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RESEARCH ARTICLE

Optimizing maize productivity: Impact of sowing dates on growth and yield parameters of diverse genotypes in Karnataka's southern dry zone

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Abstract

This study examined the impact of various sowing windows on growth parameters and yield attributes of maize genotypes in the southern dry zone of Karnataka, India. Field experiments were conducted during the *Kharif* seasons of 2021 and 2022 at Haradanahally village, Chamarajanagara district, using a Randomized Complete Block Design (RCBD) with three replications. Two maize hybrids MAH 14-5 and Hema were evaluated across four sowing windows (1st week of June 3rd week of June 1st week of July and 3rd week of July) under rainfed conditions. Plant growth parameters (plant height, number of leaves and leaf area) were measured at 30th, 60th and 90th days after sowing (DAS) and yield attributes (cob length, kernels per cob, cob girth, rows per cob, test weight, grain yield and stover yield) were recorded at harvest. Results indicated that the MAH 14-5 hybrid, sown during the 1st week of July (H1D3), consistently performed better across both years in terms of plant height (218.23 cm), number of leaves (16.61), leaf area (8318 cm^2), cob length (17.03 cm), kernels per cob (580.64), test weight (34.46 g), grain yield (6980 kg/ha) and stover yield (9155 kg/ha). In contrast, the Hema hybrid, sown during the 1st week of June (H2D1), recorded the lowest performance across all parameters. Statistical analysis (ANOVA) revealed significant differences ($p < 0.05$) among the treatments and post hoc tests confirmed that optimal performance was achieved through the combination of MAH 14 -5 and 1st week of July sowing. These findings suggest that proper synchronization between sowing time and hybrid selection can enhance resource use efficiency and maize productivity under rainfed conditions in Karnataka's southern dry zone. This research provides site-specific recommendations to help farmers make informed decisions on the sowing time of different maize hybrids under similar agroclimatic conditions.

Keywords: genotypes; growth parameters; Hema; Karnataka; maize; MAH 14-5; sowing date; southern dry zone; yield attributes

Introduction

Maize (*Zea mays* L.), also known as corn, stands as one of the world's most vital cereal crops with cultivation spanning more than 166 countries globally (1). Its exceptional genetic yield potential has earned it the title "queen of cereals," surpassing all other cereal crops in productive capacity. The remarkable versatility of maize lies in its complete utilization every component offers economic value (2). From grain to leaves, stalk to tassel and cob, each part serves as raw material for diverse food and non-food products, making it one of agriculture's most comprehensively useful crops (3). This extraordinary adaptability has established maize as the most versatile crop in global agriculture, with a presence across varied agricultural landscapes worldwide.

Maize is the most widely cultivated and consumed cereal crop in the world and its contribution towards the food security in the world is inevitable. Sugarcane, maize, wheat and rice accounts for about half of the primary crop production in the world (4). Currently, nearly 1147.7 million metric tons of maize is being produced by over 170 countries from an area of 193.7 million hectares with average productivity of 5.75 t/ha (5). Food supply for humans is met by crops, among them grains are important and among cereals, maize is a major one due to its high potential in grain and fodder yield. The global production of corn represents a staggering volume, highlighting its critical importance in the food supply chain worldwide (6).

The 2024/25 U.S. corn forecast presents an optimistic outlook featuring expanded supplies, heightened domestic usage, increased exports and elevated ending stocks. Production is projected at 1220 million tonnes, marking a 3 % reduction from the previous year's record harvest. While planted acreage has declined, improved agricultural efficiency partially compensates for this reduction, with yields expected to reach 32.3 tons per acre. This yield projection incorporates weather-adjusted trend analysis and assumes both normal planting conditions and favorable summer growing environments. Overall corn supplies are anticipated to reach 1505.8 million tonnes the highest volume since the 2017/18 season primarily due to substantial beginning stock levels (7). Forecasted data suggests continuing trends in production efficiency, with production per hectare expected to increase across major producing countries by 2030. Forecasted data suggests continuing trends in production efficiency, with production per hectare expected to increase across major producing countries by 2030 (8).

Maize stands as the world's most adaptable crop, with cultivation spanning 166+ countries globally. The 2022-23 season saw maize grown across approximately 205 million hectares, yielding an estimated 1163 million tonnes worldwide. The United States maintains its position as the leading producer, contributing approximately 31.3 % of global production and being responsible for almost one-third of the world's corn production in 2023/24 (9). China follows with 22.9 %, while Brazil accounts for 8.8 %. The European Union and Argentina represent 5.9 % and 4.5 % respectively. India holds the seventh position in worldwide maize production with a 2.7 % share of the global total.

During the 2023-24 season, India's maize cultivation expanded to approximately 108.87 lakh hectares, up from 105.24 lakh hectares in the previous year. The *Kharif* season dominated production, accounting for 78.8 % (85.79 lakh hectares) of total cultivation, while *Rabi* season comprised the remaining 23.08 lakh hectares. Year-over-year growth showed a 3.8 % increase in *Kharif* maize area and a 2.1 % rise in *Rabi* maize cultivation. Madhya Pradesh leads *Kharif* maize production with 17.44 lakh hectares, followed by Karnataka (16.09 lakh hectares), Rajasthan (9.44 lakh hectares) and Maharashtra (9.16 lakh hectares). For *Rabi* season maize, Bihar dominates with 7.92 lakh hectares, with Maharashtra (3.37 lakh hectares) and Tamil Nadu (2.20 lakh hectares) as other significant contributors.

The Government of India's 3rd advance estimates for 2023-24 project a maize harvest of 356.73 lakh tonnes, showing a decrease from the 380.85 lakh tonnes produced in 2022-23. Karnataka emerges as the top producer with an estimated 54.90 lakh tonnes, closely followed by Bihar contributing 46.13 lakh tonnes. Madhya Pradesh holds the third position with 43.29 lakh tonnes. Other significant maize producing states include Tamil Nadu (30.57 lakh tonnes), West Bengal (26.78 lakh tonnes), Telangana (26.68 lakh tonnes) and Maharashtra (23.98 lakh tonnes).

The southern dry zone of Karnataka, characterized by limited and erratic rainfall, presents unique challenges for maize production. Even though the crop is photo insensitive, resource use efficiency, crop weed competition, pest and disease incidences and uniform moisture availability are governed by environmental conditions such as rainfall, temperature, humidity, solar radiation and wind velocity. The soil moisture availability plays a vital role in seed germination and total population establishment under rainfed situations. Research has demonstrated that planting windows significantly influence winter maize productivity, nutrient use efficiency and economic returns in southern India (10). For effective management strategies, such as optimising sowing windows, are crucial for maximising crop productivity in this region. The sowing window refers to the time period during which the seeds are planted and it plays a significant role in determining the growth, development and ultimately, the yield of maize crops (11). By carefully selecting the appropriate sowing window, farmers can optimize the utilization of available water resources and enhance the overall performance of maize genotypes. As it is photo insensitive in nature, the crop is grown in all seasons.

This study focuses on the southern dry zone of Karnataka, where limited scientific research has been conducted regarding sowing windows. The objective of this study is to investigate how different sowing windows affect the growth and yield attributes of maize genotypes in this region. The research encompasses evaluation of different dates of sowing on production and productivity of maize, examining the effect of sowing date on performance of different hybrids and conducting economic analysis of different date of sowing and performance of different hybrid combinations to provide comprehensive insights for optimal maize cultivation practices in this ecologically significant zone.

To accomplish the objectives, field experiments were conducted using a RCBD with diverse maize genotypes adapted to the local conditions. Various growth parameters were evaluated, including plant height, Leaf Area Index (LAI) and biomass accumulation, along with yield attributes such as ear length, kernel weight and grain yield (12). Statistical analyses were employed to assess the significance of the sowing window on maize growth and yield performance (13).

The findings of this study not only benefited farmers and agronomists in the southern dry zone of Karnataka but also contributed to a broader understanding of maize cultivation practices in similar agro-climatic regions.

Materials and Methods

Study region

The experiment was conducted at Haradanahally village in the Chamarajanagara district of Karnataka, India. The geographical coordinates of the site are 11.89310° N latitude and 76.95770° E longitude, with an altitude of 703.76 m above mean sea level. This region lies in the southern dry zone of Karnataka, characterized by an arid to semi-arid climate with bimodal rainfall patterns-one peak in May/June and another in September/October. The mean minimum temperature ranges from 14 °C to 30 °C and can occasionally drop to 11 °C in December, while the mean maximum temperature ranges between 27 °C and 39 °C, often peaking in May. The seasonal and monthly climatic normals of the southern dry zone, including rainfall patterns, temperature, humidity and wind speed, are provided in Table 1A and Table 1B, respectively.

Experimental design and treatments

A field experiment was laid out using a RCBD with three replications. The treatments included two maize hybrids-MAH 14-5 and Hema-sown on four different dates (first and third week of June and first and third week of July), during the *Kharif* seasons of 2021 and 2022. Treatment combinations are described in Table 2.

Seed source and sowing

Certified seeds of MAH 14-5 and Hema maize hybrids were procured from the University of Agricultural Sciences (UAS), Bengaluru. The sowing was carried out manually during the first

Table 1A. Seasonal normal rainfall of the southern dry zone

Seasons	Normal rainfall (mm)	Actual rainfall (mm)	Deviation
Winter (January-February)	8.0 (1.1)	13.3	66.25
Pre-monsoon (March-May)	193.0 (26.3)	181.3	-6.06
South-West monsoon (June-September)	301.0 (41.0)	295	-1.99
North-East monsoon (October-December)	232.0 (31.6)	200.7	-13.49
TOTAL	734.0	690.3	-5.95

Source: Organic Farming Research Station, Naganahalli, Mysuru (2022) (14)

Table 1B. Monthly climatic normal for the southern dry zone of Karnataka (zone -6) (15)

Parameter	January	February	March	April	May	June	July	August	September	October	November	December
Rainy day (days)	0.2	0.3	0.7	3.2	6.0	6.4	7.7	7.4	7.8	8.0	3.6	1.0
Max. Temp °C	28.6	31.0	33.5	34.5	33.1	29.2	27.8	27.6	28.8	28.7	28.0	27.5
Min. Temp °C	15.3	17.0	19.1	20.8	20.6	19.8	19.4	19.3	19.2	19.1	17.8	16.0
RH (%) I hr	74.8	70.5	69.5	75.0	78.8	83.3	84.8	85.8	85.3	83.5	79.8	78.5
RH (%) II hr	43.3	38.5	34.8	41.8	54.3	69.3	73.0	73.0	68.5	67.5	62.3	55.0
VP (I hr)	16.7	17.6	19.9	23.3	24.2	23.6	22.9	22.7	22.8	22.7	20.6	18.2
VP (II hr)	15.4	15.6	16.3	19.6	22.3	23.4	23.0	23.1	23.1	22.5	20.4	18.0
Wind speed (Kmph)	5.1	5.2	4.8	4.9	5.4	7.2	6.9	6.3	5.3	4.1	4.6	5.1

Table 2. Treatment combinations of maize hybrids (MAH 14-5 and Hema) with different sowing windows during *Kharif* 2021 and 2022

Treatment	Treatment details	
	Sowing date	Maize Hybrid
H1D1	June 1st week	MAH 14-5
H1D2	June 3rd week	MAH 14-5
H1D3	July 1st week	MAH 14-5
H1D4	July 3rd week	MAH 14-5
H2D1	June 1st week	Hema
H2D2	June 3rd week	Hema
H2D3	July 1st week	Hema
H2D4	July 3rd week	Hema

Foot notes:

H1 = Maize hybrid MAH 14-5

H2 = Maize hybrid Hema

D1 = Sowing date: June 1st week

D2 = Sowing date: June 3rd week

D3 = Sowing date: July 1st week

D4 = Sowing date: July 3rd week

and third weeks of June and July in both 2021 and 2022, respectively, according to the treatment schedule. Seeds were sown at a spacing of 60 cm between rows and 30 cm between hills at a depth of 5 cm.

Soil sampling and preparation

Before sowing, composite soil samples were collected randomly from a depth of 0-20 cm to analyze the physicochemical properties. Land preparation involved conventional tillage up to 15 cm depth, followed by leveling and layout according to the experimental plan. Well-decomposed farmyard manure (FYM) was applied 15 days before sowing.

Fertilizer application

Nutrients were applied at the recommended rate of 100:50:25 kg/ha of N:P:K, respectively. Nitrogen was applied in two equal splits: half as a basal dose and the remaining half top-dressed at the knee -high stage. Phosphorus and potassium were applied as basal doses. The sources of nutrients were urea (46 % N), DAP (46 % P_2O_5 with 18 % N) and muriate of potash (MOP). Additionally, zinc sulphate was applied at 10 kg/ha as a micronutrient supplement.

Crop management

The crop was raised under rainfed conditions and weeds were controlled manually through periodic hand weeding. No chemical pesticides or herbicides were applied during the cropping season.

Measurement of growth parameters

Data on plant growth and development were recorded at regular intervals. The key parameters included:

Plant height (cm)

Number of functional leaves per plant

Leaf Area Index (LAI)

Days to tasseling and silking

Cob length and girth

Grain yield (kg/plot) and converted to kg/ha

All measurements were taken from randomly selected plants within each plot to ensure consistency and reduce bias.

Results

Impact of planting date on growth parameters of maize

Plant height

The plant height of the crop showed a consistent and progressive increase from 30 DAS to harvest across all treatments during both years and in the pooled data, reflecting robust vegetative growth (Fig. 1). Among the treatments, MAH 14-5 sown in the first week of July (H1D3) recorded the highest plant height at all growth stages. At 30 DAS, 60 DAS, 90 DAS and at harvest, the plant height under H1D3 was (24.75, 187.28, 215.78 and 218.11 cm) during the first year, (27.12, 196.91, 220.67 and 202.39 cm) during the second year and (25.94, 192.09, 218.23 and 210.25 cm) in the pooled data, respectively.

In contrast, the lowest plant height was consistently recorded under the treatment Hema sown in the June first week (H2D1) at all stages. At 30 DAS, 60 DAS, 90 DAS and at harvest, plant height under H2D1 was (16.34, 145.96, 160.37 and 166.48 cm) in the first year, (17.83, 155.59, 165.26 and 177.01 cm) in the second year and(17.09, 150.78, 162.81 and 171.74 cm) in the pooled data, respectively.

Number of leaves (plant^{-1})

The number of leaves exhibited a steady increase from 30 DAS to harvest across all treatments during both years and in the pooled data (Fig. 2). Among the treatments, MAH 14-5 sown in the first week of July (H1D3) consistently produced the highest number of leaves at all growth stages. At 30, 60 and 90 DAS and at harvest, H1D3 recorded values of (6.07, 15.12, 15.55 and

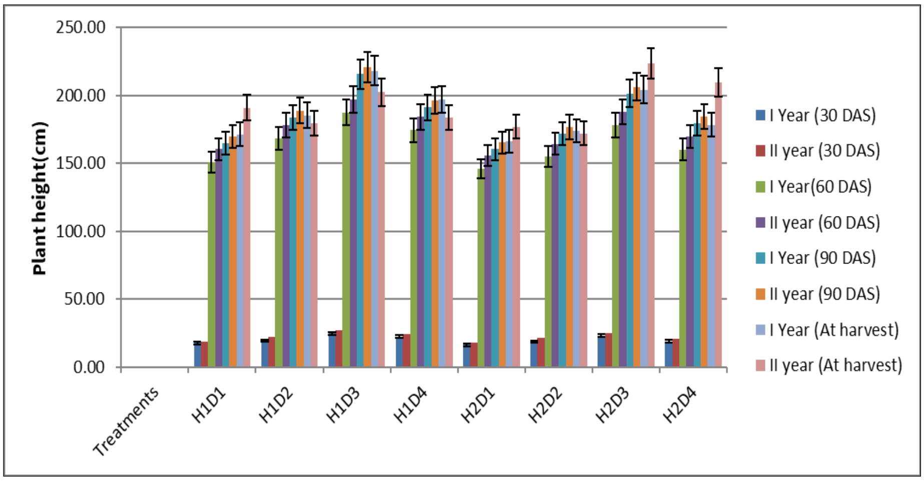

Fig. 1. Influence of sowing windows on plant height at different growth intervals of 30, 60, 90 and at harvest in maize under different treatments H1D1: Maize hybrid MAH 14-5 sown on June 1st week, H1D2: Maize hybrid MAH 14-5 sown on June 3rd week, H1D3: Maize hybrid MAH 14-5 sown on July 1st week, H1D4: Maize hybrid MAH 14-5 sown on July 3rd week, H2D1: Maize hybrid Hema sown on June 1st week, H2D2: Maize hybrid Hema sown on June 3rd week, H2D3: Maize hybrid Hema sown on July 1st week, H2D4: Maize hybrid Hema sown on July 3rd week.

12.04) in the first year, (6.32, 16.29, 17.67 and 13.72) in the second year and(6.19, 15.70, 16.61 and 12.88) in the pooled data, respectively.

Conversely, the lowest number of leaves was observed under treatment Hema sown in the June first week (H2D1) with values of 4.98, 11.42, 12.52 and 7.35 in the first year, 5.23, 12.59, 14.64 and 8.58 in the second year and 5.11, 12.00, 13.58 and 7.97 in the pooled data, respectively.

Leaf area (cm^2 plant^{-1})

The leaf area of the crop exhibited a progressive increase from 30 DAS to harvest in all treatments during both years and in the pooled data, indicating a healthy growth pattern (Fig. 3). Among the treatments, MAH 14-5 sown in the first week of July (H1D3) consistently recorded the highest leaf area across all stages of crop growth. At 30 DAS, 60 DAS, 90 DAS and at harvest, the leaf area under H1D3 was (2060.33, 7873, 8147 and 5738 cm^2) during the first year (2446, 8285, 8489 and 5980 cm^2) during the second

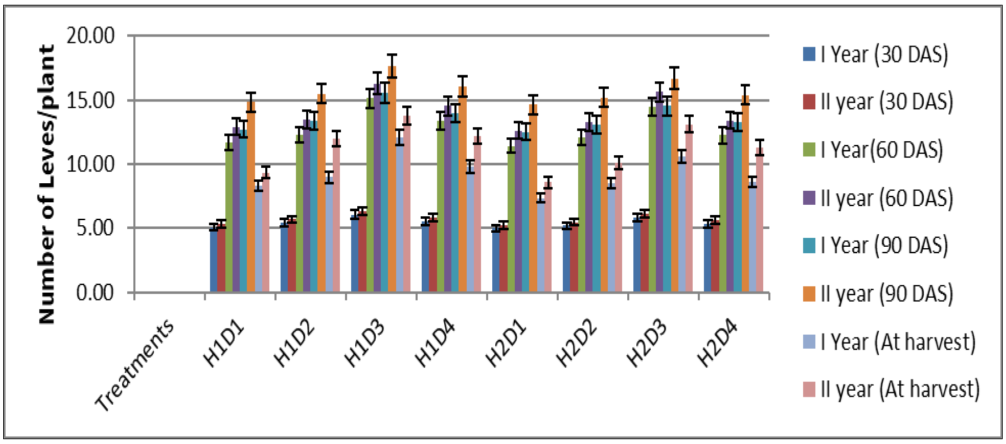

Fig. 2. Influence of sowing windows on Number of leaves at different growth stages of 30th, 60th, 90th DAS and at harvest in maize under different treatments H1D1: Maize hybrid MAH 14-5 sown on June 1st week, H1D2: Maize hybrid MAH 14-5 sown on June 3rd week, H1D3: Maize hybrid MAH 14-5 sown on July1st week, H1D4: Maize hybrid MAH 14-5 sown on July3rdweek, H_2D_1: Maize hybrid Hema sown on June 1st week, H_2D_2: Maize hybrid Hema sown on June 3rd week, H_2D_3: Maize hybrid Hema sown on July 1st week, H_2D_4: Maize hybrid Hema sown on July 3rd week.

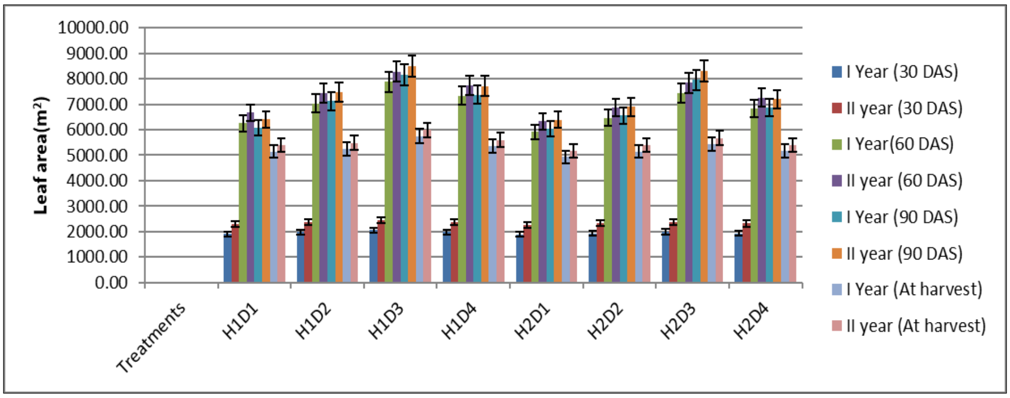

Fig. 3. Influence of sowing windows on leaf area at different growth intervals of 30th, 60th, 90th DAS and at harvest in maize under different treatments H1D1: Maize hybrid MAH 14-5 sown on June 1st week, H1D2: Maize hybrid MAH 14-5 sown on June 3rd week, H1D3: Maize hybrid MAH 14-5 sown on July1st week, H1D4: Maize hybrid MAH 14-5 sown on July3rd week, H_2D_1: Maize hybrid Hema sown on June 1st week, H_2D_2: Maize hybrid Hema sown on June 3rd week, H_2D_3: Maize hybrid Hema sown on July 1st week, H_2D_4: Maize hybrid Hema sown on July 3rd week.

year and (2253, 8079, 8318 and 5859 cm^2) in the pooled data, respectively. Conversely, the lowest leaf area was recorded under the treatment Hema sown in the June first week (H2D1). At the same growth stages (30 DAS, 60 DAS, 90 DAS and at harvest), the leaf area under H2D1 was (1889.67, 5909, 6046 and 4926 cm^2) during the first year (2276, 6321, 6388 and 5168 cm^2) during the second year and (2083, 6115, 6217 and 5047 cm^2) in the pooled data, respectively.

Impact of planting date on yield parameters of maize

The detailed effects of sowing windows and maize genotypes on reproductive parameters are presented in Table 3.

Cob length (cm)

Among all the treatments, treatment MAH 14-5 sown in the first week of July (H1D3) recorded significantly higher cob length with values of (16.54, 17.51 and 17.03) during the first year, second year and pooled data, respectively. This treatment consistently outperformed all others, indicating its superior performance in terms of cob length across both years.

In contrast, the lowest cob length was observed in treatment Hema sown in the June first week (H2D1) with values of (11.94, 12.91 and 12.43) during the first year, second year and pooled data, respectively. This suggests that Hema sown in the June first week (H2D1) had a relatively poor performance compared to other treatments, making it the least effective in terms of cob length.

Kernal per cob

Among all the treatments, MAH 14-5 sown in the first week of July (H1D3) recorded significantly higher kernels per cob with values of (541.98, 619.30 and 580.64) during the first year, second year and pooled data, respectively. This treatment consistently showed superior performance in terms of kernel count across both years.

However, the lowest number of kernels per cob was observed in treatment Hema sown in the June first week (H2D1) with values of (365.14, 440.79 and 402.97) during the first year, second year and pooled data, respectively.

Cob girth

Among all the treatments, MAH 14-5 sown in the first week of July H1D3 showed significantly higher cob girth with values of (16.32, 16.58 and 16.45) during the first year, second year and pooled data, respectively, indicating its superior performance in cob girth across both years.

Treatment Hema sown in the June first week (H2D1), however, recorded the lowest cob girth with values of (13.11, 13.37 and 13.24) during the first year, second year and pooled data, respectively.

Rows per cob

Among all the treatments, MAH 14-5 sown in the first week of July (H1D3) recorded significantly higher rows per cob with values of (15.39, 16.11 and 15.75) during the first year, second year and pooled data, respectively, indicating its superior performance in row production across both years.

However, treatment Hema sown in the June first week (H2D1) recorded the lowest rows per cob with values of (12.41, 13.13 and 12.77) during the first year, second year and pooled data, respectively.

Table 3. Effect of sowing windows and maize genotypes on reproductive parameters and yield components in southern dry zone of Karnataka (2021-2022)

Treatments	Cob length (cm) (I Year)	Cob length (cm) (II Year)	Pooled	Kernel per cob (I Year)	Kernel per cob (II Year)	Pooled	Cob girth (I Year)	Cob girth (II Year)	Pooled	Rows per cob (I Year)	Rows per cob (II Year)	Pooled	Test weight (g) (I Year)	Test weight (g) (II Year)	Pooled
H1D1	13.59	14.56	14.08	365.14	440.79	402.97	13.34	13.74	13.54	12.75	13.47	13.11	28.30	29.06	28.68
H1D2	14.96	15.93	15.44	436.05	505.70	470.88	14.54	14.80	14.67	13.74	14.46	14.10	30.49	31.25	30.87
H1D3	16.54	17.51	17.03	541.98	619.30	580.64	16.32	16.58	16.45	15.39	16.11	15.75	34.15	34.77	34.46
H1D4	15.56	16.53	16.04	486.34	561.99	524.16	15.75	16.01	15.88	14.86	15.58	15.22	32.99	33.61	33.30
H2D1	11.94	12.91	12.43	345.93	423.25	384.59	13.11	13.37	13.24	12.41	13.13	12.77	27.28	28.30	27.79
H2D2	14.53	15.50	15.02	409.63	485.28	447.45	13.43	13.87	13.65	12.80	13.73	13.27	28.57	29.33	28.95
H2D3	16.20	17.17	16.69	510.28	585.93	548.11	15.79	16.05	15.92	14.89	15.61	15.25	33.03	33.82	33.43
H2D4	14.71	15.68	15.20	419.55	495.20	457.38	13.61	14.02	13.82	13.01	13.92	13.47	28.89	29.65	29.27
SEm ±	0.282	0.285	0.284	1.720	1.738	1.7292	0.298	0.161	0.229	0.242	0.22	0.231	0.381	0.424	0.403
CD(P=0.05)	0.8556	0.8644	0.860	5.218	5.272	5.2451	0.903	0.4873	0.695	0.734	0.68	0.707	1.1555	1.287	1.221

SEm = Standard error of mean, CD= Critical difference

Test weight (g)

Among all the treatments, MAH 14-5 sown in the first week of July (H1D3) recorded significantly higher test weight with values of (34.15, 34.77 and 34.46) during the first year, second year and pooled data, respectively, highlighting its superior performance in this characteristic.

In contrast, treatment Hema sown in the June first week (H2D1) recorded the lowest test weight with values of (27.28, 28.30 and 27.79) during the first year, second year and pooled data, respectively.

Grain yield (Kg/ha)

Among all the treatments, MAH 14-5 sown in the first week of July (H1D3) achieved the highest maize grain yield, with values of (6810, 7149 and 6980) in the first year, second year and pooled data, respectively, demonstrating its superior performance in grain yield across both years. The yield of treatment H1D3 surpassed all other treatments.

On the other hand, treatment Hema sown in the June first week (H2D1) recorded the lowest yield, with values of (4522, 4817 and 4669) in the first year, second year and pooled data, respectively. The grain and stover yield under different treatments are compared in Fig. 4.

Stover yield (Kg/ha)

Among all the treatments, MAH 14-5 sown in the first week of July (H1D3) recorded the highest stover yield with values of (7849, 10462 and 9155) during the first year, second year and pooled data, respectively, indicating its superior biomass production across both years.

However, treatment Hema sown in the June first week (H2D1) registered the lowest stover yield with values of (6659, 7029 and 6844) during the respective periods.

Discussion

The progressive increase in plant height, number of leaves and leaf area from 30 DAS to harvest observed in the current study is indicative of vigorous vegetative growth, a key contributor to overall crop productivity. Enhanced vegetative growth, particularly under favorable treatment combinations, is closely linked with efficient nutrient uptake, photosynthetic efficiency and optimal plant density (14).

Among the treatments, the consistent superior performance of H1D3 across all parameters may be attributed to a synergistic effect of the genotype and sowing window that promoted better utilization of environmental resources. The maize hybrids sown during optimal windows achieved greater biomass accumulation due to prolonged vegetative phases and efficient light interception.

In contrast, the relatively lower performance observed under the H2D1 treatment highlights the critical influence of sowing time and genotype-environment interaction on maize development. Early sowing with a genotype not well-adapted to prevailing conditions may expose seedlings to suboptimal soil moisture or insufficient radiation, which can limit photosynthetic efficiency and hinder canopy expansion. Such early setbacks can be difficult to overcome, especially in rainfed systems where environmental buffers are limited (15).

Previous works noted that delayed sowing or mismatched genotype selection often results in shorter plants and reduced leaf area due to inadequate thermal time accumulation and unfavorable photoperiodic cues (16). Under high temperature stress or terminal drought, physiological processes like pollen viability and grain filling are adversely affected. Hence, the poor performance of H2D1 can be attributed to a combination of genetic limitations and an unsupportive microclimate. This emphasizes the importance of synchronizing sowing time with genotype-specific growth requirements.

The strong correlation between leaf area and grain yield observed in studies like those of early results (17) underscores the pivotal role of canopy development in maize productivity. A larger leaf area enhances the plant's ability to capture solar radiation, which directly translates into higher photosynthetic activity. This process is essential during the reproductive phase when the plant is building the grain.

Early works support this relationship, suggesting that a greater leaf area facilitates improved dry matter production, a key factor influencing yield (18). The larger canopy allows the plant to sustain higher photosynthesis, increasing the dry matter subsequently partitioned into the grain. Moreover, with a longer-lasting canopy, these hybrids maintain higher photosynthetic rates through grain filling, enhancing kernel size and overall yield (19-21).

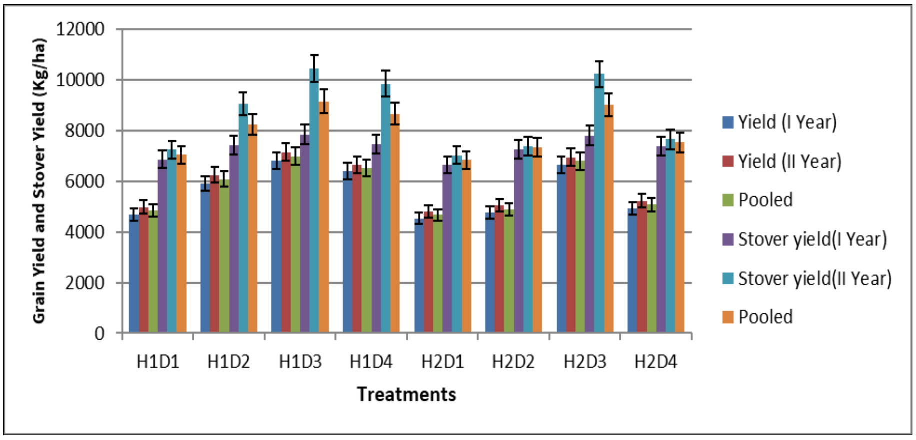

Fig. 4. Influence of sowing windows on grain yield (kg/ha) and stover yield at different growth intervals of 30, 60, 90 and at harvest in maize under different treatments. H1D1: Maize hybrid MAH 14-5 sown on June 1st week, H1D2: Maize hybrid MAH 14-5 sown on June 3rd week, H1D3: Maize hybrid MAH 14-5 sown on July1st week, H1D4: Maize hybrid MAH 14-5 sown on July3rd week, H_2D_1: Maize hybrid Hema sown on June 1st week, H_2D_2: Maize hybrid Hemasown on June 3rd week, H_2D_3: Maize hybrid Hema sown on July 1st week, H_2D_4: Maize hybrid Hema sown on July 3rd week.

An increased number of leaves contributes to higher assimilate production, as each leaf acts as a photosynthetic unit. The increase in leaves in earlier stages plays a critical role in establishing sink capacity and contributes to final yield (22). The results highlight that proper treatment combinations significantly affect vegetative traits, which ultimately influence yield attributes.

Yield attributes such as cob length, cob girth, number of kernels per cob, rows per cob and test weight are significantly influenced by genotypic characteristics and agronomic practices, including sowing time. Optimal treatment combinations aligning with suitable climatic windows and responsive genotypes exhibit superior yield traits (23).

The better performance of specific treatments in terms of yield attributes can be attributed to improved vegetative parameters like plant height and leaf area, enhancing photosynthetic capacity and assimilate partitioning towards reproductive organs (24). Treatments with greater cob length and girth are typically associated with efficient sink development and carbohydrate allocation (25).

A higher number of kernels per cob and rows per cob indicate superior pollination efficiency, influenced by environmental conditions during the reproductive stage. The proper sowing time ensures favorable conditions during tasseling and silking, critical for kernel set (26).

Test weight reflects grain filling duration and efficiency. A higher test weight is associated with optimal resource availability during the reproductive phase. This finding aligns with early findings who emphasized that early sowing leads to better seed development and higher 100-seed weight (27).

The grain yield is a cumulative outcome of these yield components. Treatments showing better vegetative growth and yield attributes translated into higher productivity. This correlation has been documented and observed that cob traits and seed weight were reliable predictors of maize grain yield (28).

Stover yield also followed a similar trend, with better-performing treatments producing significantly more fodder. Increased stover yield is associated with robust plant architecture and longer growth duration, contributing to dual-purpose utility in maize systems (29).

The findings underscore the interplay between genotype selection and sowing time in determining productivity, particularly in rainfed regions (30). Selecting a genotype well-suited to local conditions ensures better resource use efficiency. Drought-tolerant varieties or those with a longer vegetative phase may survive and produce better during periods of water scarcity.

The timing of sowing is equally important. Early or late sowing can expose crops to unfavorable climatic conditions. Synchronizing sowing with optimal environmental conditions ensures that the plant undergoes critical growth phases under favorable conditions, leading to improved grain and stover yields.

Conclusion

In conclusion, this 2021-2022 field study in the southern dry zone of Karnataka highlights the critical importance of selecting the right sowing window and maize hybrid to optimize productivity under the region's challenging agro-climatic conditions. The superior performance of the MAH 14-5 hybrid sown in the first week of July (H1D3) demonstrates the benefits of aligning sowing dates with favorable environmental conditions, leading to better resource utilization, enhanced photosynthetic efficiency and improved grain and stover yields.

By analyzing the interaction between sowing time and maize genotypes, we aim to provide valuable insights into the optimal sowing practices that can maximize maize productivity under the prevailing climatic conditions. Understanding the impact of sowing windows on growth and yield attributes is crucial for multiple reasons. Firstly, it helps farmers make informed decisions about the appropriate timing for sowing maize, reducing risks associated with drought stress, pests, diseases and other environmental factors. Secondly, the findings from this research can contribute to the development of site-specific recommendations and agricultural extension services tailored specifically to the southern dry zone of Karnataka.

In contrast, the Hema hybrid sown in early June (H2D1) showed suboptimal performance, emphasizing the need for genotype-specific sowing recommendations. The strong correlation between early vegetative growth and yield components further reinforces the importance of optimizing early growth for higher productivity. These findings provide practical guidelines for improving maize production in similar agro-climatic regions and offer a foundation for future research to refine sowing practices and explore additional management strategies for enhancing maize yields and sustainability in rainfed systems.

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Authors' contributions

HPR and CK conceived the research idea, designed the comprehensive study framework, implemented the experiment and drafted the manuscript. MH, HRB participated in the experimental design, supervised maize genotype evaluation, coordinated field activities and contributed significantly to data interpretation and manuscript writing. VVE and GSY were participated in data collection and conducted the statistical analysis. P and RK participated in the manuscript preparation and review. All authors read and approved the final manuscript.

Compliance with ethical standards

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