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Influence of sowing dates on physiological traits, yield components and grains rot disease resistance in maize (*Zea mays* L.) cultivars

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The study investigated the impact of three sowing dates (May 15, June 15, and July 15) on physiological traits, yield components, and grain rot disease infection rates in maize cultivars, including single-cross hybrids (SC131 and SC168) and the three-way cross TWC324 during the 2023 and 2024 growing seasons. Early planting (May 15) resulted in the highest significant values for dry matter accumulation (g/m²) and leaf area per plant (cm²). Additionally, early sowing significantly enhanced photosynthetic pigment content in leaves, yield and yield components (plant height [cm], ear diameter [cm], ear height [cm], ear weight [g], ear length [cm], 100-grain weight [g], grain weight per ear [g], grain yield [ard/feddan]), as well as grain crude protein and carbohydrate content (%). Furthermore, early planting reduced infection levels by *Fusarium verticillioides, F. semitectum, Aspergillus niger, A. flavus,* and *Penicillium spp*. compared to later sowing dates (June 15 or July 15). Among the tested cultivars, SC168 outperformed the others in all measured traits. The highest mean values for physiological parameters, yield characteristics, grain quality components, and resistance to grain rot disease were achieved by planting SC168 at the early sowing date (May 15) in both growing seasons. Therefore, this combination is recommended for optimal maize production under similar conditions.

Keywords: Maize; Sowing dates; Physiological characters; Yield characters; Grains rot

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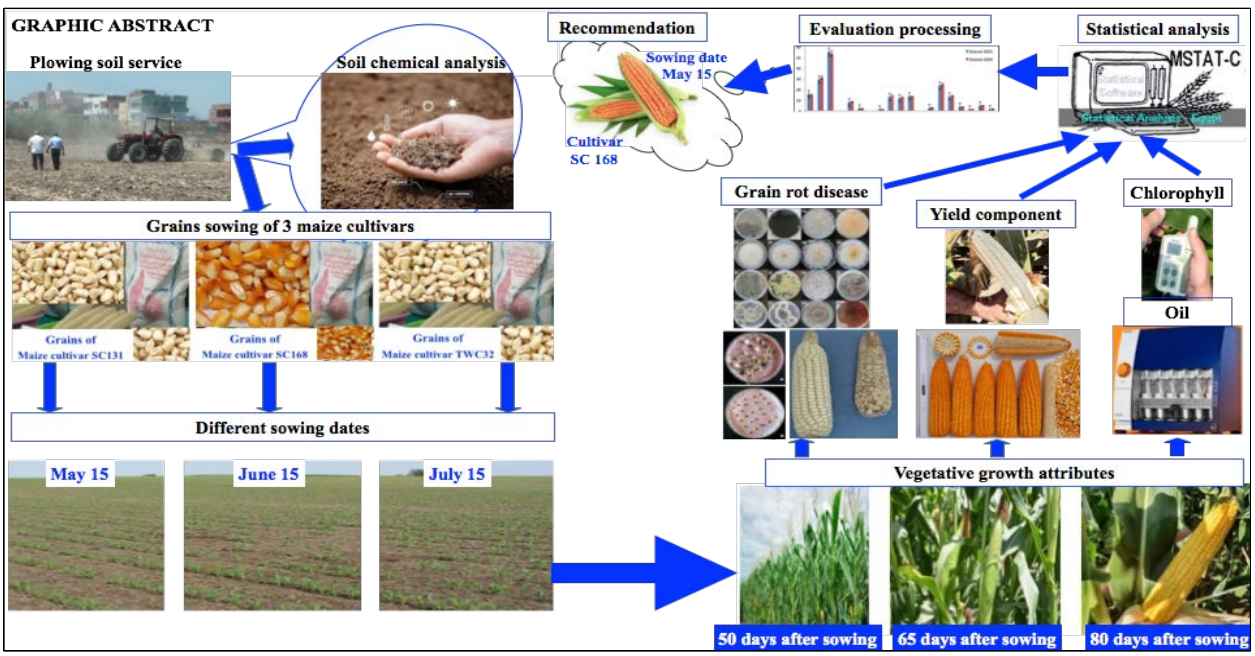

INTRODUCTION

Zea mays L. is a crucial crop in Egypt and globally. It is a key component in industrial feeds, human health foods, and veterinary nutrition due to its high starch, protein, fat, vitamin, and mineral content. However, maize production and consumption have stagnated recently, with significant variability among hybrid cultivars. The Egyptian Field Crops Research Institute has developed high-yielding single and three-way-cross hybrids adapted to summer growing conditions, following optimized cultivation practices (Buriro et al., 2015; Liaqat et al., 2018; El-Hosary et al., 2019).

Sowing dates are critical in determining maize yield components and grain quality. Optimal sowing periods enhance crop growth rate, dry matter accumulation, and plant height, whereas delayed planting negatively affects both yield and quality (Prasad et al., 2017; Rahuma, 2018; Alam et al., 2020; Rabbani & Safdary, 2021; Afzal et al., 2022; Liu et al., 2023).

Delaying sowing by 15 days increases kernel fiber and fat content but reduces crude protein and starch levels. Moreover, late sowing adversely impacts yield performance and grain quality (Qian et al., 2016; Liaqat et al., 2018). Thus, selecting appropriate planting dates is essential for maximizing maize yield and quality while mitigating biotic and abiotic stress effects (Gurmu & EshetuYadete, 2020; Jahangirlou et al., 2021; Liu et al., 2023; Elsayed et al., 2024).

Compared to late sowing (beyond 20 days after the recommended date), optimal sowing dates significantly improve crop growth rate, dry matter production, and plant height. Cultivation timing also differentially affects relative growth rate and stands density, with some hybrids exhibiting higher dry matter accumulation than others (Prasad et al., 2017; Massoud et al., 2020). The interaction between sowing dates and maize genotypes enhances vegetative growth, photosynthetic pigment concentrations (chlorophyll a, b, carotenoids, and total pigments), and yield potential (Afzal et al., 2022).

Fusarium spp. pathogens exhibit higher prevalence in maize cultivated under dry soil than in optimal moisture regimes. Additionally, maize hybrids demonstrate differential susceptibility to *F. verticillioides* and other grain rot pathogens (Rahuma, 2018; Bocianowski et al., 2020). Early sowing can substantially reduce disease incidence and mycotoxin contamination in temperate agricultural regions in maize grain, though interannual climate variability may alter this effect. Consequently, early planting combined with rot-tolerant hybrid selection is recommended for sustainable maize production with minimized disease risk (Krnjaja et al., 2022; Kaur et al., 2023; Edzili Awono et al., 2025). Late-planted maize shows increased vulnerability to western bean cutworm infestation and ear rot infection, resulting in significantly reduced yields compared to early-sown crops (Abdel-Kader et al., 2024; Elsayed et al., 2024). While early planting generally decreases disease pressure and mycotoxin accumulation, climate variability can modulate these benefits. The adoption of early sowing dates and rot-resistant hybrids synergistically enhances maize quality parameters while reducing ear and kernel rot incidence (Garba & Ogara, 2016; Kamle et al., 2019; Kaur et al., 2023; Singh et al., 2025).

This work investigates the influence of maize planting dates on physiological characteristics, crop production, yield components, and grain rot disease infection. Also, to determine the best planting date and high grain yield, quantitative and qualitative selection and disease resistance for the examined region.

MATERIALS AND METHODS

All maize plant materials and cultivars were gently obtained from the Maize Production Dept., Sakha Agricultural Research Station, Field Crops Research Institute- Agricultural Research Center, Egypt.

Experimental design

One experiment was performed during two successive seasons (2023 and 2024) at the Sakha Agricultural Research Farm using a split-plot design with three replicates. The main plots consisted of three sowing dates: 15 May, 15 June, and 15 July. The sub-plots were planted with three maize genotypes: single-cross hybrids (SC131 and SC168) and a three-way cross hybrid (TWC324). Each plot comprised six rows spaced 80 cm apart, covering an area of 24 m² (5 m length × 4.8 m width). Plants were thinned to one plant per hill at 25 cm spacing. All recommended agronomic practices were applied at their appropriate timings. Weather data were recorded by the Rice Research & Training Center Weather Station (Sakha, Kafr El-Sheikh, Egypt). During the 2023 season, the mean minimum: maximum temperatures were 23.2:31.1°C (May 15), 26.6:34.4°C (June 15), and 28.8:36.3°C (July 15). In 2024, temperatures averaged 22.8:30.6°C (May 15), 26.3:32.1°C (June 15), and 27.6:35.0°C (July 15). Mean relative humidity values were 68.3% (May 15), 79.8% (June 15), and 86.9% (July 15) in 2023, and 65.4% (May 15), 76.8% (June 15), and 90.2% (July 15) in 2024.

Studied characters

Soil chemical analysis

Representative soil samples were collected from each experimental location at 0-30 cm depth during both growing seasons. Samples were immediately air-dried, ground, and passed through a 2-mm sieve. The processed samples were thoroughly homogenized prior to chemical analysis following standard protocols (Ryan et al., 1996; Abo-Marzoka et al., 2017).

Vegetative growth attributes

Five plants were randomly selected from each plot's second and third rows at 50, 65, and 80 days after planting (DAP) to evaluate vegetative growth parameters. The following measurements were taken leaf area (LA), leaf area index (LAI), photosynthetic pigment content (chlorophyll a, b, and carotenoids), dry matter accumulation, crop growth rate (CGR), relative growth rate (RGR), and net assimilation rate (NAR).

Leaf area/plant (cm^2) and leaf area index (LAI)

Maize leaf area was measured using the CI-203 laser area meter. The leaf area index (LAI) was calculated according to Abo-Marzoka et al. (2017) using the formula: LAI = Total plant leaf area/Plant ground area occupied.

Corn leaf area (cm^2)

Five corn leaves were used to determine the average flag leaf area at 100 days after sowing for each plot (Abo-Marzoka et al., 2017).

Leaves photosynthetic pigment contents

Photosynthetic pigments (chlorophyll a, b, and carotenoids) were determined from five leaf discs sampled from maize foliage. Pigments were extracted by homogenizing the tissue in 20 mL of 85% aqueous acetone containing a pinch of $CaCO_3$. After filtration, the final extract volume was adjusted to 20 mL. Pigment concentrations (mg/L) were determined spectrophotometrically at 662 nm, 644 nm, and 470 nm using the equations of Lichtenthaler & Buschmann (2001):

Chl. a = $11.24(A_{662}) - 2.04(A_{644})$
Chl. b = $20.13(A_{644}) - 4.19(A_{662})$
Carotenoids = $[1000(A_{470}) - 1.90(\text{Chl. a}) - 63.14(\text{Chl. b})]/214$.

Dry matter accumulation (g/m^2)

Maize plants were separated into stems, leaves, ears, and tassels, then dried to constant weight in a forced-air oven at 105 °C. Dry weights were recorded following the methodology of Abo-Marzoka et al. (2017).

Crop growth rate (CGR)

The CGR was estimated to measure the increase rate of maize material/unit of ground area/unit of time through 2 intervals such as; $CGR= (W_2-W_1)/(T_2-T_1)$ g/m^2/week (W2= 2nd weight; W1= 1st weight; T2= 2nd time; and T1= 1s time; Abo-Marzoka et al., 2017).

Relative growth rate (RGR)

RGR was calculated to assess the growth efficiency per unit of existing biomass between two intervals using the formula: $RGR = (\ln W_2 - \ln W_1)/(T_2 - T_1)$ [g/g/week].

Where: W_2 = Dry weight at time 2 (g), W_1 = Dry weight at time 1 (g), T_2 = Time at second sampling (weeks), and T_1 = Time at first sampling (weeks) (Abo-Marzoka et al., 2017).

Net assimilation rate (NAR)

NAR was calculated to quantify biomass accumulation per unit leaf area over time using the formula:

$NAR = (W_2 - W_1)(\ln A_2 - \ln A_1) / (A_2 - A_1)(T_2 - T_1)$ [g/m^2/week].

Where: W_1, W_2 = Dry weight at times 1 and 2 (g); A_1, A_2 = Leaf area at times 1 and 2 (m^2); and T_1, T_2 = Time at sampling points 1 and 2 (weeks) (Abo-Marzoka et al., 2017).

Yield and yield components

At harvest, 10 plants were harvested from the 2nd and 3rd ridges of each plot to determine the length of plant (cm), ear height (cm), ear length (cm), ear weight (g), rows no./ear, kernels no./row, ear diameter (cm), weight/100-grain (g), grain weight/ear (g) and the grain yield/two on fourth and fifth rows (kg/two rows) in each plot on each replicate.

Chemical analysis

In both seasons, chemical analyses were performed on maize samples 80 days after planting (expressed as percentages specific to sample dry weight) (AOAC, 1990). 250 g of grain samples were picked randomly from every plot, then directly ground, and fine powder was obtained by passing through a 2 mm mesh for the determination of N% × 5.75 for crude protein, Carbohydrates, Fiber, Ash%, Silica (mg/100g) and Oil content by Soxhlet extraction method (Tolba & El-Sayed, 2002). Furthermore, the electrical conductivity (EC) was measured at 20 °C by a calibrated conductivity meter for 50 weighted seeds from 4 sub-samples/each seed grade that were individually placed in 250 mL distilled water and then incubated at 25 °C for 24 hrs (AOAC, 1990).

Fungal pathogen frequency incidence

The incidence of fungal pathogen frequency was examined by randomly collecting 500-g grain samples from maize cultivars SC131, SC168, and TWC324 at harvest for each sowing date (May 15, June 15, and July 15). Samples were stored under laboratory conditions until analysis. Sterilized 100-kernel samples were cultured in Petri plates containing 10 mL potato dextrose agar (PDA) (Massoud et al., 2023). Plates were incubated at 26-27 °C for 7-12 days. Emergent fungi from infected kernels were light microscopy (400× magnification) using an Otika digital camera (Model B-193, Germany) and quantified as occurrence (%) based on isolation frequency (ISTA, 1985). Fungal isolates were purified via the hyphal tip technique and identified at the Mycology Department, Plant Pathology Research Institute, ARC, Giza, Egypt.

Statistical analysis

All recorded data were statistically analyzed using the MSTAT-C software package (Version 1988). Mean comparisons were performed with Duncan's multiple range test (Duncan, 1955) at a 5% probability level.

RESULTS

Soil chemical analysis

The results in Figure 1 show the soil particle size distribution (%) comprised as; Sand: 15.70% (2023), 14.90% (2024); Silt: 29.20% (2023), 31.30% (2024); Clay: 55.10% (2023), 53.80% (2024); Soil texture: Clay (both seasons). Soil chemical properties were pH: 7.92 (2023), 8.56 (2024); EC (dS/m): 2.31 (2023), 2.42 (2024); Soluble cations (K^+, Ca^{++}, Mg^{++}, Na^+) and anions (CO_3^- + HCO_3^-, Cl^-, SO_4^-) were measured at 1:2 ratio (cmol/kg soil). Additionally, all values differed between 2023 and 2024 seasons parameters included Calcium carbonate (%), total nitrogen (%), available phosphorus (mg/kg) and organic matter (%).

Growth characteristics

The study analyzed the growth characteristics of maize cultivars at different sowing dates, as shown in Table 1. The highest leaf area values were recorded for the first sowing date (May 15) at 50, 65, and 80 days after sowing, reaching 4440.64, 4961.0, and 5033.9 cm^2/m^2 in the 2023 season, and 4852.75, 5421.39, and 5501.0 cm^2/m^2 in the 2024 season, respectively. In contrast, the lowest values were observed at the last sowing date (July 15), with measurements of 3553.72, 3970.2, 4028.4 cm^2/m^2 in 2023 and 3277.52, 3661.61, and 3715.3 cm^2/m^2 in 2024.

The variety SC168 exhibited the highest leaf area values at 50, 65, and 80 days after sowing, followed by SC131, whereas the lowest values were recorded for TWC324 across all tested sowing dates. Specifically, the highest leaf area values at the three growth stages were observed for SC168 at the first sowing date, reaching 4574.8, 5110.8, and 5185.9 cm^2/m^2 in 2023, and 5427.5, 6063.8, and 6152.6 cm^2/m^2 in 2024. Conversely, the lowest values were recorded for TWC324 at the last sowing date, with measurements of 3518.9, 3931.3, and 3989.0 cm^2/m^2 in 2023, and 2779.9, 3105.7, and 3151.3 cm^2/m^2 in 2024, at 50, 65, and 80 days after sowing, respectively, in a statistically significant interaction.

Yield and yield components

The highest crop yield characteristics and component values were observed at the first sowing dates (Table 2). These included the following measurements in the 2023 season: 504.7 kernels/ear, 36.82 g (100-kernel weight), 186.40 g (kernel weight/ear), 318.4 cm (plant height), 25.9 cm (ear length), 6.22 cm (ear diameter), 3.260 ton/feddan (grain yield), and 73.16% (shelling percentage). Similarly, in the 2024 season, the values were: 487.8 kernels/ear, 36.20 g, 176.37 g, 326.4 cm, 25.7 cm, 6.00 cm, 3.117 ton/feddan, and 67.70%, respectively.

Conversely, the lowest values were recorded at the latest sowing date. In the 2023 season, these were: 403.8 kernels/ear, 29.47 g, 119.51 g, 254.8 cm, 20.7 cm, 4.95 cm, 2.609 ton/feddan, and 58.54%.

Similarly, in 2024, the values were: 402.9 kernels/ear, 28.57 g, 117.10 g, 253.2 cm, 19.7 cm, 4.40 cm, 2.623 ton/feddan, and 58.00%. Among the cultivars, SC168 exhibited the highest values for all tested traits, including the maximum shelling percentage (68.80%), whereas TWC 324 showed the lowest (58.20%). Furthermore, the statistical interaction between sowing dates and maize cultivars revealed that SC168, when planted on the earliest sowing date (May 15), achieved the highest shelling percentage (73.19%), while TWC 324, sown at the latest date (July 15), had the lowest (54.04%).

Photosynthetic pigments contents

The highest concentrations of chlorophyll a, chlorophyll b, carotene, and their totals were observed at the early sowing date, with values of 4.415, 2.331, 1.119, and 7.864 $mg/g/dcm^2$ in the 2023 season and 4.812, 2.284, 0.884, and 7.980 $mg/g/dcm^2$ in the 2024 season, respectively. In contrast, the lowest values were recorded at the latest sowing date (Figure 2A). The cultivar SC168 exhibited the highest pigment concentrations across all sowing dates, measuring 4.201, 2.218, 1.065, and 7.483 $mg/g/dcm^2$ in 2023 and 4.374, 2.076, 0.841, and 7.254 $mg/g/dcm^2$ in 2024 for chlorophyll a, b, carotene, and their totals, respectively. Conversely, TWC324 showed the lowest values (Figure 2B).

The statistical interaction between sowing dates and cultivars revealed that SC168 achieved the highest total chlorophyll and carotene content (7.917 $mg/g/dcm^2$) when sown early (May 15), while TWC324 displayed the lowest (6.145 $mg/g/dcm^2$) at the latest sowing date (July 15) (Figure 2C).

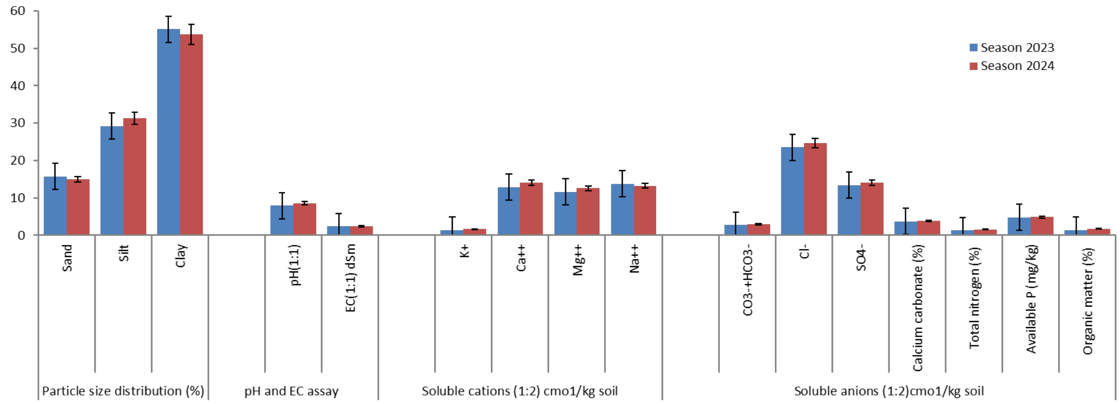

Figure 1. Some physical and chemical soil properties of maize experimental plants in the 2023 and 2024 seasons; and mean values are not significantly different at P≤0.05 at a 5% level using DMRT.

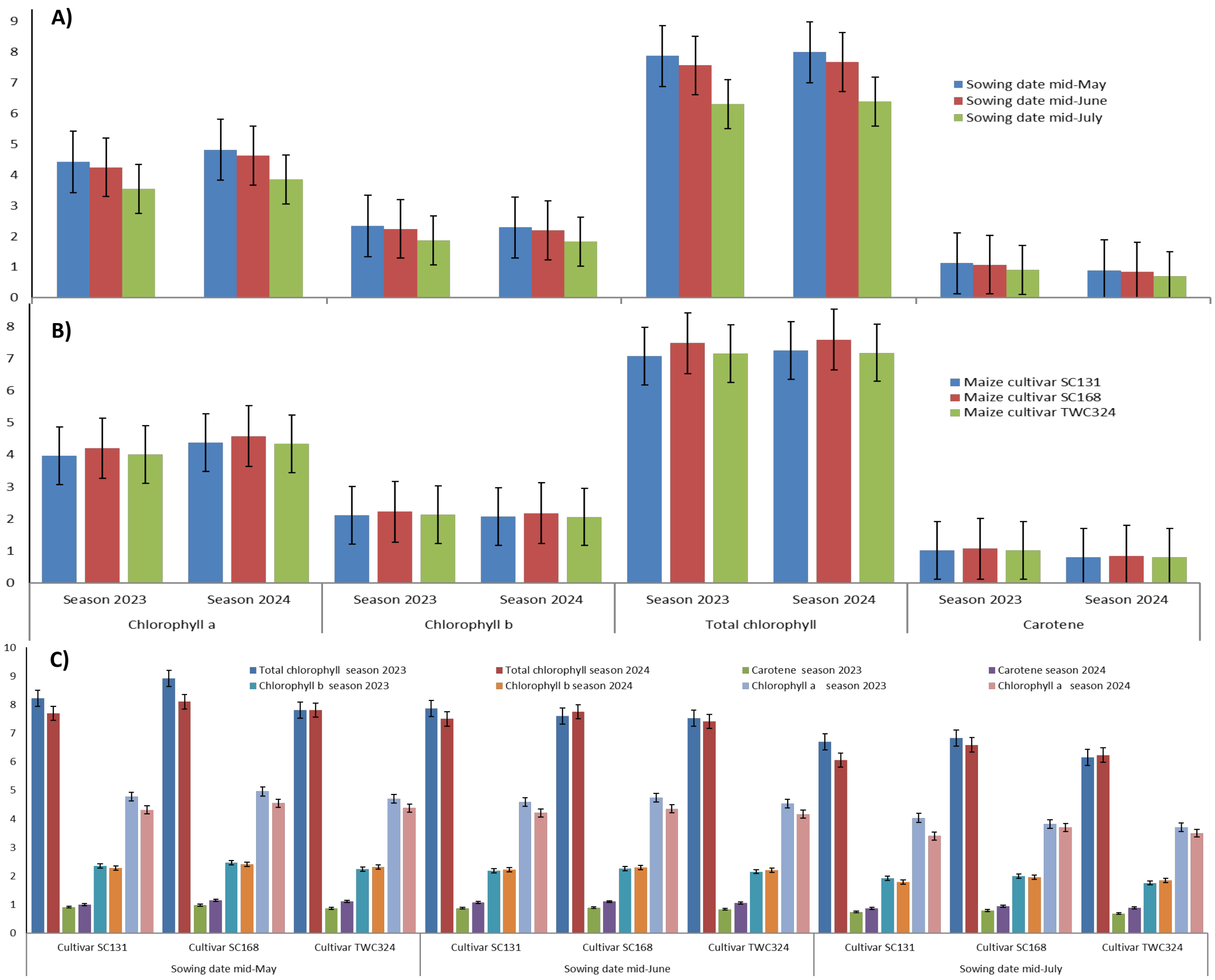

Figure 2. Chlorophyll a, b and carotene content of three tested maize cultivars during three tested sowing dates during the 2023 and 2024 growing season; (A): Mean plots-planting dates, (B): Sub plots-maize cultivars, (C): Interaction between planting dates and maize cultivars, and mean values are not significantly different at P≤0.05 at 5% level using DMRT.

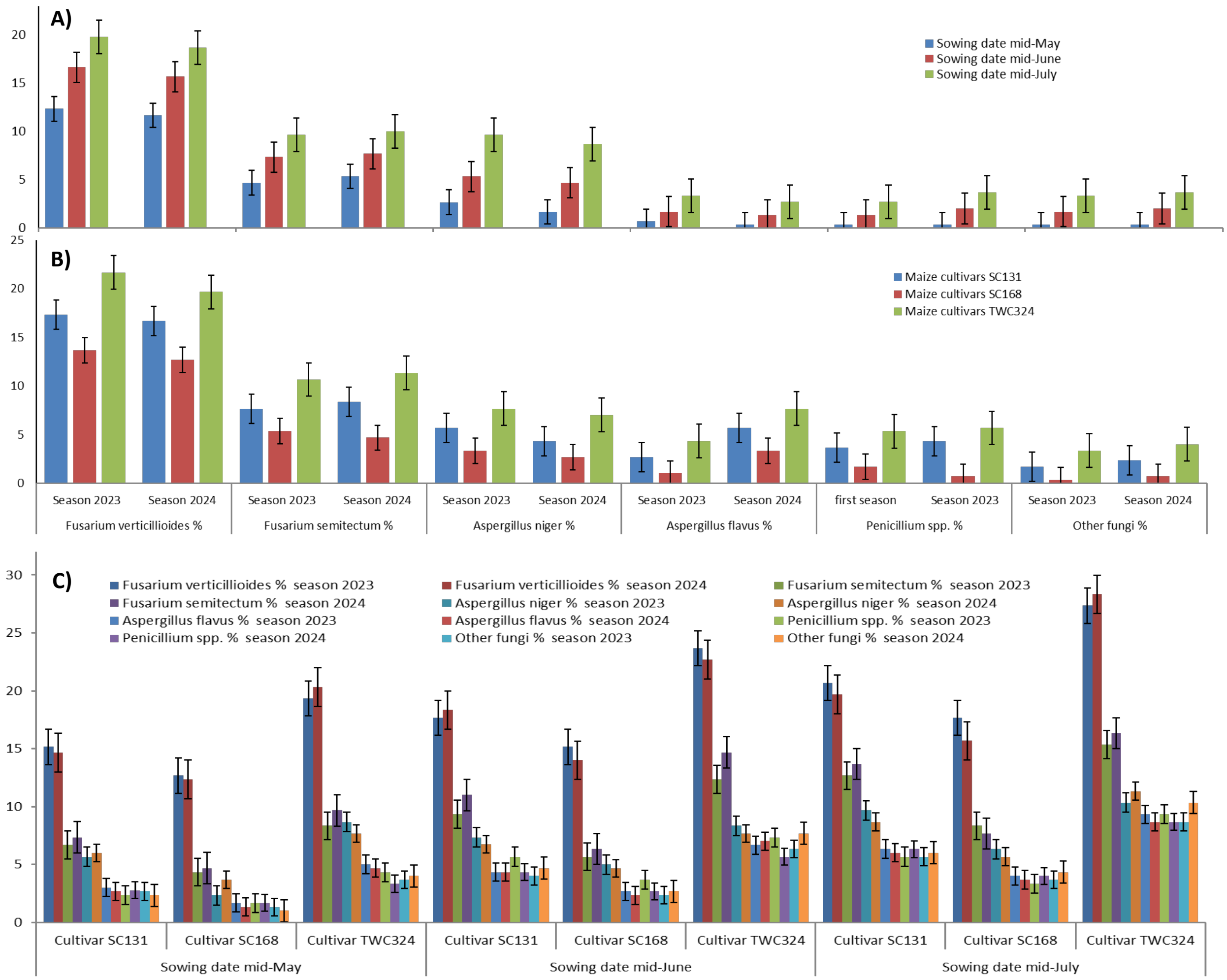

Figure 3. Effect of different sowing dates on infection by ear and kernel rot disease pathogens on three tested maize genotypes during 2023 and 2024 seasons; (A): Mean plots-planting dates, (B): Sub plots-maize cultivars, (C): Interaction between planting dates and maize cultivars, other fungi *Nigrospora oryzae, Epicoccum nigrum, F. oxysporum* and *Alternaria* sp., and mean values are not significantly different at P≤0.05 at 5% level using DMRT.

Table 1. Leaf area, leaf area index, and relative photosynthesis in 50, 65, and 80 days of sowing under three different sowing dates on three tested maize cultivars during the 2023 and 2024 growing seasons.

Treatments		Leaf area (cm²/m²)						Leaf area index						Relative of photosynthesis			
		at 50 days		at 65 days		at 80 days		at 50 days		at 65 days		at 80 days		at period of 50-65 days (g/m²/week)		at period of 65-80 days (g/m²/week)	
Season		2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Mean plots-planting dates (A)																	
Planting date (A)	May 15	4440.64 a	4852.75a	4961.0a	5421.39a	5033.9a	5501.0a	2.115 a	2.311 a	3.236 a	3.536 a	4.553 a	4.943 a	12.645a	15.553a	18.996a	21.845a
	June 15	4265.55 b	4426.54b	4765.4b	4945.24b	4835.4b	5017.8b	2.031 b	2.108 b	3.109b	3.226 b	4.344 b	4.508 b	12.147b	14.940b	18.247b	20.985b
	July 15	3553.72 c	3277.52c	3970.2c	3661.61c	4028.4c	3715.3c	1.692 c	1.561 c	2.590 c	2.388 c	3.620 c	3.338 c	10.120c	12.448c	15.201c	17.481c
F test		**	**	**	**	**	**	*	*	*	*	*	*	*	**	*	**
Sub plots-maize cultivars (B)																	
Maize cultivars (B)	SC131	4532.3c	3998.17c	4422.82b	4466.7c	4941.10b	4532.3c	1.904 b	2.004 b	2.914 b	3.223 b	4.072 b	4.505 b	11.385c	14.138b	17.103c	19.857b
	SC168	4789.6a	4225.19a	4628.66a	4720.3a	5171.05a	4789.6a	2.012 a	2.106 a	3.079 a	3.373 a	4.303 a	4.714 a	12.032a	14.801a	18.073a	20.785a
	TWC324	4575.8b	4036.55b	3505.33c	4509.6b	3916.09c	4575.8b	1.922 ab	1.671 ab	2.942 ab	2.555 ab	4.111 ab	3.570 ab	11.495b	14.004c	17.267b	19.669c
F test		*	*	**	**	**	*	*	*	*	*	*	*	**	*	*	*
Interaction (A×B)																	
May 15	SC131	4342.0c	5078.0b	4850.1b	5673.0b	4922.0b	5756.3b	2. 2.068 b	2.418 ab	3.164 b	3.705 ab	4.422 b	5.172 ab	12.364a	15.428ab	18.575b	21.67b
	SC168	4574.8a	5427.5a	5110.8a	6063.8a	5185.9a	6152.6a	2.178 a	2.585 a	3.334 a	3.955 a	4.660 a	5.528 a	13.027a	16.025a	19.569a	22.505a
	TWC324	4440.0b	4052.8e	4921.1b	4527.7e	4993.7b	4594.2e	2.098 ab	1.930 b	3.210 ab	2.954 b	4.487 ab	4.128 b	12.545a	15.208b	18.844a	21.36b
June 15	SC131	4233.1d	4868.1c	4729.2c	5438.5c	4798.6c	5518.4c	2.016 bc	2.251 bc	3.085 bc	3.446 bc	4.311 bc	4.816 bc	12.055b	14.828bc	18.109c	20.825bc
	SC168	4378.0c	4728.2d	4891.0b	5282.3d	4962.8b	5359.8d	2.085 ab	2.318 ab	3.190 ab	3.548 ab	4.459 ab	4.954 ab	12.467a	15.335b	18.727ab	21.538b
	TWC324	4185.6d	3683.3f	4676.0d	4114.9f	4744.7c	4175.3f	1.993 c	1.754 c	3.050 c	2.684 c	4.263 c	3.752 c	11.919b	14.660c	17.905c	20.593c
July15	SC131	3419.4g	3462.3h	3820.1g	3868.0h	3876.2f	3924.8h	1.628 e	1.649 e	2.492 e	2.523 e	3.483 e	3.526 e	9.737d	12.325de	14.627e	17.308e
	SC168	3722.9e	3590.4g	4159.1e	4011.2g	4220.2d	4070.0g	1.773 cd	1.710 cd	2.713 cd	2.616 cd	3.792 cd	3.657 cd	10.601bc`	13.043d	15.925d	18.313d
	TWC324	3518.9f	2779.9i	3931.3f	3105.7i	3989.0e	3151.3i	1.676 f	1.324 f	2.564 f	2.026 f	3.584 f	2.832 f	10.021c	11.978e	15.052e	16.822e
F test		**	**	**	**	*	**	**	*	**	*	*	*	*	*	*	**

* and ** indicate P < 0.05, P < 0.01 and not significant, respectively. The means of each column designated by the same letter are not significantly different at the 5% level using DMRT.

Table 2. Yield, yield component, and shelling% of three tested maize cultivars under three tested sowing dates during the 2023 and 2024 seasons.

Treatments		No of kernels/ear		Weight of 100 kernels (g)		Weight of kernels/ear (g)		Plant length (cm)		Ear length (cm)		Ear diameter (cm)		Grain yield (ton/feddan)		Shelling%	
Season		2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Mean plots-planting dates (A)																	
Planting date (A)	May 15	504.7 a	487.8 a	36.82 a	36.20 a	186.40 a	176.37 a	318.4 a	326.4 a	25.9 a	25.7 a	25.9 a	25.7 a	3.260 a	3.117 a	73.16 a	67.70 a
	June 15	484.8 b	442.9 b	35.36 b	32.77 b	172.00 b	167.57 b	305.8 b	303.8 b	24.9 b	24.4 b	24.9 b	24.4 b	3.132 b	2.799 b	70.27 b	66.30 b
	July 15	403.8 c	402.9 c	29.47 c	28.57 c	119.51 c	117.10 c	254.8 c	253.2 c	20.7 c	19.7 c	20.7 c	19.7 c	2.609 c	2.623 c	58.54 c	58.00 c
F test		**	*	*	**	*	*	**	*	*	**	*	*	*	*	*	*
Sub plots-maize cultivars (B)																	
Maize cultivars (B)	SC131	454.4 b	439.8 b	33.15 b	32.17 b	162.71 a	150.17 a	286.7 a	303.0 a	23.3a	22.4 a	5.59 a	5.10 a	2.935 b	2.840 b	65.87 b	63.30 b
	SC168	480.1 a	462.6 a	35.03 a	34.70 a	169.91 b	166.07 b	302.9 b	296.0 b	24.6b	24.7 b	5.91 b	5.80 b	3.102 a	3.070 a	69.60 a	68.80 a
	TWC324	458.7 c	431.2 c	33.46 c	30.67 c	155.23 c	144.80 c	289.4 c	284.4 c	23.5c	22.7 c	5.64 c	4.90 c	2.963 c	2.629 c	66.50 c	58.20 c
F test		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Interaction (A×B)																	
May 15	SC131	493.6 ab	481.4 b	36.00 b	35.80 b	178.2 b	173.1 b	311.3 ab	320.9 b	25.3 b	24.9 b	6.08 b	5.81 b	3.188 ab	3.091 b	71.53 b	69.53 b
	SC168	519.9 a	504.1 a	37.93 a	38.22 a	197.7 a	191.7 a	328.0 a	341.0 a	26.7 a	26.9 a	6.40 a	6.35 a	3.359 a	3.274 a	75.38 a	73.19 a
	TWC324	500.6 b	477.9 ab	36.53 ab	34.63 ab	183.4 ab	164.3 ab	315.8 b	317.2 b	25.7 b	25.4 b	6.19 b	5.71 ab	3.234 b	2.986 ab	62.58 c	60.35 c
June 15	SC131	481.1 bc	435.7 bc	35.10 bc	32.81 bc	169.4 b	161.5 b	303.5 b	311.9 b	24.7 b	23.9 b	5.95 b	5.09 b	3.108 bc	2.794 bc	69.75 bc	63.52 bc
	SC168	497.5 b	465.1 b	36.30 b	34.63 b	181.1 ab	183.4 ab	313.9 ab	302.4 bc	25.5 ab	26.1 ab	6.15 ab	6.08 ab	3.215 b	3.039 b	72.10 b	70.04 b
	TWC324	475.8 c	427.8 c	34.68 c	30.91 c	166.4 bc	157.8 bc	300.1 c	297.1 bc	24.4 bc	23.2 bc	5.81 bc	5.00 bc	3.073 c	2.564 c	58.95 c	60.23 c
July 15	SC131	388.7 e	402.3 d	28.35 d	27.94 d	110.5d e	115.9 d	245.2 f	276.3 d	19.9 de	18.3 de	4.75 de	4.29 de	2.510 d	2.635 d	56.33 d	56.92 d
	SC168	423.0 cd	418.7 cd	30.88 cd	31.33 cd	131.0 d	123.1 d	266.9 d	244.5 f	21.7 d	21.2 d	5.17 d	5.10 d	2.733 cd	2.898 cd	61.33 cd	63.11 cd
	TWC324	399.7 d	387.9 e	29.18 e	26.59 e	117.0 e	112.3 e	252.3 e	238.9 e	20.5 e	19.5 e	4.92 e	3.95 e	2.583 e	2.336 e	53.00 e	54.04 e
F test		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

* and ** indicate P < 0.05, P < 0.01 and not significant, respectively. The means of each column designated by the same letter are not significantly different at the 5% level using DMRT.

Table 3. Dry maturity, crop growth rate and relative growth rate at the periods of 50, 65, and 80 days of sowing dates during 2023 and 2024 growing seasons.

Treatments		Dry mature(g/m^2)						Crop growth rate (g/m^2/week)				Relative growth rate (g/m^2/week)			
		at 50 days		at 65 days		at 80 days		at period of 50-65 days of sowing		at period of 65-80 days of sowing		at period of 50-65 days of sowing		at period of 60-80 days of sowing	
Season		2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
Mean plots-planting dates (A)															
Planting date (A)	May 15	293.0 7a	320.29 a	519.70 a	567.93 a	851.87 a	930.92 a	382.74 a	418.26 a	609.01 a	665.53 a	0.408 a	0.446 a	0.700 a	0.518 a
	June 15	261.54 b	292.16 b	499.21 b	518.05 b	818.28 b	849.16 b	367.65 b	381.53 b	585.00 b	607.08 b	0.392 b	0.406 b	0.734 a	0.471 a
	July 15	234.55 c	216.32 c	415.90 c	383.58 c	681.72 c	628.74 c	306.30 c	252.49 c	487.37 c	449.49 c	0.326 c	0.301 c	0.600 b	0.349 b
F test		*	**	*	*	*	**	**	**	**	**	**	**	*	*
Sub plots-maize cultivars (B)															
Maize cultivars (B)	SC131	263.88 b	291.91 b	467.91 b	517.61 b	766.98 b	848.45 b	344.60 b	381.21 b	548.33 c	606.57 a	0.367	0.406 a	0.554 a	0.471 a
	SC168	278.87 a	305.50 a	494.48 a	541.70 a	810.54 a	887.93 a	364.17 a	398.94 a	579.47 a	634.80 a	0.388	0.425 a	0.509 a	0.492 a
	TWC324	266.42 b	231.36 ab	472.41 ab	410.24 ab	774.34 ab	672.44 ab	347.91 b	302.13 c	553.59 b	480.74 b	0.371	0.322 b	0.403 b	0.374 b
F test		*	*	*	*	**	**	*	**	**	*	NS	*	*	*
Interaction (A×B)															
May 15	SC131	286.58 b	335.18 b	508.15 c	594.29 b	832.94 b	974.13 b	374.24 b	437.61 b	591.49 bc	696.42 b	0.399	0.467 a	0.603	0.541
	SC168	301.94 a	358.22 a	535.39 a	635.10 a	877.60	1041.2 a	394.30 a	467.80 a	627.41 a	744.36 a	0.420	0.499 a	0.584	0.579
	TWC324	290.75 b	267.79 b	515.55 b	474.31 c	ab 845.06	777.46 c	379.69 b	349.31 d	604.15b	555.82 d	0.405	0.372 b	0.491	0.432
June 15	SC131	279.39 c	312.07 bc	495.41 bc	553.36 b	812.05 b	907.03 bc	364.85 c	407.53 c	580.55 c	648.46 c	0.388	0.434 ab	0.464	0.504
	SC168	288.95 b	321.30 ab	512.37 ab	569.72 ab	839.85 ab	933.06 ab	377.34 b	419.58 c	600.43 b	667.63 c	0.402	0.447 a	0.529	0.518
	TWC324	276.25 c	243.10 c	489.85 c	431.07 c	802.93 c	706.58 c	360.76 c	317.47 e	574.03c	505.15 e	0.385	0.339 bc	0.385	0.393
July 15	SC131	225.69 f	228.52 e	400.18 e	405.20 e	655.96 e	664.18 e	294.72 f	298.42 f	468.95 f	474.40 g	0.314	0.318 c	0.335	0.369
	SC168	245.72 cd	236.97 cd	435.70 cd	420.19 cd	714.17 cd	688.75 cd	320.88 d	309.46 e	510.57 d	492.83 f	0.342	0.330 bc	0.402`	0.383
	TWC324	232.25 e	208.48 f	411.82f f	325.34 f	675.04 f	533.28 f	303.30 e	239.60 g	482.60 e	381.25 h	0.323	0.255 d	0.306	0.296
F test		**	*	*	**	**	*	*	**`	**	**	NS	*	N.S	N.S

* and ** indicate P < 0.05, P < 0.01 and not significant, respectively. The means of each column designated by the same letter are not significantly different at the 5% level using DMRT.

Table 4. Maize grain analysis in three tested hybrids under three different sowing dates during the 2023 and 2024 seasons.

Treatments		Crud protein %		Carbohydrates %		Oils %		Ash %		Fiber %		Electrical conductivity (EC)		Germination %		Plume		Radical	
Season		2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2
Mean plots-planting dates (A)																			
Planting date (A)	May 15	10.501a	9.991a	71.574a	70.892a	6.246c	6.120c	1.569c	1,432c	2.337c	2.299c	8.514c	9.022c	94.378a	95.648a	9.798a	9.904a	13.910a	13.
	June 15	9.644b	9.534b	70.887b	70.453b	6.964b	6.573b	1.706b	1.631b	2.479b	2.531b	10.378b	10.865b	91.944b	92.334b	9.253b	9.599b	12.893b	11.
	July 15	9.296c	9.022c	70.452c	70.111c	7.223a	6.988a	1.898a	1.901a	2.737a	2.795a	11.988a	11.995a	90.578c	90.972c	8.703c	8.623c	10.536c	10.
F test		*	*	*	*	**	*	*	**	**	**	**	*	*	**	**	*	**	
Sub plot-maize cultivars (B)																			
Maize cultivars (B)	SC131	9.775 b	9.901b	71.134b	70.992b	6.692b	6.703b	1.667b	1.658b	2.593b	2.457b	9.911b	9.102b	93.122a	94.677a	9.762b	9.457b	11.987b	11.
	SC168	10.223a	10.561a	71.884a	71.434a	6.860a	6.901a	1.899a	1.799a	2.809a	2.789a	9.267c	8.985c	92.622b	92.546b	10.263a	9.888a	13.891a	13.
	TWC324	9.209c	9.032c	70.494c	70.122c	6.421c	6.498c	1.469c	1.501c	2.396c	2.287c	10.592a	9.898a	90.752c	91.111c	9.109c	8.658c	10.334c	10.
F test		**	**	**	**	*	*	**	*	**	**	**	**	**	**	**	*	**	
Interaction (AxB)																			
May 15	SC131	10.122c	10.186c	71.564b	71.399b	6.711bc	6.634cd	1.633b	1.598bc	2.511d	2.487f	9.712f	9.613f	95.221a	95.643a	9.966b	9.861b	12.899b	12.
	SC168	11.102a	11.009a	71.933a	71.801a	6.901a	6.877c	1.745ab	1.644b	2.799c	2.722c	9.165h	9.112h	92.133c	93.143b	10.433a	10.653a	14.132a	13.
	TWC324	9.854c	9.789c	70.687d	70.500d	6.564c	6.411d	1.530c	1.399c	2.299e	2.167g	10.433c	10.289c	90.989d	91.085d	8.922e	9.122e	10.534d	9.
July 15	SC131	9.989c	9.855c	71.111c	71.001c	6.899ab	6.744c	1.811ab	1.689b	2.713c	2.679d	9.991e	10.003d	93.767b	93.324b	9.423d	9.223d	11.122c	11.
	SC168	10.768b	10.697b	71.566b	71.311b	6.998a	6.877c	1.921a	1.874a	2.888b	2.821b	9.465g	9.389g	91.554cd	91.233d	9.765c	9.565c	12.310b	12.
	TWC324	9.365d	9.288d	70.322e	70.133e	6.644bbc	6.514d	1.699b	1.499c	2.511d	2.435f	11.254b	11.122b	90.111d	90.033e	8.465f	8.265g	9.523e	8.
July 15	SC131	9.232d	9.198d	70.799cd	70.567d	6.988a	6.881c	1.988a	1.799ab	2.899b	2.863b	10.122d	10.109d	92.522c	92.122c	9.122e	9.001f	9.546e	9.
	SC168	9.985c	9.887c	70.991c	70.772d	7.211a	7.366a	2.003a	1.969a	2.987a	2.911a	9.988e	9.866e	90.302d	91.002d	9.425d`	9.133de`	10.573d	10.
	TWC324	8.884e	8.653e	70.132e	70.033e	7.001a	7.121b	1.876a	1.678b	2.677cd	2.599e	11.999a	11.799a	89.134e	88.934f	8.122g	8.088h	8.115f	9.
F test		**	**	**	*	*	*	**	**	**	**	**	**	**	**	**	**	**	

* and ** indicate P < 0.05, P < 0.01 and not significant, respectively. The means of each column designated by the same letter are not significantly different at the 5% level using DMRT.

Dry matter and growth rate

The highest dry matter values at 50, 65, and 80 days after sowing were recorded at the earliest sowing date, measuring 293.07, 519.70, and 851.87 g/m² in 2023 and 320.29, 567.93, and 930.92 g/m² in 2024, respectively. Similarly, the crop growth rate (CGR) during 50-65 and 65-80 day intervals and relative growth rate (RGR) during the same periods reached their maxima at the early sowing date, with values of 382.74, 609.01, 0.408, and 0.700 g/m²/day in 2023 and 418.26, 665.53, 0.446, and 0.518 g/m²/day in 2024, respectively.

Among cultivars, SC168 consistently showed superior performance in all measured traits, while TWC324 exhibited the lowest values. The interaction analysis revealed that SC168 achieved peak dry matter accumulation (at 50, 65, and 80 days) and other growth parameters when sown early, whereas TWC324 displayed minimal values when sown late (Table 3).

Chemical analyses

Chemical analysis of corn hybrids revealed superior nutritional quality at early sowing dates. The earliest planting dates showed peak values for crude protein (10.501%) and carbohydrates (71.574%) in the 2023 season, followed by 9.991% and 70.892% in 2024. Conversely, oil content (6.246%), ash (1.569%), and fiber (2.337%) reached their lowest levels in 2023, with similar trends in 2024 (6.120%, 1.432%, and 2.299%, respectively).

Germination parameters followed the same pattern, with the earliest sowings achieving 94.378% germination, 9.798 cm plumule length, and 13.910 cm radicle length in 2023, improving to 95.648%, 9.904 cm, and 13.891 cm in 2024. Electrical conductivity (EC) showed an inverse relationship, increasing significantly with delayed planting in both seasons.

Among hybrids, SC168 outperformed others, demonstrating the highest grain quality metrics and maximal plumule/radicle lengths, followed by SC131 and TWC324. The sowing date × hybrid interaction analysis confirmed these trends: SC168 at early sowing achieved optimal chemical properties (11.102% protein, 71.933% carbohydrates) and growth parameters (10.433 cm plumule, 14.132 cm radicle) in 2023, with comparable results in 2024 (11.009%, 71.801%, 10.653 cm, and 13.998 cm) (Table 4).

Fungal pathogen frequency incidence

The early sowing date was recorded the lowest infections percentage by *Fusarium verticillioides*, *F. semitectum*, *Aspergillus niger, A. flavus*, *Penicillium* spp. and other fungal pathogens as 12.33, 4.67, 2.66, 0.66, 0.33 and 0.33% during season 2023 and, 11.67, 5.33, 1.67, 0.33, 0.33 and 0.33 % via season 2024, respectively (Figure 3A).

The SC168 corn hybrid had the lowest percentage of ear and kernels disease pathogens infection as 0.33 to 13.66% during season 2023 and, 0.67 to 12.67% during season 2024, while TWC324 had the highest percentage of infection (3.33 to 21.66% during season 2023) and (4.00 to 19.67% during season 2024) (Figure 3B). The SC168 corn hybrid can be used in breeding programs as a source of resistance to the tested diseases.

The statistical interactions between sowing dates and maize hybrids tested revealed that the lowest infection percentages on maize hybrid SC168 ranged from 1.33 to 12.67% during season 2023 and from 1.00 to 12.33% during season 2024 at the earliest sowing dates, while the highest infection percentages were recorded at the latest sowing date TWC 324 (Figure 3C).

DISCUSSION

The physical and chemical properties of the investigated soils, averaged across both seasons, were suitable for maize cultivation. The soil texture was clay, which is highly favorable for growing most current crops. The soil pH was alkaline, and the cation and anion levels were optimal for maize and other crops, supporting high yield productivity per feddan, consistent with the findings of Abo-Marzoka et al. (2017).

The study revealed that maize plants sown at an early planting date (May 15) exhibited the highest leaf area, leaf area index, and relative photosynthesis rate (g/m²/week), whereas delayed planting reduced yields. These results agree with Liaqat et al. (2018) and Rahuma (2018), who reported that sowing time significantly influences maize phenology, including emergence, tasseling, silking, and maturity periods, as well as crop growth parameters such as leaf area, plant height, photosynthetic efficiency, and ear height. Additionally, sowing time affects yield components, including rows per ear, ear length, grains per ear, shelling percentage, and grain weight, collectively influencing biomass and grain yield. Early sowing resulted in higher yields and better crop performance, whereas delayed sowing substantially reduced productivity.

Based on the current findings, it can be concluded that the optimal maize planting window ranges from

May to June, as this period maximizes yield potential through improved growth traits. Furthermore, early sowing allowed maize plants to avoid ear and kernel rot diseases, while also enhancing quality parameters and milk yield, as supported by Garba & Ogara (2016) and Kaur et al. (2023).

The study also revealed that the early sowing date (May 15) resulted in the highest values for plant height (cm), ear length (cm), number of kernels per ear, ear diameter (cm), 100-kernel weight (g), kernel weight per ear (g), grain yield (ton/feddan), and shelling percentage. In contrast, the lowest values were recorded for the late planting date. Similar trends were observed for yield and yield components. Significant variations were detected among the tested maize hybrids for the traits. These findings align with those reported by Gurmu & EshetuYadete (2020), Rabbani & Safdary (2021), and Krnjaja et al. (2022), who demonstrated that optimal sowing dates maximize maize grain yield and yield components, while delayed sowing leads to substantial reductions.

Among the three maize genotypes evaluated, grain yield and yield components varied significantly under the tested environmental conditions. Kaur et al. (2023) further emphasized that using improved maize hybrids, combined with optimal planting time, is an effective strategy for enhancing yield. Also, proper sowing timing is critical in improving quantitative and qualitative yield while mitigating adverse biotic and abiotic stresses.

Chlorophyll a, chlorophyll b, and carotenoid content in maize plants were highest at early planting dates and lowest at late planting dates. These results are supported by Nasr-Eldin et al. (2018), El-Sherif et al. (2019), Massoud et al. (2020), Afzal et al. (2022), Elhalag et al. (2025), and Li et al. (2025), who confirmed that planting time significantly influences chlorophyll and carotenoid levels in plants.

The study also demonstrated that early sowing dates promoted faster maize growth rates and shorter dry maturity periods than late sowing. These observations are consistent with Prasad et al. (2017), who reported that sowing time strongly affects maize population dynamics and growth rates. Similarly, Jiang et al. (2023) found that maize emergence rate, dry matter accumulation, and relative growth rate were primarily determined by sowing dates and regional temperature conditions.

Overripe dent maize grain is composed of starch (60-72%), protein (8-11%), and oil (4-6%), with amylose and amylopectin being glucose polymers that influence starch physicochemical properties (Rausch et al., 2019). Our results demonstrated that early sowing dates increased protein and carbohydrate content in maize grains while reducing ash and fiber content. Conversely, late sowing dates resulted in lower grain yields and reduced grain filling, potentially leading to diminished nutrient accumulation. These findings are consistent with Jiang et al. (2023), who reported the lowest crude protein and carbohydrate levels alongside the highest oil, ash, and fiber content in the latest sowing dates, particularly in cultivar TWC423. Elsayed et al. (2024) further noted that under optimal conditions, maize grains exhibited elevated oil, protein, carbohydrate, and fiber content, whereas unfavorable conditions increased undesirable components such as free fatty acids, ash, and acid value.

Our findings indicated that early sowing dates produced maize grains with higher protein and carbohydrate content, while late sowing led to increased oil, ash, and fiber levels. This aligns with Megahed et al. (2019), Jahangirlou et al. (2021), Megahed et al. (2023), and Liu et al. (2023), who concluded that early sowing maximized protein, starch, and amylopectin content while minimizing oil and total unsaturated fatty acids. Additionally, delayed planting shortened the grain-filling period, impaired yield potential, and reduced nutrient accumulation, as supported by Qian et al. (2016), Impa et al. (2019), Nasr-Eldin et al. (2019), and Alam et al. (2020).

Early planting dates also exhibited the lowest incidence of kernel infections by fungal pathogens (*F. verticillioides*, *F. semitectum*, *A. niger*, *A. flavus*, *Penicillium* spp.). In contrast, late sowing dates showed the highest infection rates, underscoring the importance of early sowing to mitigate ear and kernel rot diseases. These results corroborate with Rahuma (2018), who observed that corn borers-vectors of rot-causing fungi were more prevalent in late-sown crops. Furthermore, Garba & Ogara (2016), Kamle et al. (2019), Bocianowski et al. (2020), Krnjaja et al. (2022), Kaur et al. (2023), and Singh et al. (2025) confirmed that early sowing enhanced resistance to ear and kernel rot diseases, improved grain quality, and increased milk yield. These studies highlight that combining early planting with resistant hybrids can optimize disease-free, high-yield maize production. Researchers can better assess cultivar suitability for diverse production and consumption periods by evaluating these factors.

CONCLUSION

The study underscores the importance of evaluating multiple factors-including phenotypic traits, yield components, and physiological characteristics-when selecting maize cultivars for specific purposes. Optimal results were observed when maize was planted early, particularly in mid-May, with this timing maximizing desired traits and yield potential. Under Egyptian growing conditions, employing high-performing hybrids like SC168 and adhering to suitable planting schedules can significantly enhance yield while mitigating biotic and abiotic stresses. Notably, the hybrid SC168 demonstrates strong resistance to tested diseases, making it a valuable candidate for breeding programs to improve maize resilience.

ABBREVIATIONS

LAI; leaf area index, CGR; crop growth rate, (RGR; relative growth rate, NAR; Net assimilation rate

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All data and materials are available.

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Not applicable

CONSENT FOR PUBLICATION

Applicable.

CONFLICT OF INTEREST

The authors declare no competing interests.

AUTHORS' CONTRIBUTIONS

All authors shared experimental designing, work, discussion, and comments on the manuscript.

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