drying of leaves. Open-pollinated maize varieties (OPV), viz 'CM 500'and'CM 501', were the most susceptible which exhibited severe yellowing and drying of leaves followed by 'CM 111', 'CM 135', 'CM 136', 'CM 137' and 'CM 138' which showed chlorotic leaves with less drying than open-pollinated varieties. Parental lines 'CM 300', 'CM 400' and 'CM 600' exhibited poor growth with yellowing and 'CM 202' showed mild yellowing with purpling of leaves during this period. Single crosses 'CM400' × 'CM 300' and 'CM 202' × 'CM 111' were least susceptible and exhibited better growth and least yellowing and drying of leaves among the genotypes (Table 1). The results indicated that yellowing of leaves is a better criterion for selection of cold tolerance than purpling of leaves. Significant genotypic differences for low temperature injury in maize and better tolerance of single crosses were also reported by Dhillon *et al.* (1988), Mahajan and Patil (1992) and Giauffret *et al.* (2000).

Cold tolerance is genetically controlled, inherited with maternal effects and is related to germination, early seedling and vegetative growth and physiological maturity of the line (Revilla *et al.* 2000 ,2003, Zaborszky *et al.* 2002). In our study cold tolerance of single crosses were not related to inbred cold tolerance, confirming the findings of Hodges *et al.* (1997).

Effect of low temperature on plant growth, flowering behaviour and seed yield

The length of vegetative phase in maize is closely related to daily average temperatures during crop growth. The plant development was retarded by sub-optimum temperature prevalent in the winter leading to altered plant type. The magnitude of increase in plant height was slow up to 70 days after sowing (DAS), as the minimum temperature was below 10°C, which restricted the vegetative growth(plant height) and photosynthetic activity of the crop. However, with the rise in the minimum temperature above 10°C, a significant increase in plant height was observed. The absence of active plant growth during this period led to the deposition of photosynthates in root and stem, resulting in thick stem, short internodes and well-developed root-system. The low temperature had marginal effect on final plant height, leaves/plant, seed yield and weight but greater effect on anthesis silking interval (ASI), days to flowering and its duration (Tables 2 ,3). The low temperature had differential effect on genotypes. Low vigour genotypes, viz 'CM 202', 'CM 111' and 'CM 300', showed greater effect of sub-optimal temperature on flowering behaviour when compared with other genotypes under study (Tables 2,3). Genotypic differences were significant for all the flowering

Table 2 Effect of low temperature on vegetative growth and days to flowering of maize parental lines

Genotype	Leaves/plant		Plant height (cm)		Days to 50% tasseling		Days to 50% silking		ASI (days)	
	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98
'CM 300'	11.8	11.5	116.0	118.2	160.3	158.3	165.3	163.0	5.0	4.7
'CM 400'	12.2	13.0	126.2	132.1	159.0	157.3	163.3	161.6	4.3	4.3
'CM 600'	12.4	12.5	131.7	131.8	142.3	133.3	145.0	137.0	2.6	3.6
'CM 400' × 'CM 300'	14.2	14.0	172.0	169.4	148.3	140.3	152.0	143.6	3.6	3.3
'CM 202'	11.5	11.8	129.2	126.8	158.3	159.3	167.3	166.3	9.0	7.3
'CM 111'	12.6	13.2	133.4	133.1	149.0	148.3	155.6	154.6	6.6	6.3
'CM 500'	13.1	13.5	143.7	141.8	143.3	138.3	146.3	141.3	3.0	3.0
'CM 501'	13.4	13.3	144.3	151.3	145.0	138.6	148.0	141.0	3.0	3.3
'CM 202' × 'CM111'	14.0	14.0	174.2	165.1	149.6	138.3	152.6	141.3	3.0	3.0
'CM 135'	12.4	12.1	132.8	130.9	141.0	143.6	144.0	147.6	3.0	4.0
'CM 136'	12.0	12.2	136.3	134.9	142.0	145.6	144.0	149.0	2.0	3.3
'CM 137'	12.1	12.6	136.3	135.1	142.6	144.3	145.3	147.6	2.6	3.3
'CM 138'	12.3	12.9	133.1	133.1	141.0	143.6	145.3	147.3	2.3	3.6
Mean	12.6	12.8	139.2	138.7	147.8	145.3	151.8	149.3	3.8	4.1
CD (P = 0.05)	0.46	0.48	3.41	3.40	1.13	1.07	1.18	1.14	0.67	0.99

ASI, Anthesis silking interval (difference of days between anthesis and silking)

Table 3 Effect of low temperature on duration of flowering and seed yield of maize parental lines

Genotype	Duration of tasseling (days)		Duration of silking (days)		Seed yield (g/cob)		100-seed weight (g)	
	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98	1996–97	1997–98
'CM 300'	7.3	8.7	12.6	8.7	40.8	45.6	20.8	21.9
'CM 400'	6.7	8.1	12.4	12.3	42.7	49.5	24.1	24.0
'CM 600'	6.9	8.3	12.9	12.6	47.4	48.4	23.7	24.9
'CM 400' × 'CM 300'	7.9	8.9	13.6	12.5	65.2	77.1	26.7	26.7
'CM 202'	5.6	6.4	12.3	8.8	39.8	35.0	18.8	19.5
'CM 111'	8.4	9.7	12.1	10.4	42.4	49.0	20.4	20.5
'CM 500'	6.9	10.1	13.9	13.3	54.6	51.2	22.9	21.7
'CM 501'	7.4	10.3	14.0	13.1	56.3	58.4	23.4	23.1
'CM 202' × 'CM111'	10.2	11.2	15.7	13.5	68.7	66.1	25.0	24.9
'CM 135'	8.3	8.2	13.3	13.6	47.3	46.8	17.8	17.8
'CM 136'	8.3	8.2	13.0	13.6	44.6	43.8	16.5	17.1
'CM 137'	7.9	8.3	13.3	13.7	49.7	47.1	17.8	18.3
'CM 138'	7.9	7.9	13.0	13.6	47.2	44.4	17.0	17.2
Mean	7.7	8.8	13.2	12.3	49.7	51.0	21.1	21.3
CD ($P = 0.05$)	0.88	0.63	1.33	0.95	8.80	4.44	0.70	0.70

traits. Single crosses had longer duration of flowering (tasselling and silking) while the inbred 'CM 202' exhibited late flowering, shorter silk receptivity (8–12 days) and prolonged ASI of 7–9 days (Tables 2,3) among genotypes. Since the low temperature regime persisted only during early vegetative phase and favourable temperature prevailed during flowering and post-flowering phase, thus the performance of genotypes was as per their expression during winter under north Indian conditions.

The study helped in generation of information on relative behaviour of parental lines under low temperature regimes prevalent during winter in northern India. The results indicated that for screening genotypes for low temperature tolerance or injuries, quantifying intensity of yellowing of leaves gives reliable assessment of actual performance of genotypes under low temperature stress. Parental lines of short duration hybrids; ('PHM 1' and 'PHM 2') viz 'CM 135', 'CM 136', 'CM 137' and 'CM 138' and single crosses showed lesser injuries and better growth under sub-optimum conditions thus would be preferable over other susceptible lines for winter cultivation. Besides, identification of genotypes capable of rapid growth under low temperature regimes would help in development of maize hybrids capable of normal physiological maturity under low temperature stress.

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