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MICRONUTRIENTS AND PLANTING TIME EFFECTS ON MAIZE GROWTH, FERTILITY, AND YIELD-RELATED TRAITS UNDER HEAT STRESS CONDITIONS

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SUMMARY

The recent study pursued determining the ideal quantity of micronutrients and planting time to enhance maize (*Zea mays* L.) pollen fertility and production under heat-stress conditions. The study set up a maize experiment in a randomized complete block design (RCBD) with split-plot arrangement and three replications, carried out in the crop season 2020 at the Babylon Muradia Research Center, Iraq. The trials comprised two factors: first, planting times placed in main plots, i.e., June 25 (A1), July 10 (A2), and July 25 (A3), and the second included foliar applications of a composition of six microelements (iron, manganese, zinc, boron, copper, and molybdenum) with four concentrations, i.e., 0 (C0), 20 (C1), 30 (C2), and 40 (C3) g L^{-1}. The results indicated that maize planting at later dates, specifically between July 10 and 25, resulted in the maximum levels of moisture, pollen vitality, and fertility percentage, which led to an increase in yield components and grain output. The findings also demonstrated that foliar application of micronutrients effectively creates a conducive environment for developing pollen grains. The micronutrient concentration of 40 g L^{-1} gave the optimal moisture and vitality of the pollen grains, leading to the highest quantity of grains per row and, ultimately, maximizing the maize yield. The July 10 planting date proved the ideal time for seeding maize because it contributed to reducing temperatures' effects and increasing productivity. In addition, foliar application of micronutrients (40 g L^{-1}) creates an optimal environment for pollen grains, improving grain composition and yield. With the pollen grain's better vitality, the favorable situation improves pollination and fertilization, eventually increasing the maize yield.

Keywords. Corn (*Zea mays* L.), micronutrients, foliar nutrition, sowing dates, pollen moisture, fertility, pollination and fertilization, yield-related traits

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Key finding: Maize (*Zea mays* L.) planting time between July 10 and 25, along with foliar application of micronutrients (40 g L^{-1}), optimized and promoted pollen grains' moisture, growth, vitality, and fertility percentage, which eventually boosted the yield traits' components and grain yield.

INTRODUCTION

Maize (*Zea mays* L.) is the third most important cereal and food crop worldwide after wheat and rice, based on cultivated area, production, and consumption. Recently, a decline occurred in the maize yield deemed due to poor pollination and fertilization (Erenstein *et al*., 2022), with the said problem impacting more effects on maize production, especially when planting transpired in the fall (Singh *et al*., 2022). Hence, plants' foliar feeding became a significant approach to fertilization, as it effectively addresses the plants' nutrient deficiencies. Additionally, foliar application can reduce energy consumption associated with the elemental ions' transfer within the plants, thereby facilitating improved nutrient uptake in maize hybrids (Chinipardaz *et al*., 2022).

The nutrition requirement for various macro- and microelements the corn crop can easily absorb through foliar application, as these elements are crucial in meeting about 85% of the plant's nutrient needs (Akça *et al*., 2022). Foliar spraying technology is very applicable to enhance plants' absorption of nutrients, especially potassium and magnesium (Mohammed et al., 2021; Al-Tamimi and Farhood, 2022). Essential elements are necessary in small quantities that have direct or indirect involvement in various physiological processes in plants, including photosynthesis, respiration, protein synthesis, and reproductive phase. These micronutrients actively participate in plant metabolism, influencing processes ranging from cell wall development to chlorophyll formation, enzyme activity, nitrogen fixation, and reduction (Zewide and Sherefu, 2021).

Inadequate microelements can disrupt the fertilization process and the production of grains by impeding pollen germination and the growth and development of the pollen tube. It negatively impacts fertility and hinders grain development in maize (*Zea mays* L.) (Balawejder *et al*., 2019). According to Kumari *et al*. (2022), incorporating micronutrients, such as zinc, manganese, sulfur, and molybdenum, has shown favorable effects in enhancing maize productivity, resulting in a grain yield of 5.99 tons ha^{-1}.

Heat stress is a rise in temperatures above the regular level for a specific time sufficient to cause irreversible damage to crop plants. Temperature disturbs the balance between photosynthesis and respiration; when temperatures increase beyond the optimum, the physiological activities of plants negatively affect the synthesis of proteins, disrupting the mechanism of enzymatic action (Amarasinghe *et al*., 2022). High temperatures can also lead to increased production of free oxygen radicals, which further proceed to oxidative stress, inhibition of seed germination, and incomplete growth and development. Plants with variations in photosynthesis, dry matter distribution, and large water consumption severely affect and decrease the maize crop yield and quality (Wedow *et al*., 2021).

The flowering stage is well-recognized as a critical phase in the life cycle of plants, wherein susceptibility to elevated temperatures is most prominent. This developmental period is very vulnerable to adverse impacts of excessive temperatures, which can significantly impede overall productivity. According to Bheemanahalli *et al*. (2022), it has been apparent that the viability of pollen grains can be compromised when the tassel incurs prolonged exposure at 38 °C temperature in maize (*Zea mays* L.). One of the primary obstacles maize farmers encounter is determining the optimal timing for planting maize to mitigate the detrimental effects impacting either early or late-maize planting (Singh *et al*., 2016, 2020).

The primary cause of low production, resulting from the delay in the optimal planting date, can refer to the unfavorable environmental circumstances experienced by the crop during the development of its reproductive organs. Additionally, the variations in the rate of photosynthesis also contribute to this phenomenon in cereal crops (Zenda *et al*., 2022). Negative consequences resulting from postponing the planting date depended mainly on the adverse impact of elevated temperatures. Research has demonstrated that the development of yellow maize, from the initial seed stage to the point of physiological maturity, has significant influences from ambient air temperature (Dong *et al*., 2021). Hence, the presented study seeks to ascertain the optimal quantity of micronutrients and planting schedule that can impact the development and viability levels of maize pollen grains and fertilization, thereby leading to an enhanced crop yield.

MATERIALS AND METHODS

The relevant study aimed to determine the effects of micronutrients and planting times on the growth, pollen viability, and grain yield of maize (*Zea mays* L.) under heat-stress conditions. The study set up an experiment in a randomized complete block design (RCBD) with split-plot arrangement and three replications. After preparing the soil, the trial commenced during the crop season 2020 at the Babylon Muradia Research Center, Iraq. The ground was compatible with the nature of growth of this crop (Table 1), where the experiment comprised two factors, with the first as planting times placed in main plots, i.e., June 25 (A1), July 10 (A2), and July 25 (A3), while the second factor included foliar applications of a composition of six microelements (iron, manganese, zinc, boron, copper, and molybdenum) in four concentrations, i.e., 0 (C0), 20 (C1), 30 (C2), and 40 (C3) g L^{-1} (Table 2). The foliar application ensued two times, specifically at 30 and 45 days following the sowing process (Gomaa *et al*., 2021). The cultivation, fertilization, and control processes followed recommended protocols. A sample of 20 plants' random selection from the cultivated variety, a local variety with seeds taken from the Seed Inspection and Certification Center, Ministry of Agriculture, Iraq, served as specimens for scrutiny of the following parameters upon reaching maturity.

Table 1. Chemical and physical characteristics of the soil before planting.

Chemical Attributes	Value
Degree of soil reaction (pH)	7.6
Electrical conductivity Desi $Siemens^{-1}$	2.5
Ready nitrogen (mg kg^{-1} soil)	55
Ready phosphorus (mg kg^{-1} soil)	14.59
Ready potassium (mg kg^{-1} soil)	27.00
Organic matter (g kg^{-1} soil)	1.4
Soil components	
Sand (g kg^{-1} soil)	322
Silt (g kg^{-1} soil)	563
Clay (g kg^{-1} soil)	316

Table 2. Components of microelements used in a composition for foliar application in maize.

Elements	Concentration
Iron	6%
Manganese	5%
Zinc	7%
Boron	2%
Copper	1%
Molybdenum	0.05%

Studied traits

Pollen moisture (%)

Pollen grain collection from five plants ensued in the morning, placing them in plastic bags to prevent moisture loss before directly taking them to the laboratory. An earlier prepared glass container (weight W1) acquired the pollen grains and weighed (W2). Then, the glass container with pollen grains proceeded to be baked in the oven at a temperature of 100 °C until stabilizing the weight. From the stove, weighing the container followed to represent the weight after drying (W3), then calculating the moisture content employing the below equation (A.O.A.C., 1995).

$$PollenMoisture\,(\%) = \frac{W3 - W1}{W2 - W1} \times 100$$

Pollen vitality (%)

Pollen vitality determination continued by collecting pollen grains from five plants in the morning and storing them in plastic bags to minimize moisture loss. Immediate transport followed of the samples to the laboratory to undergo dyeing with the safranin-glycerin dye. This dye comprised combining one part safranin dye with six parts glycerin. Dropping a small amount of the dye onto a glass slide, it received a measured quantity of pollen grains using a dissecting needle. The collected pollen grains, placed onto the dye drop, incur an even dispersion to achieve a homogenous distribution. Then, the covered slide sustained scrutiny under an optical microscope at a 40× magnification. The viable pollen grains exhibit a pink hue, possessing a complete, spherical morphology, whereas the non-viable pollen grains lack pigmentation, displaying a wrinkled structure. Determining the vitality ratio involved the calculation of the proportion of viable pollen grains concerning the total number of grains observed inside the designated area on the slide.

Fertility (%)

The fertility percentage calculation employed the following formula:

$$Fertility(\%) = \frac{Numberofeargrains}{numberofearovaries} \times 100$$

The rows per ear and grains per row determination continued via manual computation, with the average values calculated. For the 500-grain weight (g) determination, each sample from the experimental units consisted of five plants, with a total of 500 grains counted. The measurement of the weight of the grains used a precision electric scale. Computing grain yield (tons ha^{-1}), the calculation involved determining the average weight of one plant's yield by taking the average of five plants gathered from each experimental unit multiplied by the plant density per hectare (Qazi *et al.,* 2014).

Statistical analysis

All the data on the quantitative traits of maize underwent the analysis of variance (ANOVA). The least significant difference (LSD) test helped compare and distinguish the means. Running the statistical analysis at the Gene Stat software application compared the arithmetic means.

RESULTS AND DISCUSSION

Pollen grains moisture (%)

The results revealed that foliar application comprising six micronutrients, planting dates, and their interactions raised the moisture content of the pollen grains of maize (*Zea mays* L.) positively (Table 3). The micronutrients at a concentration of 40 g L^{-1} exhibited the highest average moisture in the pollen grains (58.62%), surpassing the control

Table 3. Effect of foliar application of micronutrients, planting dates, and their interactions on the pollen moisture content (%) in maize.

Planting dates	Micronutrient concentrations				Means (%)
	C0	C1	C2	C3	
25 June	44.92	46.89	52.19	54.21	49.55
10 July	45.21	52.89	54.89	60.76	53.43
25 July	46.18	52.82	54.99	60.89	53.72
Means (%)	45.43	50.86	54.02	58.6	

$LSD_{0.05}$ Planting dates = 2.52, $LSD_{0.05}$ Micronutrient = 0.73, $LSD_{0.05}$ P × M Interaction = 1.46

Table 4. Effect of foliar application of micronutrients, planting dates, and their interactions on the pollen vitality (%) in maize.

Planting dates	Micronutrient concentrations				Means (%)
	C0	C1	C2	C3	
25 June	71.53	75.31	82.11	84.12	78.26
10 July	72.31	80.97	85.33	92.88	82.87
25 July	73.12	81.21	84.44	90.98	82.43
Means (%)	72.32	79.16	83.96	89.32	

$LSD_{0.05}$ Planting dates = 3.16, $LSD_{0.05}$ Micronutrient = 1.02, $LSD_{0.05}$ P × M Interaction = 2.05

treatment (C0), which recorded a moisture level of 44.92%. It can be due to the impact of micronutrients on enhancing the pollen grains' moisture content of maize through their influence on root development, weight gain, and relative water content in plants. Additionally, micronutrients are crucial in enhancing plants' capacity to absorb and distribute water within their tissues (Ciampitti and Vyn, 2013). Consequently, applying the substance elevated the moisture level of the pollen grains in treated plants.

The sowing dates of July 10 and 25 exhibited nonsignificant differences in the maize's pollen grains moisture, with respective values of 53.43% and 53.72%. In contrast, the early sowing of June 25 significantly differed from the earlier dates, with a reduced pollen moisture level (49.55%). The increase in the percentage of pollen moisture at the planting dates of July 10 and 25 could be due to a rise in the relative water content of the plants, which, in turn, improves the crop's moisture and, thus, reduces the rate of water loss through transpiration. As a result, it is possible to directly attribute the higher moisture percentage in pollen grains to this occurrence. Additionally, it is worth noting that a decrease in temperature has been apparent to lower the transpiration rate, thereby further enhancing the water condition of maize plants (Gajghate *et al*., 2020).

Based on the results of the interaction of micronutrients and planting times, it was evident that varying concentrations of micronutrients significantly impacted the influence of planting dates in mitigating transpiration and, consequently, augmenting the moisture content of the maize pollen grains. Specifically, the planting dates of July 10 and 25, with micronutrients at a concentration of 40 g L^{-1}, exhibited the highest average levels of pollen grains' moisture, measuring 60.76% and 60.89%, respectively.

Pollen vitality (%)

The term 'pollen vitality' pertains to the specific duration in which pollen grains ably undergo germination (Yang *et al*., 2012). The results demonstrated a significant impact of micronutrient spraying, maize planting dates, and their interaction on pollen grain vitality (Table 4). Specifically, the foliar application of micronutrients with a concentration of 40 g L^{-1} exhibited the highest average pollen vitality (89.32%), surpassing the control treatment's vitality of 71.53%. The observed enhancement in pollen vitality resulting from the foliar application of micronutrients can be due to the activation of plant enzymes in pollen grain production and development (Jolli *et al*., 2020). The maize planting dates of July 10 and 25 exhibited the maximum levels of pollen vitality, with average values of 82.87% and 82.43%, respectively (Table 4). Inversely, the sowing date of June 25 resulted in the lowest average pollen vitality (78.26%). The observed rise in pollen vitality on July 10 and 25 can refer to their impact on increasing the moisture percentage within the pollen grains (Table 3). The said relationship was significant as the vitality of pollen grains closely correlated linkage with their moisture content, and the relative water content within the pollen grains is a crucial factor in determining their vitality and transmission dynamics. Maize pollen grains were found susceptible to drought conditions in the atmosphere, and their viability receives strong influence from their water content and the factors contributing to dryness (Mohan *et al.,* 2023).

Based on the interaction data of micronutrients and planting times, it was evident that the maize planting of July 10, with the highest micronutrient concentration (40 g L^{-1}), exhibited the ultimate average vitality (92.88%). In contrast, the first and second sowing dates (June 25 and July 10), with a low concentration of micronutrients, displayed vitality levels of 71.53% and 72.31%, respectively. These findings highlight the significance of maintaining elevated micronutrient concentrations under moderate temperatures.

Fertility (%)

The results revealed a considerable increase in pollen fertility by applying the micronutrients at several doses to the maize crop (Table 5). Furthermore, noteworthily, these concentrations exhibited substantial differences in their respective effects. The use of micronutrients at a concentration of 40 g L^{-1} resulted in the highest level of pollen fertility, scoring an average value of 93.02%, compared with the control treatment, with the lowest average rate of 84.88%. The observed rise in fertility resulting from the foliar application of micronutrients can connect with their ability to enhance the moisture content and viability of maize pollen grains (Tables 3 and 4). This improvement in pollination and fertilization processes can be due to the contribution of microelements to the growth and functionality of reproductive tissues responsible for pollen grain production in maize and various other species (Ghaffari *et al.*, 2011). The foliar application of microelements may be responsible for activating assorted enzymes essential for pollen grain generation, stamen and gynoecium development, and pollination and fertilization processes (Li *et al.,* 2023).

Based on the data presented in Table 5, it was evident that the sowing dates of July 10 and 25 displayed the highest fertility rates, averaging 90.87% and 91.24%, respectively. Notably, nonsignificant differences were visible between these two dates. Conversely, the sowing date of June 25 had the lowest fertility

Table 5. Effect of foliar application of micronutrients, planting dates, and their interactions on the fertility (%) in maize.

Planting dates	Micronutrient concentrations				Means (%)
	C0	C1	C2	C3	
25 June	81.20	82.75	86.21	88.88	84.76
10 July	86.13	90.95	92.08	94.33	90.87
25 July	87.32	88.88	92.90	95.86	91.24
Means (%)	84.88	87.52	90.39	93.02	

$LSD_{0.05}$ Planting dates = 2.24, $LSD_{0.05}$ Micronutrient = 0.37, $LSD_{0.05}$ P × M Interaction = 0.73

rate, averaging at 84.76%. The rise in the fertility rate may be because of several factors, including moderate temperatures, an increase in the percentage of moisture in pollen grains (Table 3), and an increase in pollen vitality percent (Table 4). These factors have collectively contributed to enhancing the pollination and fertilization processes.

The interaction data of the micronutrient concentration (40 g L^{-1}) and maize sowing dates (July 10 and 25) showed the supreme means for the fertility rate (95.86% and 94.33%, respectively), compared with the planting date of June 25, with micronutrient concentration (20 g L^{-1}) and the control variant, which showed the minimum averages of 82.75% and 81.20%, respectively.

Rows per ear

According to the results, a considerable increase in the number of rows per ear was visible with foliar application of micronutrients at various concentrations in maize (Table 6). The micronutrient concentrations exhibited significant differences, and the highest micronutrient concentration (40 g L^{-1}) showed the maximum number of rows per ear (18.15 rows ear^{-1}) versus the control treatment, with the lowest average (15.13 rows ear^{-1}). The observed augmentation in the number of rows per ear, with the foliar application of micronutrients, can refer to its beneficial impact on enhancing plant hydration. It, in turn, mitigates the susceptibility of plants to water stress, which is the primary factor influencing the particular trait in maize crops (Ghazvineh and Yousefi, 2012).

The findings revealed that the July 10 and 25 sowing dates yielded the utmost average number of rows per ear in maize, with values of 17.14 and 17.14 rows ear^{-1}, respectively (Table 6). On the other hand, the June 25 planting date produced the fewest average rows (15.45 rows ear^{-1}). The moderation of temperatures during the planting dates of July 10 and 25 can correlate to the observed rise in the number of rows in the ear. According to Mason *et al.* (2019), the cooling of temperatures caused the transpiration process to decrease and the water quality of the maize plants to improve. These two dates also significantly increased the pollen grains' moisture content and viability, increasing the number of rows per ear.

The interaction findings also showed that, with an average of 18.78 rows ear^{-1}, the micronutrient concentration (40 g L^{-1}) applied on July 10 produced the foremost mean number of rows per ear (Table 6). On the other hand, the June 25 planting date for the control treatment (C0) produced the lowest mean number of rows per ear (13.55 rows ear^{-1}).

Grains per row

The results showed an average of 38.02 grains per row, with the foliar treatment of micronutrient concentration (40 g L^{-1}) as the most grains per row generated (Table 7). Conversely, the mean for the control treatment was the lowest–30.65 grains row^{-1}. The influence of micronutrient spraying on improving the moisture content and viability of pollen grains might be the reason for the apparent increase in the number of grains per

Table 6. Effect of foliar application of micronutrients, planting dates, and their interactions on the rows per ear in maize.

Planting dates	Micronutrient concentrations				Means (#)
	C0	C1	C2	C3	
25 June	13.55	15.34	15.86	17.06	15.45
10 July	15.89	16.00	17.92	18.78	17.14
25 July	15.95	16.35	17.43	18.62	17.12
Means (#)	15.13	15.89	17.07	18.15	

$LSD_{0.05}$ Planting dates = 0.20, $LSD_{0.05}$ Micronutrient = 0.26, $LSD_{0.05}$ P × M Interaction = 0.51

Table 7. Effect of foliar application of micronutrients, planting dates, and their interactions on the grains per row in maize.

Planting dates	Micronutrient concentrations				Means (#)
	C0	C1	C2	C3	
25 June	30.18	32.26	35.33	36.43	33.55
10 July	30.65	34.68	36.23	38.98	35.13
25 July	31.12	34.95	36.23	38.66	35.24
Means (#)	30.65	33.96	35.93	38.02	

$LSD_{0.05}$ Planting dates = 1.45, $LSD_{0.05}$ Micronutrient = 0.63, $LSD_{0.05}$ P × M Interaction = 1.25

Table 8. Effect of foliar application of micronutrients, planting dates, and their interactions on the 500-grain weight (g) in maize.

Planting dates	Micronutrient concentrations				Means (g)
	C0	C1	C2	C3	
25 June	164.45	181.50	197.63	218.33	190.47
10 July	197.89	213.35	214.22	234.50	214.99
25 July	199.46	207.36	215.70	221.69	211.05
Means (g)	187.22	200.73	209.18	224.84	

$LSD_{0.05}$ Planting dates = 1.45, $LSD_{0.05}$ Micronutrient = 0.63, $LSD_{0.05}$ P × M Interaction = 1.25

row (Tables 3 and 4). It finally resulted in a rise in grains per row and a greater fertility rate, as seen in Table 4. Furthermore, the foliar application of microelement is essential for improving the efficiency of metabolite transport to different plant organs, raising the yield of maize crop seeds per row (Yosefi *et al*., 2011).

With an average of 35.24 and 35.13 seeds per row, the July 10 and July 25 planting dates gave the most seeds per row, respectively (Table 7). On the other hand, the June 25 maize early seeding produced the lowest average seeds per row (33.55 seeds). The outcomes detailed in Tables 3 and 4 demonstrate that the later stages of the row's increased grain amount significantly affected the pollen grains' moisture content and vitality. This improvement in pollen quality subsequently enhanced the fertility rate, as indicated in Table 5, ultimately raising the overall number of grains in the row. Furthermore, the correlation between maize planting dates and the resulting grain yield can be due to variations in ripening durations. Maize crops' exposure to higher temperatures exhibited an accelerated life cycle, leading to weakened physiological processes (Farhood *et al*., 2020; Jahangirlou *et al.*, 2020).

500-grain weight (g)

The findings demonstrated that the foliar application of micronutrients resulted in a significant augmentation in the 500-grain weight in maize (Table 8). The treatment with foliar application of micronutrient concentration (40 g L^{-1}) yielded the maximum 500-grain weight, exhibiting an average weight of 224.84 g. In contrast, the control treatment (C0) had the lowest average weight of 187.22 g. The observed augmentation in grain weight following the application of micronutrients is attributable to their role in enhancing pollen moisture content and vitality (Tables 3 and 4) and increasing fertility rates (Table 5). Utilizing micronutrients improved the vegetative growth, boosting the 500-grain weight (Filipović *et al.,* 2019).

The maize planting date of July 10 generated the highest 500-grain weight, totaling 214.99 g (Table 8). In contrast, the sowing date of June 25 resulted in the lowest average 500-grain weight (190.47 g). The noted increase in the 500-grain weight on the second planting date can be because of the influence of this particular date on enhancing growth characteristics in maize, thereby improving the efficiency of the photosynthesis

Table 9. Effect of foliar application of micronutrients, planting dates, and their interactions on grain yield (tons ha^{-1}) in maize.

Planting dates	Micronutrient concentrations				Means (tons ha^{-1})
	C0	C1	C2	C3	
25 June	4.040	5.333	5.680	6.540	5.398
10 July	5.630	6.431	7.280	8.703	7.011
25 July	5.001	6.452	7.499	8.660	6.903
Means (tons ha^{-1})	4.890	6.072	6.819	7.967	

LSD$_{0.05}$ Planting dates = 1.45, LSD$_{0.05}$ Micronutrient = 0.63, LSD$_{0.05}$ P × M Interaction = 1.25

process and increasing the efficiency of resource utilization. Consequently, these improvements enhanced grain plumpness and weight gain in tropical maize (Noor *et al*., 2019). The interference data reveals that available high concentrations of micronutrients significantly improved the maize plants' reaction to the planting on July 10, resulting in the paramount average of the said characteristic, with a total of 234.50 g.

Grain yield (t ha^{-1})

The results presented that the foliar application of micronutrients significantly augmented maize grain production (Table 9). The treatment with micronutrient concentration (40 g L^{-1}) produced the highest grain yield (7.967 t ha^{-1}), whereas the control treatment exhibited the lowest average grain yield (4.890 t ha^{-1}). The observed enhancement in grain yield can be due to the application of micronutrient sprays, causing a considerable improvement in yield-related traits, including the number of grains per row and the 500-grain weight (Tables 6 and 7). Moreover, the foliar application of micronutrients helped enhance the efficacy of the photosynthetic process and expedite the transportation of assimilates inside the plant body. Consequently, this phenomenon contributes to an augmentation in the yield components and, subsequently, influences the grain yield in maize. Increased fertilization rate also has effectively determined the location of grain establishments in one row, established in the vegetative growth stages, and thus, reflects positively on increasing grain yield (Stewart *et al.,* 2021).

The outcomes revealed a significant amplification in grain production across various maize planting dates (Table 9). The planting date of July 10 resulted in the highest grain yield, averaging 7.011 t ha^{-1}. However, this production was at par with the grain yield obtained from the sowing date of July 25 (6.903 t ha^{-1}). Inversely, the sowing date of June 25 indicated the lowest grain yield, averaging 5.398 t ha^{-1}. The noted rise in grain yield is ascribable to moderate temperatures, with the concurrent augmentation in grains per row and 500-grain weight (Tables 6 and 7), causing an overall increase in maize production.

The analysis of the interactions specified a significant relationship between the maize planting dates and the different concentrations of micronutrients. The treatment with a sowing date of July 10 and micronutrient concentration (40 g L^{-1}) exhibited the highest mean grain yield (8.703 t ha^{-1}), and the treatment with a sowing date of July 25 and control treatment (C0) had the lowest maize grain yield (4.040 t ha^{-1}).

CONCLUSIONS

Based on the results, an inference can be that maize (*Zea mays* L.) sowing at the later dates of July 10 and 25 leads to a favorable environment for the emergence and development of pollen grains characterized by moderate temperatures. This satisfactory condition also encourages the efficiency of the pollination and fertilization processes, owing to the pollen grains' increased moisture content and vitality and, consequently, a maize grain yield increase. In addition, the foliar application of microelements has also proven to generate an optimal development environment for pollen grains, resulting in enhanced grain composition and yield.

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