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Original Article

Effect of Nano-Zinc Chelate and Phosphorus on the Physiological Response of Some Maize hybrids

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ABSTRACT

Maize is a strategic commodity because of its high productivity and diverse uses. To investigate the impact of different levels of nano-zinc chelate and phosphorus fertilizer on the growth and yield of maize hybrids. Field experiments were conducted at the Qlyasan Agriculture Research Station in Sulaymaniyah, Iraq. The treatments included three maize hybrids (G1, G2, and G3), three levels of nano-zinc fertilizer 10 and 20 mg L^{-1}, and three levels of phosphorus 100 and 200 kg h^{-1}. The randomized complete block design evaluated growth, chemical, and yield parameters. In both experiments, the G3 surpassed both genotypes in kernel yield, 14.410 and 13.522 tons ha^{-1}, respectively. Concerning nano-Zn chelate, control and 20 mg L^{-1} gave maximum kernel yield with 19.323 tons ha^{-1} for both experiments. An increase in oil in both experiments was associated with G2 (3.885% and 4.002%, respectively). Protein gave a maximum value of 6.977% for G3 in the P fertilizer. The 10 mg L^{-1} zinc gave the highest oil (5.748%). Control recorded a maximum protein content of 10.328 % in the 1st experiment. In contrast, 100 kg ha^{-1} phosphorus recorded a maximum value of 10.353 in the 2nd experiment. Both experiments' G2 and the highest fertilization level gave a maximum oil (3.940% and 4.255%), respectively. The highest protein was associated with the interaction between G3× 20 mg L^{-1} nano-zinc chelate, while the interaction between G1×100 kg ha^{-1} phosphorus gave the highest protein content. The study demonstrated that maize hybrid G3 generally outperformed the others in kernel yield and protein content, while G2 showed higher oil content across both experiments. nano-zinc chelate and phosphorus application influenced various physiological traits, though the control treatments unexpectedly yielded the highest kernel production, suggesting possible over-fertilization effects or genotype-specific nutrient responses.

Keywords: Zea mays L., Nano-zinc chelate, Phosphorus fertilization, physiological parameter, growth, Yield performance, and Oil and protein content.

1 Introduction

Maize (*Zea mays L.*) is a cereal crop with essential food and industrial applications. Available data reveal that the vitamin A content of corn grains is 20 times higher than that of wheat [1]. According to the United States Department of Agriculture, Iraq's corn production for the 2024-2025 marketing year is estimated at 500,000 metric tons, representing a 7.0% increase over the 5-year average from 2019 to 2023 [2]. This increase is attributed to favorable weather conditions and government support, with subsidies for irrigation, inputs, and mechanization as well as guaranteed procurement prices. Yellow maize cultivation has been distributed over northern, central, and southern Iraq, and its area reached 76000 hectares in 2016, and the average production was 3.42 megagrams h^{-1} [3]. Nonetheless, Iraq's maize production is below that of developed countries. Maize contains 9.5% protein and 73-75% carbohydrate; its oil production is approximately 172 ha^{-1}. In addition to its consumption, its kernel is used in various types of food and drinks, and can be treated as feed [4]. A critical factor contributing to the high production and productivity of corn is the utilization of superior varieties. Hybrid varieties have more advanced yield potential than local varieties [5]. Nanotechnology is one of the most revolutionary scientific discoveries of the 21st century and is used in all spheres of life. Phosphorus (P) is an essential micronutrient involved in most metabolic processes and is a constituent of various biomolecules, including energy transfer bodies, signal transmission molecules, biosynthesis of diverse macromolecules, photosynthesis, and respiration. An increase in P rate leads to increased salt tolerance in various crops [6].

Nano-fertilizer production is essential for reducing fertilizer nutrient losses through increased nutrient management and micronutrient use efficiency [7]. Modern fertilizers must be

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considered substitutes for traditional fertilizers, providing the nutrients necessary for plant growth, increasing productivity, and maintaining clean and good soil [8]. Micronutrients, the nutrients required in smaller quantities by plants, play a significant role in improving crop yields and quality. nano-zinc chelate (Zn) is an essential micronutrient in plant nutrition and an integral component of many enzyme proteins. It is one of the most vital components for the unadulterated development of crops, such as wheat. nano-zinc chelate is an essential cofactor for over 300 enzymes that are involved in several physiological processes [9]. Therefore, methods and techniques should be applied to enhance productivity. Thus, this study aimed to investigate the impact of different phosphor and nano-Zn chelate fertilization levels on the physiological characteristics of maize hybrids' growth, yield, and its components.

2 Materials and methods

2.1 Experiment site

In 2022- 2023, two experiments were conducted at the Qlyasan Agriculture Research Station (2 km northwest of the city at 35°34'17' 'N, 45°22'00 '' E, and an elevation of 757 m above sea level), Department of Biotechnology and Crop Sciences, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaymaniyah City, Iraq. The physical and chemical properties of the soil at the experimental site were assessed (Table 1).

Table 1: Soil analysis of the Qlyasan region, Sulaymaniyah City, Iraq.

Property	Variable	Value
Physical	Sand	87 gk g^{-1}
	Silt	435 gk g^{-1}
	Clay	458 gk g^{-1}
	Texture	Silty clay
	Ph	7.59
	Electrical conductivity	490 µS cm^{-1}
Chemical	Organic matter	22.4 gk g^{-1}
	$CaCo_3$	304.3 gk g^{-1}

2.2 Experiment parameter

Number of leaves per plant (NLP), leaf area index (LAI; cm^2), plant height (PH; cm), two stages chlorophyll content before and after silking estimation by CCM-200 plus, dry matter (DM) accumulation (assessed for all plant parts, including roots, stems, leaves, and ears), number of kernel ear^{-1} (NKE), weight of kernel ear^{-1} (WKE), number of kernels row^{-1} (NKR), number of rows ear^{-1} (NRE), 300 kernels weight (300-KW; g), biological yield (BY; tons ha^{-1}), kernel yield (KY; tons ha^{-1}), harvest index (HI), with oil and protein percentages [10].

2.3 Statistical analysis

Statistical Package for Social Science (SPSS, Chicago, USA, Version 27) was used to analyze the data. Two-way analysis of Variance (ANOVA) was used to evaluate the effects of different concentrations of nano-Zn/P fertilizer treatments on the growth and yield of maize hybrids. The least significant difference (LSD) test ($p \leq 0.05$) was performed to compare the mean values [11].

2.4 Plant material

For both experiments, three maize hybrids (MGW16×NADH52 (G1), NADH704×NADH52 (G2), and ZY52×NADH102 (G3)) obtained from Baghdad University, Baghdad, Iraq, were used.

2.5 Field experiment

In both experiments, a factorial experiment (3×3) with three replications using a randomized complete block design (RCBD), focused on applying different fertilizer levels compared to controls (no treatments).

2.6 Fertilization treatment

In the 1st experiment, different levels of nano-Zn chelate were used, including 0.0 (control), 10-, and 20-mg L^{-1} as a foliar spray at two plant stages (before and after silking). The 2nd experiment involved the application of different levels of P fertilizer: 0.0 (control), 100, and 200 kg ha^{-1} [12].

2.7 Agricultural conditions

In July 2023, seeds from the three hybrids were sown directly in 2 m^2 plots with a row spacing of 25 cm. The soil was primed for cultivation by plowing with a harrow and broad plow during the fieldwork. Weeds were manually controlled whenever necessary. Meteorological data for successive years were obtained from the Department of Natural Resources, Meteorological Station, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaymaniyah, Iraq (Table 2).

Table 2: Meteorological data for the growing season in 2022-2023 at Qlyasan region, Sulaimaniyah, Iraq.

Month	Average Temperature (°C)	Rainfall (mm)
Oct-2022	23.59	15.8
Nov-2022	13.9	80.8
Dec-2022	10.02	46
Jan-2023	7.04	94
Feb-2023	7.36	85.8
Mar-2023	13.65	240.2
Apr-2023	16.96	113.4
May-2023	23.2	39
Total		715

3 Results and discussion

This study highlights the significant influence of P and nano-Zn chelate fertilizers on the physiological responses, growth, and reproductivity of maize hybrids under Sulaimani environmental conditions.

3.1 Vegetative growth character

As shown in Table 3 and Supplementary Table 1, in the 1st experiment, the vegetative and chemical characteristics of maize genotypes revealed significant differences ($p \leq 0.05$) among genotypes in root DM content after-silking, shoot DM content after-silking, chlorophyll content before-silking, oil%, and protein%. In the 2nd experiment, significant differences ($p \leq 0.05$) among genotypes were observed, specifically in shoot DM after-silking, oil, protein, and chlorophyll contents within the studied characters.

In the 1st experiment, the maximum value (153.474 g) of shoot DM content after-silking was obtained by G1, while G3 showed a minimum value of 115.6 g. Conversely, in the 2nd experiment, G3 demonstrated the highest value (165.261 g), and G2 had the lowest (108.129 g). In the 1st experiment, G3 was superior in root DM content after-silking, with the highest value of 32.486 g. In comparison, G1 had the lowest value (19.150 g). G2 had the highest value (32.511 µg g^{-1}), exceeding G1 in terms of chlorophyll content at before-silking, with the lowest value (22.711 µg g^{-1}).

Conversely, the 2nd experiment showed no significant differences among the genotypes in most characteristics. After-silking in the 2nd experiment, the chlorophyll content of G2 gave a higher value (11.383 µg g^{-1}), and G3 had a minimum value of 8.528 µg g^{-1}. Conversely, the 1st experiment showed no significant differences among the genotypes. The results demonstrated a higher root DM and chlorophyll contents after-silking among genotypes, which may be due to the higher performance of these two genotypes, the higher means of daily temperature, and DM accumulation during the growing seasons [13]. In the 1st experiment, the oil for G2 recorded a maximum value (3.885%), and G3 recorded a minimum value (3.383%). In the 2nd experiment for the oil, G2 yielded the highest value (4.002%), and the lowest value was demonstrated by G1 (3.520%). In the 1st experiment, G3 recorded a maximum value of 6.740% protein, and G2 recorded a minimum value (6.413%). In the 2nd experiment, G3 yielded the highest value of 6.977% and the minimum value recorded by G2 (6.377%). In both experiments, there were no significant differences among genotypes in DM accumulation before the silking stage of shoots and roots. The differences in protein and oil content indicate genetic variation in maize, possibly due to genotypic behavior under environmental conditions (Table 2) [14].

Table 3: The mean vegetative and chemical characters of maize genotypes.

Genotype	DM in shoot/before silking (g)	DM in root /before-silking (g)	DM in shoot/after-silking (g)	DM in the root after silking (g)	Chlorophyll content before silking (µg g^{-1})	Chlorophyll content after silking (µg g^{-1})	Oil (%)	Protein (%)
Nano-Zn chelate								
G_1	8.072±2.430	1.723±0.629	153.474±10.008	19.150±9.706	22.711±2.050	9.006±1.302	3.615±0.072	6.415±0.611
G_2	6.710±2.219	1.330±0.508	127.851±30.041	26.061±8.323	32.511±5.571	10.511±1.742	3.885±0.082	6.413±0.289
G_3	7.287±1.521	1.597±0.563	115.600±24.280	32.486±7.583	22.767±3.646	8.822±1.873	3.383±0.549	6.740±0.507
LSD ($p \leq 0.05$)	NS	NS	26.888	7.720	4.452	NS	0.279	NS
Phosphorus fertilizer								
G1	5.475±2.650	1.313±0.639	134.711±29.290	37.619±25.887	24.833±3.307	9.017±1.274	3.520±0.021	6.812±0.643
G2	6.442±1.308	1.320±0.502	108.129±19.141	31.117±12.121	25.017±6.467	11.383±2.049	4.002±0.207	6.377±0.215
G3	6.902±0.988	1.095±0.123	165.261±30.259	45.600±18.955	21.656±3.924	8.528±1.751	3.688±0.055	6.977±0.215
LSD ($p \leq 0.05$)	NS	NS	31.838	NS	NS	1.982	0.132	0.391

DM: Dry matter, NS: Nonsignificant, LSD: Least significant difference.

As shown in (Table 4 and Supplementary Table 1), data in the 1st experiment, the vegetative and chemical characteristics of the maize genotype affected by nano-zinc chelate fertilizer showed significant differences ($p \leq 0.05$) among various Zn levels in several characteristics (root DM content at before -silking, root DM accumulation at after-silking, oil, and protein%). The 2nd experiment also showed significant differences ($p \leq 0.05$) among the studied characters' P levels in character protein content. In the

1st experiment, the maximum value (3.080 g) of root DM content at before-silking was demonstrated with treatment with 20 mg L^{-1} nano-zinc chelate fertilizer, whereas the control showed a minimum value of 1.910 g. The maximum value of 49.148 g of root DM accumulation after-silking was recorded by the treatment of 20 mg L^{-1} nano-zinc chelate fertilizer. In comparison, the 10 mg L^{-1} nano-zinc chelate fertilizer treatment gave a minimum value of 29.822 g. Concerning the treatment with 10 mg L^{-1} nano-zinc chelate fertilizer, a maximum value of 5.748% for the oil and a minimum of 4.993% for the control were observed. The increase in root dry weight might be due to the elongation of the roots under the effect of nano-zinc chelate fertilizer, which induced the uptake ability of the roots to nutrients and a positive increase in the yield parameters because of the improvement of the root system as a source-sink relationship to the reproductive part (shoot) [14].

The 2nd experiment showed non-significant differences among fertilizer applications in both characteristics of DM in shoot and root at before- and after-silking, chlorophyll content before- and after-silking, and oil%. In the 1st experiment, protein had a maximum value of 10.328% in the control, with a minimum value of 9.060% in the 10 mg L^{-1} nano-zinc chelate fertilizer treatment. Conversely, in the 2nd experiment, the 100 kg ha^{-1} P fertilizer treatment demonstrated the highest value of 10.353%, and the 200 kg ha^{-1} P treatment had the lowest value of 9.568% for protein. In both experiments, there were no significant differences in fertilization on DM accumulation at before-silking of the shoot, root DM accumulation at after-silking, and chlorophyll content at before and after silking. These findings indicate that fertilizers can significantly enhance protein content in maize by improving nutrient availability, promoting plant growth, and boosting photosynthetic efficiency [15].

Table 4: The mean vegetative and chemical characteristics affected by nano-zinc chelate and Phosphorus fertilizers.

Fertilization	**DM in shoot/before silking (g)**	**DM in root /before-silking (g)**	**DM in shoot/after-silking (g)**	**DM in the root after silking (g)**	**Chlorophyll content before silking (µg g^{-1})**	**Chlorophyll content after silking (µg g^{-1})**	**Oil (%)**	**Protein (%)**
	Nano-Zn chelate							
Control	10.063±1.80	1.910±0.46	191.868±27.41	37.575±3.78	39.775±5.78	15.233±1.93	4.993±0.51	10.328±0.26
10 mg L^{-1}	9.920±2.34	1.985±0.33	210.015±30.84	29.822±9.69	41.208±7.26	14.008±0.83	5.748±0.12	9.060±0.09
20 mg L^{-1}	13.120±1.49	3.080±0.56	193.504±25.08	49.148±10.88	36.000±5.17	13.267±2.18	5.585±0.16	9.965±0.54
LSD ($p \le 0.05$)	NS	0.516	NS	7.720	NS	NS	0.279	0.379
	Phosphorus fertilizer							
Control	10.063±1.80	1.910±0.46	208.034±41.82	59.575±23.65	39.775±5.78	15.233±1.93	5.493±0.11	10.328±0.26
100 kg ha^{-1}	9.450±1.30	1.900±0.45	196.992±26.88	52.290±23.45	34.783±2.50	14.317±2.98	5.620±0.19	10.353±0.53
200 kg ha^{-1}	8.715±2.35	1.783±0.54	207.126±38.34	59.639±12.95	32.700±4.82	13.842±1.01	5.703±0.35	9.568±0.42
LSD ($p \le 0.05$)	NS	NS	NS	NS	NS	NS	NS	0.391

DM: Dry matter, NS: Nonsignificant, LSD: Least significant difference.

Regarding (Table 5 and Supplementary Table 1), the 1st experiment presents the response of vegetative and chemical characteristics to the interaction between genotype and nano-zinc chelate treatments, revealing significant differences ($p \le 0.05$) among several characteristics (shoot DM content after-silking, oil, and protein %). The 2nd experiment also shows substantial differences in the vegetative and chemical characteristics of the interaction between genotype and P fertilizer ($p \le 0.05$) in root and shoot DM content after silking, chlorophyll content before silking, oil, and protein.

In the 1st experiment, the maximum value (161.33 g) of shoot DM content after silking was demonstrated by the interaction of G1×10 mg L^{-1} nano-zinc chelate fertilizer, whereas the G2×control showed a minimum value (92.4 g). Regarding the 2nd experiment, the interaction of G3×200 kg ha^{-1}, P fertilizer demonstrated the highest value of 183.466 g, and G2×control had the lowest value (92.3 g). Concerning the characteristics in the 2nd experiment, root DM content after-silking was recorded with the interaction of G1×control (70.27 g), and the interaction between G1×100 kg ha^{-1} and P fertilizer had a minimum value of 15.275 g. Conversely, the 1st experiment showed non-significant differences in the interaction between genotype and nano-zinc chelate. The interaction between G2×control recorded the highest value of 33.35 g, exceeding G3×200 kg ha^{-1} P fertilizer in terms of chlorophyll content at before-silking, with the lowest value

(17.05 g). Conversely, the 1st experiment showed non-significant differences between genotypes and fertilizers. The higher amount of shoot DM and chlorophyll content might be related to the response of maize genotypes to fertilizers, which can vary based on genetic traits, environmental conditions, and their impact on nutrient availability and growth, which positively influences maize photosynthesis more actively [16].

Table 5: The mean vegetative and chemical characters affected by the interaction of genotypes and fertilization (mg L^{-1} Zn, kg ha^{-1} P) in both experiments.

Genotypes × Fertilizations	DM in shoot/before silking (g)	DM in root /before-silking (g)	DM in shoot/after-silking (g)	DM in root after silking (g)	Chlorophyll content before silking (μg g^{-1})	Chlorophyll content after silking (μg g^{-1})	Oil (%)	Protein (%)
Nano-Zn chelate								
G_1 × Control	7.990±1.890	1.615±0.415	144.348±6.621	26.270±4.030	21.050±1.975	8.883±1.468	3.530±0.030	7.225±0.025
G_1 × 10	6.365±3.275	1.105±0.165	161.330±11.672	8.915±0.604	22.233±1.222	9.433±0.611	3.690±0.010	5.945±0.045
G_1 × 20	9.860±0.370	2.450±0.010	154.743±0.830	22.265±10.605	24.850±0.250	8.700±1.952	3.625±0.015	6.075±0.045
G_2 × Control	5.955±1.765	1.065±0.595	92.400±9.680	23.030±1.190	33.350±2.599	11.450±2.693	3.785±0.025	6.660±0.020
G_2 × 10	6.580±3.230	1.505±0.435	158.740±4.168	19.460±0.240	35.633±7.112	9.183±0.804	3.930±0.060	6.035±0.035
G_2 × 20	7.595±2.025	1.420±0.570	132.514±11.798	35.692±7.573	28.550±5.254	10.900±0.200	3.940±0.010	6.545±0.025
G_3 × Control	6.180±1.580	1.140±0.200	147.088±3.031	25.850±5.480	25.150±2.350	10.133±0.764	2.670±0.020	6.770±0.020
G_3 × 10	6.895±0.755	1.360±0.320	99.961±6.115	31.268±0.427	24.550±2.250	9.400±1.300	3.875±0.075	6.140±0.020
G_3× 20	8.785±0.865	2.290±0.080	99.750±8.973	40.340±6.246	18.600±1.803	6.933±1.823	3.605±0.015	7.310±0.010
LSD ($p \leq 0.05$)	NS	NS	46.571	NS	NS	NS	0.482	0.656
Phosphorus fertilizer								
G_1 × Control	7.990±1.890	1.615±0.415	144.348±6.621	70.270±9.940	21.050±1.975	8.883±1.468	3.530±0.030	7.223±0.025
G_1 × 100	5.385±1.165	1.645±0.695	161.310±4.852	15.275±3.065	25.950±1.350	9.217±1.545	3.520±0.020	7.255±0.015
G_1 × 200	3.050±2.200	0.680±0.270	98.476±13.932	27.313±8.061	27.500±2.000	8.950±1.361	3.510±0.010	5.955±0.015
G_2 × Control	5.955±1.765	1.065±0.595	92.300±9.680	23.030±1.190	33.350±2.599	11.450±2.693	3.785±0.025	6.660±0.020
G_2 × 100	6.295±1.635	1.135±0.055	99.777±0.699	24.055±5.905	20.850±1.250	12.950±0.950	3.965±0.015	6.200±0.020
G_2 × 200	7.075±0.255	1.760±0.460	132.311±3.699	46.265±5.855	20.850±1.650	9.750±0.976	4.255±0.045	6.270±0.020
G_3 × Control	6.180±1.580	1.140±0.200	179.421±33.076	25.850±5.480	25.150±2.350	10.133±0.764	3.670±0.020	6.770±0.020
G_3 × 100	7.220±0.470	1.020±0.001	132.897±4.472	65.250±4.500	22.767±1.301	6.467±0.702	3.755±0.005	7.250±0.020
G_3 × 200	7.305±0.105	1.125±0.085	183.466±13.396	45.700±14.920	17.050±1.550	8.983±0.797	3.640±0.030	6.910±0.040
LSD ($p \leq 0.05$)	NS	NS	55.145	41.483	8.947	NS	0.229	0.677

DM: Dry matter, NS: Nonsignificant, LSD: Least significant difference.

In the 1st experiment, the interaction of G2×20 mg L^{-1} nano-zinc chelate fertilizer was superior in oil (3.940%), whereas the interaction of G3×control had the lowest value (2.67%). In the 2nd experiment, G2×200 kg ha^{-1} P fertilizer demonstrated the highest value of 4.255%, and G1×200 kg ha^{-1} interaction had the lowest value (3.51%). Regarding the 1st experiment, protein gave the maximum value of 7.310% due to the interaction of G3×20 mg L^{-1} nano-zinc chelate fertilizer, while the minimum value of 5.945% was obtained by G1×10 mg L^{-1} nano-zinc chelate fertilizer. Conversely, in the 2nd experiment, the G1×100 kg ha^{-1} of P fertilizer demonstrated the highest value of 7.255%, and the G1×200 kg ha^{-1} P interaction had the lowest (5.955%). In both experiments, there were no significant differences in interaction genotype and fertilization on the DM accumulation before and after-silking of the root and chlorophyll content after-silking. The increase in oil and proteins in both experiments can be attributed to the genotype's response to the fertilizer. Genotypes with higher nutrient uptake efficiency tend to show improved growth and development, which results in more excellent protein and oil content in the grains [17].

Table 6: The mean reproductive characters of maize genotypes.

Genotype	**PH (cm)**	**NLP**	**LAI before silking (cm^2)**	**LAI after silking (cm^2)**	**NRE**	**NKR**	**NKE**	**WKE (g)**	**300 KW (g)**	**HI**	**BY (tons ha^{-1})**	**KY (tons ha^{-1})**
Nano-Zn chelate												
G_1	171.556 ±9.435	14.444 ±0.527	0.457 ±0.283	1.562 ±0.300	17.333 ±1.803	30.667 ±4.213	535.083 ±71.970	103.919 ±19.976	65.690 ±5.777	0.355 ±0.042	33.081 ±4.099	11.370 ±2.372
G_2	164.889 ±5.061	14.778 ±0.833	0.270 ±0.080	1.781 ±0.092	17.111 ±1.900	29.583 ±2.077	513.000 ±56.448	107.588 ±8.492	70.965 ±4.274	0.371 ±0.042	30.071 ±4.653	11.114 ±1.962
G_3	163.106 ±9.787	14.444 ±0.726	0.357 ±0.092	1.799 ±0.086	16.444 ±0.882	35.556 ±2.651	591.250 ±37.641	140.881 ±16.127	76.305 ±3.343	0.435 ±0.017	33.492 ±2.509	14.410 ±1.405
LSD (p≤0.05)	NS	NS	NS	0.195	NS	2.746	47.062	13.974	4.930	0.035	2.732	1.717
Phosphorus fertilizer												
G_1	165.778 ±13.917	14.444 ±0.527	0.267 ±0.141	1.537 ±0.286	16.778 ±1.856	30.444 ±5.918	533.417 ±122.930	116.830 ±30.876	68.975 ±4.051	0.359 ±0.043	34.111 ±5.033	11.683 ±3.088
G_2	158.556 ±12.660	14.000 ±0.000	0.246 ±0.078	1.633 ±0.055	17.444 ±2.128	31.000 ±4.213	544.417 ±73.084	117.411 ±15.748	69.655 ±5.044	0.360 ±0.053	30.550 ±3.494	11.186 ±1.543
G_3	161.333 ±15.492	14.778 ±0.667	0.324 ±0.091	1.800 ±0.131	16.667 ±0.866	31.667 ±3.082	536.917 ±68.598	131.886 ±13.377	76.725 ±2.574	0.430 ±0.024	31.525 ±2.428	13.522 ±0.676
LSD (p≤0.05)	NS	0.544	NS	0.205	NS	NS	NS	NS	4.595	0.038	NS	1.849

DM: Dry matter, NS: Non-significant, LSD: Least significant difference, PH: Plant height, NLP: Number of leaves per plant, LAI: Leaf area index, NKE: Number of kernel ear, WKE: Weight of kernel ear, NKR: Number of kernels row, NRE: Number of rows ear, KW: Kernels weight, BY: Biological yield, KY: Kernel yield, HI: harvest index.

3.2 Reproduction character

In the 1st experiment, the reproductive characteristics of maize genotypes revealed significant differences (p≤0.05) among genotypes in LAI after silking, NKR, NKE, WKE, 300-KW, HI, BY, and KY. In the 2nd experiment, significant differences (p≤0.05) among genotypes in NLP, LAI after-silking, 300-KW, HI, and KY were observed in (Table 6 and Supplementary Table 2). In addition, NLP recorded a maximum value of 14.778 leaves for G3, whereas G2 showed a minimum value of 14.000 leaves. Conversely, in the 1st experiment, non-significant differences among genotypes were observed for this characteristic. The LAI after-silking for G3 recorded a maximum value of 1.799 $cm^{2,}$ and G1 recorded a minimum value of 1.562 cm^2. Simultaneously, in the 2nd experiment, G3 gave the highest value of 1.800 cm^2, and the minimum value recorded with G1 was 1.537 cm^2. In the 1st experiment, NKR and NKE were demonstrated by G3 with values of 35.556 and 591.250 kernels, respectively, and G2 had a minimum value of 29.583 and 513 kernels, respectively. Conversely, the 2nd experiment showed no significant differences among the genotypes for these characteristics. In 1st experiment, G3 was superior in WKE, with the highest value of 140.881 g, while G1 had the lowest (103.919 g). Conversely, the 2nd experiment showed no significant differences in genotype. These results suggest that the highest variations in LAI and yield components were primarily due to genetic differences that might be influenced by the different maturity stages of these genotypes [18].

In the 1st experiment, the 300-KW and HI for G3 recorded a maximum value of 76.305 g and 0.435, respectively, and G1 recorded a minimum value of 65.690 g and 0.355, respectively. Concerning the 2nd experiment, G3 gave the highest values of 76.725 g and 0.430 for 300-KW and HI, respectively, and the minimum value with G1 (68.975 g and 0.359, respectively). In the 1st experiment, G3 recorded the highest value of 33.492 tons ha^{-1}, exceeding G2 in BY, with the lowest value of 30.071 tons ha^{-1}. Conversely, the 2nd experiment showed no significant differences among the genotypes in these characteristics. In the 1st experiment, the maximum value of 14.410 tons ha^{-1} of KY was recorded by G3, while G2 showed a minimum value of 11.114 tons ha^{-1}. Conversely, in the 2nd experiment, G3 demonstrated the highest value of 13.522 tons ha^{-1}, whereas G2 had the lowest (11.186 tons ha^{-1}). In both experiments, no significant differences were observed among genotypes in PH, NRE, LAI before-silking, and NRE (Table 6 and Supplementary Table 2). The results showed the highest LAI after-silking and KWE, which may be due to differences among the genotypes that can enhance crop yield and quality, positively affecting corn growth, the number of grains per cob, and 1000-grain weight [19].

Furthermore, Table 7 and Supplementary Table 2 showed that the 1st experiment presents the reproductive characteristics of the maize genotype affected by nano-zinc chelate fertilizer, revealing significant differences ($p \leq 0.05$) among various nano-zinc chelate levels in PH, NKE, WKE, BY, and KY. The 2nd experiment also showed essential differences ($p \leq 0.05$) among the P levels in PH, LAI at before-silking, and KY.

Table 7: The mean reproductive characteristics are affected by Zinc and Phosphorus fertilizers.

Fertilizer	PH (cm)	NLP	LAI before silking (cm^2)	LAI after silking (cm^2)	NRE	NKR	NKE	WKE (g)	300 KW (g)	HI	BY (tons ha^{-1})	KY (tons ha^{-1})
Nano-Zn chelate												
Control	259.177 ±11.26	22.000 ±0.71	0.545 ±0.12	2.380 ±0.33	25.167 ±1.39	49.000 ±4.42	836.875± 59.56	189.118 ±9.47	110.370±2.63	0.585 ±0.04	50.556 ±2.18	19.662 ±1.53
10 mg L^{-1}	247.158 ±5.06	21.667 ±0.53	0.413 ±0.09	2.689 ±0.06	24.167 ±1.17	46.167 ±3.73	747.750± 68.00	155.398 ±21.28	102.885±7.70	0.582 ±0.06	42.288 ±3.52	16.357 ±2.59
20 mg L^{-1}	243.000 ±5.68	21.833 ±0.88	0.669 ±0.27	2.643 ±0.06	27.000 ±1.66	48.542 ±4.01	874.375± 32.30	184.066 ±28.12	106.185±6.78	0.574 ±0.05	52.121 ±2.75	19.323 ±2.58
LSD ($p \leq 0.05$)	8.347	NS	NS	NS	NS	NS	47.062	13.974	NS	NS	2.732	1.717
Phosphorus fertilizer												
Control	259.167 ±11.26	22.000 ±0.71	0.545 ±0.12	2.380 ±0.33	25.167 ±1.39	49.000 ±4.42	836.875± 59.56	196.618 ±15.33	110.370±2.63	0.585 ±0.04	50.556 ±2.18	19.665 ±1.53
100 kg ha^{-1}	219.833 ±6.21	21.333 ±0.44	0.329 ±0.04	2.447 ±0.05	25.500 ±2.40	42.833 ±3.57	755.125± 107.78	164.769 ±28.24	105.503±7.35	0.536 ±0.07	45.250 ±3.10	15.644 ±2.63
200 kg ha^{-1}	249.500 ±6.20	21.500 ±0.50	0.382 ±0.10	2.626 ±0.12	25.667 ±1.17	47.833 ±4.48	830.125± 89.48	187.804 ±15.52	107.160±4.78	0.601 ±0.04	48.473 ±5.43	19.280 ±1.26
LSD ($p \leq 0.05$)	9.270	NS	0.104	NS	NS	NS	NS	NS	NS	NS	NS	1.849

DM: Dry matter, NS: Non-significant, LSD: Least significant difference, PH: Plant height, NLP: Number of leaves per plant, LAI: Leaf area index, NKE: Number of kernel ear, WKE: Weight of kernel ear, NKR: Number of kernels row, NRE: Number of rows ear, KW: Kernels weight, BY: Biological yield, KY: Kernel yield, HI: harvest index.

In the 1st experiment, the control gave a higher PH (259.177 cm) while the 20 mg L^{-1} treatment gave a minimum PH (243.000 cm). The treatment of 20 mg L^{-1} resulted in a higher value of 874.375 kernels for NKE, while the 10 mg L^{-1} treatment showed a minimum value of 747.750 kernels. The control was superior in WKE, with the highest value of 189.118 g. In comparison, the treatment with 10 mg L^{-1} nano-zinc chelate fertilizer had the lowest value of 155.398 g. The treatment with 20 mg L^{-1} nano-zinc chelate fertilizer recorded the highest value of 52.121 tons ha^{-1}, exceeding 10 mg L^{-1} BY, with the lowest value of 42.288 tons ha^{-1}.

Conversely, the 2nd experiment showed non-significant differences among the genotypes in these characteristics (Table 7 and Supplementary Table 2). These results indicate that higher NKE and BY values are related to varying nano-zinc chelate levels. nano-zinc chelate also directly influences KW by enhancing enzyme activity, and a better nutrient supply increases the storage capacity of kernels, resulting in heavier grains. Additionally, nano-zinc chelate contributes to overall plant growth and leads to an increase in total plant biomass by improving root development, nutrient uptake, and photosynthetic efficiency [20].

The maximum PH in the 2nd experiment was associated with the control, with a value of 259.167 cm, and the 100 kg ha^{-1} of P fertilizer treatment recorded a minimum value of 219.833 cm. The maximum LAI before silking in the 2nd experiment was associated with the control, with a value of 0.545 cm^2, and the 100 kg ha^{-1} of P fertilizer treatment recorded a minimum value of 0.329 cm^2. The 1st experiment showed no significant differences among the various fertilizers. In the 1st experiment, the maximum value of 19.662 tons ha^{-1} of KY was associated with the control, whereas the 10mg L^{-1} nano-zinc chelate fertilizer showed a minimum value of 16.635 tons ha^{-1}. Conversely, in the 2nd experiment, the control demonstrated the highest value of 19.665 tons ha^{-1}, and 100 kg ha^{-1} had the lowest value of 15.664 tons ha^{-1} KY. In both experiments, there were no significant differences among the fertilizers in NLP, LAI after-silking, NRE, NKR, and HI. The response of maize to P fertilizer generally increases PH and NLP, as P promotes overall growth processes, such as root development, energy transfer, and photosynthesis (Table 7 and Supplementary Table 2). This relationship is mutually reinforcing, where taller plants with well-developed roots produce more leaves, improving their capacity to capture sunlight and support further growth. Therefore, P plays a crucial role in optimizing these key growth characteristics, ultimately enhancing maize productivity [21].

Moreover, in the 1st experiment, the response of reproductive characteristics to the interaction between genotype and nano-zinc chelate fertilizer revealed significant differences ($p \leq 0.05$) in PH, NLP, LAI after–silking, and WKE. The 2nd experiment also showed essential differences ($p \leq 0.05$) in PH, LAI after-silking, NKE, and BY (Table 8 and Supplementary Table 2). In the 1st experiment, the superiority was to the G1×control interaction, which recorded the highest value of 185.000 cm, compared to the lowest value of 155 cm with G3×20 mg L^{-1} nano-zinc chelate fertilizer. Concerning the 2nd experiment, the G1×control interaction gave a maximum value of 184 cm and a minimum of 141.333 cm with the G3×100 kg ha^{-1} P fertilizer for PH. In the 1st experiment, G2×20 mg L^{-1} nano-zinc chelate fertilizer interaction exhibited the highest value of 15.667 leaves for the NLP; the interaction between G2×control recorded the lowest value of 13.996 leaves. The 2nd experiment revealed no significant differences in the genotype and P level interaction. In the 1st experiment, the maximum LAI value (1.908 cm^2) after-silking was associated with G3×control, while G1×control showed a minimum value of 1.191 cm^2. Conversely, in the 2nd experiment, G3×control demonstrated the highest value of 1.907 cm^2, and the interaction between G1×control had the lowest value of 1.190 cm^2. In the 2nd experiment, the interaction between G1×200 kg ha^{-1} P fertilizer demonstrated superiority in the NKE, with the highest value of 640 kernels. The interaction G1×100 kg ha^{-1} had the lowest value of 378.5 kernels. In contrast, the 1st experiment showed a non-significant difference in the interaction between genotype and nano-zinc chelate fertilizer. These results show that PH, BY, and HI increased by improving nutrient availability, especially P fertilizers that enhanced KW and increased grain yield, particularly when the genotype was well adapted to utilize these nutrients [22].

The WKE in the 1st experiment was associated with the interaction between G3×20 mg L^{-1} nano-zinc chelate fertilizer, with a higher value of 159.304 g, and the interaction between G1×10 mg L^{-1} nano-zinc chelate fertilizer had a minimum value of 80.531 g. Conversely, the 2nd experiment showed non-significant differences in the interaction between genotype and various fertilizers for this character. Regarding the 2nd experiment, the interaction between G1×200 kg ha^{-1} P fertilizer with a value of 39.046 tons ha^{-1} surpassed the interaction between G2×200 kg ha^{-1} P fertilizer with a minimum value of 27.775 tons ha^{-1}. Concerning the 1st experiment, no significant difference in the interaction between genotype and nano-zinc chelate fertilizer was observed. In both experiments, there were no significant differences in the interaction between genotypes and the various fertilizers in LAI at before-silking, NRE, NKR, 300-KW, HI, and KY. The results indicate a higher WKE. An appropriate combination of genotype and fertilizers improves key yield components such as NKE, KW, BY, and overall grain yield. The synergistic effect between genotype and fertilizer underscores the importance of choosing the appropriate combination to optimize maize production [3, 23,24].

Table 8: The mean reproductive characters affected by the interaction of genotypes and fertilization (ml L^{-1} Zn, kg ha^{-1} P) in both experiments.

G× Fertilizer	PH (cm)	NLP	LAI before silking (cm^2)	LAI after silking (cm^2)	NRE	NKR	NKE	WKE (g)	300 KW (g)	HI	BY (tons ha^{-1})	KY (tons ha^{-1})

	Nano-Zn chelate											
G_1 × Control	185.000±2.000	14.667±0.577	0.425±0.104	1.191±0.189	17.000±2.000	33.333±6.506	581.750±53.250	124.370±5.037	72.750±3.720	0.392±0.052	34.950±0.925	13.737±2.173
G_1 × 10	165.667±1.528	14.667±0.577	0.209±0.025	1.762±0.028	16.000±1.000	29.333±3.512	465.000±78.000	80.531±9.704	61.710±0.630	0.332±0.031	28.438±2.938	9.520±1.859
G_1 × 20	165.000±1.000	14.000±0.006	0.736±0.310	1.736±0.097	19.000±1.000	29.333±0.577	558.500±18.500	106.856±3.974	62.610±2.550	0.342±0.019	35.854±2.936	10.852±0.620
G_2 × Control	158.667±1.528	13.996±0.001	0.290±0.130	1.664±0.013	16.333±1.528	29.667±3.512	489.500±12.500	116.775±1.660	73.020±1.620	0.356±0.043	33.200±3.575	11.678±0.166
G_2 × 10	170.000±0.000	14.667±0.577	0.260±0.047	1.865±0.019	16.000±2.000	29.000±2.000	464.750±21.250	104.017±5.936	66.510±3.030	0.381±0.031	24.575±0.800	9.335±0.449
G_2 × 20	166.000±1.000	15.667±0.577	0.260±0.052	1.812±0.023	19.000±0.000	30.083±0.144	584.750±9.750	101.972±7.576	73.365±4.065	0.376±0.060	32.438±2.188	12.331±2.781
G_3 × Control	175.667±0.577	15.333±0.577	0.374±0.199	1.908±0.057	17.000±1.000	35.000±1.000	602.500±18.500	137.090±3.848	74.970±2.610	0.422±0.012	32.963±1.338	13.909±0.167
G_3 × 10	158.650±1.350	14.000±0.003	0.356±0.100	1.750±0.003	16.333±0.577	34.000±4.000	565.750±42.250	126.249±10.684	77.550±5.430	0.452±0.014	31.563±1.897	13.858±1.876
G_3× 20	155.000±4.000	14.000±0.040	0.342±0.039	1.739±0.001	16.000±1.000	37.667±0.577	605.500±45.500	159.304±7.720	76.395±1.845	0.429±0.012	35.950±2.175	15.464±1.358
LSD ($p \leq 0.05$)	14.457	1.442	NS	0.339	NS	NS	NS	24.204	NS	NS	NS	NS
	Phosphorus fertilizer											
G_1 × Control	184.000±2.000	14.667±0.577	0.425±0.104	1.190±0.189	17.000±2.000	33.333±6.506	581.750±53.250	137.370±21.730	72.750±3.720	0.392±0.052	34.950±0.925	13.737±2.173
G_1 × 100	154.333±2.517	14.667±0.577	0.219±0.071	1.631±0.007	15.000±1.000	24.000±0.000	378.500±28.500	79.528±8.193	68.205±0.555	0.320±0.030	28.338±2.938	7.953±0.819
G_1 × 200	159.000±1.000	14.000±0.022	0.156±0.069	1.790±0.006	18.333±0.577	34.000±2.000	640.000±16.000	133.593±11.513	65.970±3.960	0.364±0.001	39.046±2.062	13.359±1.151
G_2 × Control	158.667±1.528	14.000±0.007	0.290±0.130	1.664±0.013	16.333±1.528	29.667±3.512	489.500±12.500	116.775±1.660	73.020±1.620	0.356±0.043	33.200±3.575	11.678±0.166
G_2 × 100	144.000±2.000	14.000±0.031	0.206±0.040	1.633±0.093	19.000±3.000	29.667±0.577	576.750±95.750	114.300±26.135	63.420±3.390	0.319±0.053	30.675±3.700	9.763±1.448
G_2 × 200	173.000±2.000	14.000±0.021	0.243±0.029	1.601±0.011	17.000±1.000	33.667±6.506	567.000±72.000	121.158±16.433	72.525±0.015	0.404±0.034	27.775±0.500	12.116±1.643
G_3 × Control	175.667±0.577	15.333±0.577	0.374±0.119	1.907±0.057	17.000±1.000	35.000±1.000	602.500±18.500	139.090±1.675	74.970±2.610	0.422±0.012	32.963±1.338	13.909±0.167
G_3 × 100	141.333±1.528	14.000±0.020	0.233±0.004	1.631±0.007	17.000±1.000	32.000±0.001	555.000±32.000	135.710±5.300	79.380±1.800	0.433±0.023	31.488±2.863	13.571±0.530

$G_3 \times 200$	167.000±1.000	15.000 ±0.010	0.366 ±0.014	1.862 ±0.012	16.000 ±0.007	28.000 ±0.020	453.250 ±3.750	120.858 ±20.068	75.825 ±0.195	0.435 ±0.040	30.125 ±2.750	13.086 ±1.003
LSD ($p \leq 0.05$)	16.056	NS	NS	0.356	NS	NS	185.951	NS	NS	NS	6.477	NS

DM: Dry matter, NS: Non-significant, LSD: Least significant difference, PH: Plant height, NLP: Number of leaves per plant, LAI: Leaf area index, NKE: Number of kernel ear, WKE: Weight of kernel ear, NKR: Number of kernels row, NRE: Number of rows ear, KW: Kernels weight, BY: Biological yield, KY: Kernel yield, HI: harvest index.

Conclusions

The results from both experiments demonstrated that maize vegetative and chemical traits were significantly influenced by genotypic variation, fertilizer treatments, and their interactions. Notably, root and shoot dry matter accumulation, chlorophyll content, oil percentage, and protein content varied significantly among genotypes and in response to nano-zinc chelate (Zn) and phosphorus (P) fertilizers. Genotypes such as G1 and G3 consistently exhibited superior performance in dry matter accumulation and protein content, respectively, across conditions. Application of 20 mg L^{-1} nano-zinc chelate and 200 kg ha^{-1} P fertilizer was particularly effective in enhancing biomass production and grain quality components like oil and protein levels. Significant genotype × fertilizer interactions were observed, indicating that specific genotype-fertilizer combinations (e.g., G3×Zn, G2×P) can optimize vegetative growth. These findings emphasize the critical role of both genetic selection and nutrient management in improving maize productivity under varying environmental conditions.

Author contribution

DMI: Conceptualization, methodology, and writing of the original manuscript.

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Data availability

The raw and analyzed data are available from the corresponding author and can be provided upon request.

Disclosure of interest

The author has no conflict of interest related to this study.

References

[1] Orhun, G. E. Onsekiz, Ç. Üniversitesi, M. & Orhun, G. E. Maize for life. *Int J Food Sci Nutr Eng* **3** (2), 13-16, doi: 10.5923/j.food.20130302.01(2013).

[2] Drebee, H. A., Razak, N. A. A., & Mohsen, A. A. Maize Production Forecasting in Iraq: A Box-Jenkins Approach for the Period of 2022-2026. *IOP Conf. Ser.: Earth Environ. Sci.* **1259** (1), 012128, doi: 10.1088/1755-1315/1259/1/012128 (2023).

[3] Maki, M. A. & Muhammed, W. Z. Effect of Thermal treatment and acid modification for corn starch extracted from some Iraqi cultivated corn genotypes on their resistance to Alpha-amylase activity and some physicochemical properties. *Passer J. Basic Appl. Sci.* **6** (1), 1–7, doi: 10.24271/psr.2023.410479.1365 (2023).

[4] AL-Shumary, A. M. Ali, H. A. & Alabdulla, S. A. Effect of spraying concentrations of integrated nano-fertilizer on growth and yield of genotypes of corn (*Zea mays* L.). *Muthanna J. of Agric. Sci* **7** (2), 114-121, doi:10.18081/MJAS/2019-7/114-121 (2019).

[5] Kumar, V. V. Bala, R. & Pullabhotla, V. S. R. Derivatizing agents for spectrophotometric and spectrofluorimetric determination of pharmaceuticals: a review. *J Taibah Univ Sci* **17** (1), 2206363, doi.org/10.1080/16583655.2023.2206363 (2023).

[6] Raghothama, K. G. & Karthikeyan, A. S. Phosphate acquisition. *Plant Soil*, **274**, 37-49, doi.org/10.1007/s11104-004-2005-6 (2005).

[7] Hafeez, B. M. K. Y. Khanif, Y. M. & Saleem, M. Role of zinc in plant nutrition review. *Am J Exp Agric* **3** (2), 374-391, (2013).

[8] Miransari, M. Soil microbes and plant fertilization. *Microbiol. Biotechnol.* **92**, 875–885, doi 10.1007/s00253-011-3521-y (2011).

[9] Mer, M. & Ama, E. H. E. Effect of Cu, Fe, Mn, Zn foliar application on productivity and quality of some wheat cultivars (*Triticum aestivum* L.). *JAAS Journal* **2** (9**)**, 283- 291. E-ISSN: 2311-6730 (2014).

[10] Hadi, D. R. Mahmood, B. J. & Hama Kreem, T. H. K. Impact of Microelement Treatments on Nutrient Uptake in Two Wheat Varieties at Different Growth Stages. *Passer J. Basic Appl. Sci.* **7** (1), 245-256, doi: 10.24271/PSR.2025.492470.1848 (2025).

[11] Shnrwe, B. M. & Ahmed, R. M. Response of yield and chemical composition of black cumin to different fertilizers in the Sulaimani region. *Iraqi J Agric Sci* **53** (4), 901–910, doi: 10.36103/ijas.v53i4.1602 (2022).

[12] Ezaddin, N. A. & Salih, R. F. Cultivated natural fiber crops in Iraq and their uses: A review. *Passer J. Basic Appl. Sci.* **5** (1), 191-20, doi: 10.24271/PSR.2023.387490.1265 (2023).

[13] Ibrikci, H., Ryan, J., Ulger, A. C., Buyuk, G., Cakir, B., Korkmaz, K. & Konuskan, O. Maintenance of phosphorus fertilizer and residual phosphorus effect on corn production. *Nutr Cycl Agroecosyst* **72**, 279-286, doi: 10.1007/s10705-005-3367-8 (2005).

[14] Zhang, L., Yan, M., Ren, Y., Chen, Y. & Zhang, S. Zinc regulates the hydraulic response of maize root under water stress conditions. *Plant Physiol Biochem* **159**, 123-134, doi.org/10.1016/j.plaphy (2021).

[15] Khan, H. A. & Khan, A. Phosphorus and zinc fertilization on maize yield and yield components. *Int J Agric Environ Res* **1**, 62-67, (2015).

[16] Jiang, M., Ma, Y., Khan, N., Khan, M. Z., Akbar, A., Khan, R. U. & Khan, N. A. Effect of spring maize genotypes on fermentation and nutritional value of whole plant maize silage in northern Pakistan. *Fermentation* **8** (11), 587, doi.org/10.3390/fermentation8110587 (2022).

[17] Suganya, A., Saravanan, A. & Manivannan, N. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. *Commun. Soil Sci. Plant Anal* **51** (15**)**, 2001-2021, doi: 10.1080/00103624.2020.1820030 (2021).

[18] Bhattacharjee, S., Bhale, V. M., Kumar, P. & Kumar, R. Effect of potassium and zinc nutrition on growth and yield of short duration maize (*Zea mays*

L.) under dryland Vertisols. *Indian J Agric Res* **56** (1), 22-27, doi:http://dx.doi.org/10.18805/IJARe.A-5892 (2022).

[19] Khaksar, K., Chaokan, R., HEIDARI, S. H., Daneshian, J., Khazaei, F. & Farhadi, F. Study of grain yield and its components in corn hybrids in two planting dates using different rates of biofertilizers in Karaj region, Iran. *Plant Ecophysiol* **3**, 141-150, (2009).

[20] Wang, Y., Liu, X., Hou, X., Sheng, D., Dong, X., Gao, Y. & Huang, S. Maximum lethal temperature for flowering and seed set in maize with contrasting male and female flower sensitivities. *J Agron Crop Sci* **207** (4), 679-689, doi.org/10.1111/jac.12506 (2021).

[21] Gurmu, S. Review on the effect of phosphorus fertilizer and its availability on growth and development of maize (*Zea mays* L.). *J Environ Earth Sci* **13** (4), 35-43, doi: 10.7176/JEES/13-4-03 (2023).

[22] Mutambu, D., Kihara, J., Mucheru-Muna, M., Bolo, P., & Kinyua, M. Maize grain yield and grain zinc concentration response to zinc fertilization: A meta-analysis. *Heliyon* **9** (5), doi.org/10.1016/j.heliyon.2023.e16040 (2023).

[23] Naomi, M. R., & Nurmalasari, I. A. Role of phosphate fertilizer on growth and yield of hybrid maize (*Zea mays* L.). IOP Conf. Ser: *Earth Environ Sci* 637 (1), 012070. IOP Publishing, doi:10.1088/1755-1315/637/1/012070 (2021).

[24] Asma, H. M., Ali, N. Masood, R. Akbar, N., Shafqat, N. & Shad, N. Agro-morphological characterization of Pakistani maize accessions using qualitative and quantitative traits. *Brazilian J. Biol* **84**, e259729 doi.org/10.1590/1519-6984.259729 (2022).