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Enhancing maize productivity under abiotic stresses through the combined use of nitrogen, potassium humate, and zinc

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***Abstract*— *The soils found in the Kharga oasis in Egypt have been identified as having low levels of nitrogen and organic matter, along with high pH and salinity. These conditions make it difficult for the plants to absorb essential micronutrients. In order to address this issue, a study was conducted with the main objective of evaluating the interactive effect of potassium humate, zinc, and nitrogen fertilization on the grain yield of maize and its various components. The study consisted of two field experiments that took place during the growing seasons of 2022 and 2023 at the research station of the Desert Research Center in Kharga, located in the western desert of Egypt. The treatments in the experiments involved three different levels of potassium humate and zinc combinations, including 20 kg/ha of potassium humate, 375 ppm of zinc, and a combination of both, which were compared to a control group. Additionally, four levels of nitrogen fertilization were applied, ranging from 100 to 400 kg/ha. The results of the study revealed that the highest and most significant grain yields were observed in both seasons when potassium humate and zinc were applied together, resulting in yields of 10,436 and 10,590 kg/ha in the first and second seasons, respectively. Furthermore, it was found that the highest significant grain yields in both seasons were achieved by applying 300 kg of nitrogen per hectare, with yields of 9423 and 9196 kg/ha in the first and second seasons, respectively. These findings suggest that the combination of nitrogen fertilization with potassium humate and zinc proves to be effective in maximizing the grain yield of maize. This information is valuable for farmers and researchers in the Kharga oasis, as it provides insights into the optimal fertilization practices that can enhance crop productivity in this specific region with challenging soil conditions.*

***Keywords*— Maize, potassium humate, zinc, nitrogen, yield, Kharga oasis**

I. INTRODUCTION

Maize (*Zea mays* L.) is the second most important cereal crop in Egypt in terms of harvested area, serving as both a major field crop and a staple food source. In 2022, Egypt's maize production reached around 7.5 million metric tons with a slight increase of production of 6.85 % as compared to 2018-2023 production average (**FAO, 2024**). The slight increase in production may be due to the increase in the cultivated area. However, around 38% of Egypt's maize is imported because of the country’s insufficient production to meet demand (**Altaie *et al.*, 2022**). The goal of the Egyptian strategy for sustainable agricultural development (2030) was to raise maize production to 18.5 million tons in order to boost 91% of the country's self-sufficiency by 2030 (**El Shamy *et al.*, 2023**). To increase production and productivity, interventions are needed at both the production and policy levels, including the increased use of high-yielding varieties of quality seeds (**Altaie *et al.*, 2022**).

Chemical fertilizers are synthetic inorganic materials used to maintain plant development. Usually, they are rich in nutrients that are vital to plant growth, such as potassium, phosphate, and nitrogen. Chemical fertilizers tend to be less expensive than organic fertilizers and can be used to quickly address issues with plant growth, optimize soil conditions, and improve crop production and quality. On the other hand, overuse of chemical fertilizers can result in more acidic soil, chemically tainted water sources, damaged plants due to overgrowth, and emissions that contribute to climate change. Several studies have replaced partially or completely the chemical fertilizers especially NPK with organic fertilizers, for example in maize. **Li-Chao *et al.* (2023)** suggested that the kernel position effect in maize can be mitigated by applying both chemical and organic fertilizers together, which will increase post-silking nitrogen uptake and dry matter accumulation. Furthermore, it has been demonstrated that combining biochar with chemical fertilizers improves the physio-biochemical characteristics of the soil and maize production, suggesting a possibility for raising crop productivity and soil fertility (**Wu *et al.*, 2023**). These results emphasize the significance of investigating sustainable farming methods that preserve or increase crop yields while lessening dependency on synthetic fertilizers.

Nitrogen fertilization influences several aspects of plant growth and resource utilization, which is important for maximizing maize grain yield. The main benefits of nitrogen fertilization on maize include increase photosynthesis (**Nasar *et al.*, 2021)**, radiation use efficiency (RUE; **Bonelli *et al.*, 2020**), water use efficiency (WUE; **Guo *et al.*, 2021**), and nitrogen uptake (**Su *et al.*, 2020**. In addition to improve root architecture and the distribution of deep roots, increase height of the plant, ear, and leaf area, increase the number of ears per hectare and grain production per ear, higher total grain yield and nitrogen usage efficiency (NUE) **Ma *et al.*, 2022**. High nitrogen inputs may initially maximize maize yield, but they can lead to a decrease in NUE if excessive amounts are applied. Optimal nitrogen fertilizer rates typically range from 200 to 300 kilograms per hectare (kg/ha) (**Su *et al.*, 2020** and **Geith *et al.*, 2022**). Split applications of nitrogen fertilizer can help maintain NUE and reduce losses due to leaching or denitrification (**Davies *et al.*, 2020**)

The choice of nitrogen fertilizer rate and timing depends on local environmental conditions, soil types, and agronomic practices. **Omar *et al.* (2020)** found that out of the four N treatments, the optimal N application between 50–100 kg N ha^{-1} potentially increased the maize yield, however **Hammad *et al.* (2022)** recommended that for temperature-tolerant hybrid maize, applying 300 kg N ha^{-1} is advised as one of the best agricultural management techniques to get the highest possible grain production.

Foliar micronutrient application is a fast-acting and efficient method to increase crop yields and improve nutrient uptake, especially in conditions when root uptake is compromised, like late crop stages, nutrient-poor soils high soil pH. Studies show that foliar micronutrient treatment increases soil biological activity and increases nutrient-use efficiency (NUE) (**Bana et *al.*, 2022**), and improves crop bio fortification (**Hao *et al.*, 2021**). Zinc (Zn) is an essential micronutrient that is required by plants, animals and humans for growth. Zinc is required for a large number of enzymes that are involved in protein synthesis, energy transmission, and nitrogen metabolism. Zinc foliar spray can promote the formation of reproductive organs, such as ears, and improve the capacity for grain productivity in zinc-deficient maize plants, resulting in higher growth and yield (**Singh *et al.*, 2020**). While foliar treatments have these advantages, it's crucial to remember that they work better when combined with appropriate soil fertilization techniques that are based on soil and tissue tests. This ensures that all nutrients are managed thoroughly for the best possible plant growth (**Shahrajabian *et al.*, 2022**).

Several benefits in crop productivity were increased when nitrogen fertilizer and zinc foliar treatment were combined. In wheat, **Zhang *et al.*, 2021** stated that, foliar Zn and soil N applications effectively raised wheat grain production and N and Zn concentrations, especially in the endosperm, and this is could be useful approaches to treat Zn insufficiency. In dry conditions, foliar application of zinc either alone or in conjunction with other substances like trehalose can improve maize growth and nutrient status (**Klofac *et al.*, 2023**). While N fertilization increases overall grain yields and nutrient concentrations, there are still some restrictions on the precise advantages of applying N and the foliar application of Zn together. However, in order to maximize the nutritious content of cereal grains, it is still imperative to optimize the time and dosage of these inputs. Consequently, more research is required to identify the best formulations, doses, and application schedules.

Research findings indicate that humic acid may cause mild acid stress responses in maize seedlings, resulting in increased root development and physiological responses (**Baía *et al.*, 2020**). Additionally, combining humic acid with zinc foliar application enhanced sunflower production under drought stress by increasing grain weight, head diameter, and number of seeds per head (**Hammati 2016**). Although there aren't many research studies about maize in the literature, there is a general evidence supporting the idea that applying zinc and humic acid together improves crop health and productivity in a variety of crops (**Manas *et al.*, 2014 and Sharma et al.,**

2023). According to a number of studies, humic acid enhances nitrogen use efficiency (NUE), reduces nitrogen leaching, and increases maize production and nitrogen uptake (**Azeem *et al.*, 2014, Kong *et al.*, 2022 and Brodowska *et al.*, 2023**) . In conclusion, humic acid seems to be a useful tool for improving nitrogen management in maize agrosystems.

The primary aim of this research is to investigate the influence of varying nitrogen fertilization rates, in conjunction with the application of potassium humate to the soil and zinc spray on the leaves, on the yield of maize cultivated in the Kharga oasis of Egypt. The study specifically focuses on the effects of abiotic stress factors such as high temperatures and salinity on the productivity of maize.

II. MATERIALS AND METHODS

1- Experimental Site Description and Soil Properties

A field experiment was performed to evaluate the impact of nitrogen fertilization, potassium humate addition and zinc spray on the yield and its components of maize (Single hybrid; Giza 168) at the Desert Research Center station in Kharga Oasis in the New Valley Governorate (25.52° N and 30.61° E). The experiments were conducted during the two successive seasons of 2022 and 2023. Soil and irrigation water samples were taken from the experimental site before sowing in both study seasons to estimate the physical and chemical properties.

Table 1: Physical and chemical properties of the experimental soil.

Season	**Particles (%)**			**Texture**	**EC (dS/m)**	**pH**	**Soil available nutrients (ppm)**		
	Sand	**Silt**	**Clay**				**N**	**P**	**K**
2021	77.3	15.4	7.3	sand	8.6	8.1	67	6.35	110
2022	78.5	14.9	6.6		7.8	8.3	84	7.44	123

Table 2: Analysis of irrigation water

Season	**pH**	**E.C.** ds/m	**S.A.R**	**Soluble cations (meq/l)**				**Soluble anions (meq/l)**			
				Ca^{++}	**Mg^{++}**	**Na^{+}**	**K^{+}**	**CO$_3^{=}$**	**HCO$_3^{-}$**	**SO4$^{=}$**	**Cl^{-}**
2021	7.84	3.38	6.86	13.68	2.74	14.82	0.41	-	5.43	4.37	9.47
2022	7.79	3.32	6.14	15.32	2.93	14.51	0.45	-	5.69	4.76	10.24

Kharga oasis is characterized by a tropical arid climate. The mean annual temperature is 25°, average mean temperature is 12°C and the average maximum temperature is 41°C. The maximum absolute temperature is 52°C which usually occurs in August and the absolute minimum temperature is 2°C which usually occurs in January. August is typically a low-wind month; from November to January, wind speed gradually increases, peaking from March to May and producing the infamous "El-Khamasin" dust storms. The relative humidity has an annual mean value of roughly 39%. In general, atmospheric precipitation in the form of rainfall is incredibly rare (1 mm/year) with heavy rainstorms from time to time.

2. Experimental Design and Layout

The experimental treatments were set up in a split-plot design with four replications. In comparison to the control, the main plots represented the addition of potassium humate ($C_9 H_8 K_2 O_4$) to the soil at a rate of 20 kg/ha which was added three times with the N fertilization, and the application of chelated zinc spray at a rate of 250 g/100 L of water (in the form of 15% EDTA-$ZnNa_2$ ($C_{10}H_{12}N_2O_8ZnNa_2$), or 375 ppm, at three times i.e., 3,5 and 7 weeks after sowing. Sub-plots were occupied by four N fertilizer levels: 100 kg/ha, 200 kg/ha, 300 kg/ha, and 400 kg/ha. Nitrogen was supplied in three doses within 35 days of sowing, or until the 7–8 leaf stage of maize growth.

Maize was sown under drip irrigation system in ridges with 70 cm apart and 4 m in length (plot area was 28 m^2). Sowing was in hills, on one side of the ridge (the distance between hills was 25 cm)

The sowing was carried out at the first week of August in both seasons, according to the suitable sowing time of the study region. After soil preparation, The conventional crop practices of the region were applied in both seasons. P was applied in the form of calcium monophosphate (15.5% P_2O_5) at the rate of 350 Kg/ha, while N was applied in the form of Ammonium nitrate (33.5% N) and K was applied in the form of potassium sulfate (48% K_2O) at the rate of 125 Kg /ha. Experimental units were kept weed-free through hand hoeing at early stages and hand pulling at later stages to eliminate the weed effect.

3. Studied Characters and Measurements

The harvesting was performed on the same time in each treatment, where the grains moisture content was between 20% and 30%, according to the conventional harvesting practices in the region . Grain yield (Kg/ha) was determined from four inner guarded ridges of each plot and transformed to yield/ha. The yield components i.e., Plant height (cm), ear height (cm), Ear length (cm), Ear diameter (cm), number of rows per ear, number of grains per row and 100-grains weight (g) were calculated in samples of 10 plants:

4. Statistical Analysis

The data were analyzed using SPSS (version 20), and treatment means were compared using the least significant difference (LSD 0.05) for the individual factors as well as the interaction.

III. RESULTS AND DISCUSSION

1- Impact of Potassium humate and zinc application

Table 3 illustrates the impact of applying Zn and potassium humate on maize yield parameters. Notably, the most noteworthy outcomes in terms of plant height were observed during both the first and second seasons when both potassium humate and Zn were applied together. The plant height values recorded were 233.5 cm and 220.5 cm, respectively, surpassing the results obtained from individual applications. These findings strongly indicate that the combined use of potassium humate and Zn exhibits a synergistic impact on enhancing the growth of maize, specifically in relation to plant height.

Table 3. Effect of Zn and potassium humate application on maize growth parameters in the two studied seasons.

Treatment	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	No. of grains/row	100-grain weight (g)	Grain yield (kg/h)
The first season 2022								
Control	226.9 c	127.3 c	21.25 c	15.17 b	13.83 a	39.33 c	31.17 c	7528 d
Zn	229.5 b	129.8 b	22.21 b	15.63 ab	14.17 a	41.33 b	33.33 b	8773 b
P.H.	229.0 b	128.9 b	21.42 c	15.67 ab	14.58 a	39.92 c	32.33 a	8273 c
P.H.+Zn	233.5 a	132.6 a	23.92 a	15.96 a	14.67 a	43.67 a	33.42 b	10436 a
The second season 2023								
Control	218.4 b	117.5 c	21.77 b	19.23 c	14.08 b	39.25 c	29.33 c	7657 d
Zn	213.8 c	118.0 b	21.10 bc	19.81 b	14.42 ab	40.58 b	31.50 b	8675 b
P.H.	208.0 d	114.9 d	20.63 c	20.00 ab	14.42 ab	39.33 c	30.92 b	8456 c
P.H. +Zn	220.5 a	123.7 a	23.99 a	20.23 a	14.75 a	42.00 a	32.37 a	10590 a

In terms of ear height of maize, the highest significant values in both seasons were achieved by applying both potassium humate and Zn. The ear height in the first season was 132.6 cm, while in the second season it was 123.7 cm. Regarding of ear length, the most significant increase was observed when also applying both potassium humate and Zn in both seasons. During the first season, the ear length measured 23.92 cm, while in the second season it reached 23.99 cm.

During the first season, there was no significant variability in ear diameter when Zn and potassium humate were applied either individually or in combination, with values ranging from 15.63 to 15.96 cm. However, in the second season, the application of potassium humate and a combination of potassium humate and Zn resulted in significantly higher values of 20 and 20.23 cm, respectively. This demonstrates the positive impact of these treatments on ear diameter growth.

There was no consistent trend observed in the number of rows per ear in both seasons. However, there was a clear trend in the number of grains per ear. The application of potassium humate and Zn resulted in the highest significant values of 43.67 and 42.0 in the first and second seasons, respectively. This suggests that the use of potassium humate and Zn can positively impact the number of grains per ear in maize crops.

In terms of 100-grain weight, the highest significant value was observed in the first season with the application of potassium humate, yielding a value of 32.33 g. Interestingly, in the second season, the combination of potassium humate and Zn application resulted in an even higher significant value of 32.37 g. This suggests that the combined application of potassium humate and Zn may have a synergistic effect on grain weight.

Regarding maize grain yield, the highest significant values were observed in both seasons when potassium humate and Zn were applied together, outperforming individual applications. During the first season, the combined application resulted in a yield of 10,436 kg/ha, while in the second season, the yield reached 10,590 kg/ha.

The results suggest that the synergistic effect of potassium humate and Zn on maize grain yield is particularly strong when applied together. The combined application seems to have a positive impact on plant growth, development, and ultimately yield. Potassium humate, derived from natural organic matter, acts as a soil conditioner, enhancing soil structure and promoting nutrient uptake by the roots (Kumar *et al.*, 2013; Ibrahim and Ali, 2018; Jin *et al.*, 2022). This leads to improved water retention in the soil, increased availability of essential nutrients like nitrogen, phosphorus, and potassium, and enhanced microbial activity (Gatabazi, 2014; Kumar *et al.*, 2022). Zn plays a crucial role in plant development, especially in photosynthesis and enzyme activation (Solanki, 2021; Khan *et al.*, 2022). By applying potassium humate and Zn together, farmers can ensure that their crops receive all the necessary elements for healthy growth and maximal productivity. The improved yield can be attributed to the enhanced nutrient uptake and utilization, as well as the stimulation of plant metabolism by potassium humate and Zn.

2- Impact of nitrogen fertilization

Table 4 presents the impact of N application rates on maize growth parameters. In terms of plant height, the most significant increase in the first season was observed with the application of 400 kg N/ha, resulting in a height of 226.5 cm. During the second season, application rates of 300 and 400 kg N/ha produced statistically similar results, with plant heights of 215.9 cm and 216.9 cm, respectively. These results suggest that higher N application rates can lead to increased plant height in maize. However, there may be a point of diminishing returns, as the difference in plant height between the 300 kg N/ha and 400 kg N/ha treatments was not statistically significant in the second season.

Table 4. Effect of nitrogen application rate on maize growth parameters in the two studied seasons.

N levels	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	No. of grains/row	100-grain weight (g)	Grain yield (kg/h)
The first season 2022								
100 kg	226.7 c	127.9 c	21.13 b	15.29 b	14.58 a	38.17 c	31.33 c	7936 d
200 Kg	231.1 b	130.8 b	22.67 a	15.50 ab	14.33 a	40.83 b	33.08 b	8581 c
300 Kg	234.7 c	132.7 a	22.58 a	15.96 a	14.25 a	43.75 a	31.50 c	9423 a
400 Kg	226.5 a	127.3 c	22.42 a	15.67 ab	14.08 a	41.50 b	34.33 a	9070 b
The second season 2023								
100 kg	214.3 b	117.0 c	21.29 a	19.58 b	14.58 a	38.83 c	30.65 a	8322 d
200 Kg	213.8 b	117.9 c	21.75 a	19.83 ab	14.42 a	40.83 b	31.38 a	8840 c
300 Kg	215.9 a	119.1 b	21.81 a	19.83 a	14.33 a	43.25 a	31.08 a	9196 a
400 Kg	216.9 a	120.8 a	21.69 a	19.85 ab	14.33 a	38.25 c	31.38 a	9020 b

During the first season, the highest significant value for ear height was achieved by applying 300 kg N/ha, resulting in a height of 132.7 cm. In contrast, the highest value in the second season was attained by applying 400 kg N/ha, resulting in a height of 120.8 cm. However, there was no distinctive trend in terms of ear length, ear diameter, and number of rows per ear in both seasons. This suggests that while N application had a clear impact on ear height in both seasons, it did not have a consistent effect on other important maize yield components such as ear length, diameter, and number of rows per ear. This could indicate that factors other than N levels may be influencing these traits in the maize plants, highlighting the complexity of plant growth and development.

In terms of the number of grains per row, the highest significant values were achieved in both seasons by applying 300 kg N/ha, with values of 43.75 and 43.25, respectively. Additionally, the highest significant value for 100-grain weight in the first season was achieved by applying 400 kg N/ha, with a value of 34.33 grams. However, there was no specific trend observed in the second season. This suggests that the application of 300 kg N/ha is optimal for maximizing the number of grains per row in both seasons. However, when it comes to 100-grain weight, a higher rate of nitrogen application (400 kg N/ha) may be more beneficial in certain circumstances, such as in the first season. The lack of a specific trend in the second season could indicate that other factors may have influenced the results, and further investigation may be needed to determine the most effective nitrogen application rate for that particular season.

The highest significant grain yield in both seasons was achieved by applying 300 kg N/ha, with values of 9423 and 9196 kg/ha in the first and second seasons, respectively. It is noteworthy that this treatment resulted in a higher yield than applying 400 kg N/ha. This may be attributed to the fact that higher doses of N can impair yield through various mechanisms. One possible explanation for the lower yield with 400 kg N/ha could be N toxicity, where excessive N can lead to imbalances in nutrient uptake and negatively impact plant growth (Vitousek *et al.*, 2009; Guo *et al.*, 2019; Aliyu *et al.*, 2021). Additionally, high levels of N can also contribute to increased susceptibility to diseases and pests (Szulc *et al.*, 2008; Huber *et al.*, 2012; Veromann *et al.*, 2013; Virla *et al.*, 2023).

Impact of interaction between potassium humate, Zn, and nitrogen application

Table 5 shows the influence of the interaction effect between potassium humate, Zn, and N application rate on maize growth parameters. In terms of plant height, the most significant values were observed in both seasons when applying 300 kg N/ha in conjunction with potassium humate and Zn. The plant height reached 243.7 cm in the first season and 229.7 cm in the second season under these conditions. This suggests that the combination of 300 kg N/ha with potassium humate and Zn had a positive impact on the growth and development of maize plants, resulting in taller plants compared to other treatments. The significant increase in plant height could be attributed to the synergistic effects of nitrogen, potassium humate, and Zn on promoting nutrient uptake, photosynthesis, and overall plant health.

Table 5. Effect of the interaction between potassium humate, Zn, and nitrogen application rate on maize growth parameters in the two studied seasons.

Zn + P.H treatments	N	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	No. of rows/ear	No. of grains/row	100-grain weight (g)	Grain yield (kg/h)
The first season 2022									
Control	100	222.3 g	127.0 e	19.83 i	15.00 bc	13.58 a	33.67 g	30.00 f	6964 i
	200	228.3 de	127.0 e	21.67 efg	14.83 c	13.67 a	40.67 cde	31.67 ef	7305 h
	300	229.6 cde	129.0 cde	21.33 fgh	15.50 abc	13.67 a	41.00 cde	33.00 cde	7954 fg
	400	227.3 def	126.3 e	22.17 cdefg	15.33 abc	13.58 a	42.00 cd	30.00 f	7891 g
Zn	100	227.0 defg	129.3 cde	21.50 fgh	15.67 abc	14.67 a	38.67 ef	33.00 cde	8215 f
	200	229.3 cde	130.0 cde	22.00 defg	15.33 abc	14.58 a	40.67 cde	34.00 bc	8215 f
	300	234.0 bc	132.7 bc	22.17 cdefg	15.83 abc	14.33 a	45.00 ab	35.33 ab	9465 cd
	400	227.7 def	127.3 de	23.17 bcd	15.67 abc	13.67 a	41.00 cde	31.33 ef	9197 d
P.H.	100	226.3 efg	127.3 de	20.17 hi	15.33 abc	15.67 a	37.00 f	31.33 ef	7096 hi
	200	230.3 cde	129.7 cde	22.50 cdef	15.33 abc	13.67 a	39.00 ef	33.00 cde	8020 fg

	300	231.3 cd	131.0 cd	22.17 cdefg	16.17 abc	14.67 a	43.33 abc	33.00 cde	9296 cd
	400	228.0 de	127.7 de	20.83 ghi	15.83 abc	14.33 a	40.33 de	32.00 de	8678 e
P.H.+ Zn	100	231.0 cde	128.0 de	23.00 cde	15.17 abc	14.58 a	42.67 bcd	31.67 ef	9469 c
	200	236.3 b	136.3 ab	24.50 ab	16.33 ab	14.67 a	43.33 abc	33.67 bcd	10784 a
	300	243.7 a	138.0 a	24.67 a	16.50 a	14.33 a	45.67 a	36.00 a	10978 a
	400	223.0 fg	128.0 de	23.50 abc	15.83 abc	14.33 a	43.00 abcd	32.00 de	10512 b
The second season 2023									
Control	100	209.7 ef	113.0 gh	21.58 abcd	18.83 c	14.00 a	36.67 e	28.17 e	6917 g
	200	216.3 d	115.7 fg	21.67 abcd	19.33 bc	14.00 a	41.00 bcd	30.00 cde	7873 ef
	300	221.3 c	121.3 cd	22.00 abcd	19.42 bc	14.00 a	42.33 ab	30.00 cde	7936 ef
	400	226.3 ab	120.0 de	21.83 abcd	19.33 bc	14.33 a	37.00 e	29.17 de	7903 ef
Zn	100	209.7 ef	113.0 gh	20.75 bcd	19.83 ab	14.67 a	39.33 cde	30.83 bcd	8396 d
	200	211.3 ef	118.0 ef	20.83 bcd	19.67 abc	14.33 a	40.67 bcd	31.67 abc	8396 d
	300	221.3 c	122.0 bcd	21.58 abcd	19.92 ab	14.33 a	43.00 ab	32.17 abc	9020 c
	400	213.0 de	122.0 bcd	21.25 abcd	19.83 ab	14.33 a	39.33 cde	31.33 abcd	8889 c
P.H.	100	199.7 g	112.0 h	20.00 d	19.83 ab	15.00 a	37.67 e	30.33 bcde	7870 f
	200	208.0 f	112.0 h	20.33 cd	19.83 ab	13.00 a	38.67 de	30.50 bcd	8330 de
	300	213.0 de	120.3 cde	21.17 abcd	20.25 ab	14.33 a	43.33 ab	31.83 abc	8965 c
	400	212.0 ef	115.3 fg	21.00 abcd	20.08 ab	14.33 a	37.67 e	31.00 abcd	8659 cd
P.H.+ Zn	100	213.0 de	121.0 cde	22.58 abc	19.83 ab	14.67 a	39.00 cde	31.63 abc	10105 b
	200	216.3 d	123.3 abc	23.33 a	20.43 b	15.33 a	43.00 ab	32.25 abc	10762 a
	300	229.7 a	125.3 a	23.42 a	20.50 b	14.67 a	44.33 a	33.17 a	10861 a
	400	223.0 bc	125.0 ab	22.83 ab	20.17 ab	14.33 a	41.67 ab	32.42 ab	10631 a

Significant improvements in ear height were observed when applying either 200 or 300 kg N/ha in combination with potassium humate and Zn. In the first season, ear heights reached 136.3 and 138 cm, while in the second season, they measured 123.3 and 125.3 cm, respectively. Similarly, these treatments also led to the highest significant values in ear length during the first season, with measurements of 24.5 and 24.67 cm. However, no specific trend was observed in the second season. These results suggest that the combination of nitrogen, potassium humate, and Zn can have a positive impact on ear height and length in maize crops. The significant improvements seen in the first season indicate that these treatments can potentially enhance the growth and development of maize plants. However, the lack of a specific trend in the second season suggests that other factors may have influenced the results.

In terms of ear diameter, number of rows per ear, and number of grains per row, no significant trends were observed among the treatments. However, during the first season, the weight of 100 grains showed a notable result with the highest significant value of 36 grams in the treatment involving the application of 300 kg N/ha along with potassium humate and Zn. Conversely, no specific trend was evident in the second season. This suggests that the combination of 300 kg N/ha, potassium humate, and

Zn had a positive impact on grain weight in the first season. However, it is important to note that this trend was not consistent in the second season, indicating that other factors may have influenced the results.

The highest grain yields in the first season were achieved by applying either 200 or 300 kg N/ha along with potassium humate and Zn. Specifically, the grain yields in these treatments were 10,784 and 10,978 kg/ha, respectively. In the second season, applying 200 or 300 kg N/ha along with potassium humate and Zn, as well as applying 400 kg of N/ha, resulted in statistically similar values. The grain yields in these treatments were 10,762, 10,861, and 10,631 kg/ha, respectively.

These results suggest that the combination of 200 or 300 kg N/ha with potassium humate and Zn is effective in maximizing maize grain yields in the first season. However, in the second season, applying 400 kg of N/ha also produced comparable results. This indicates that there may be different optimal nutrient levels depending on the growing conditions and needs of the maize crop. Further research could help determine the most cost-effective and sustainable approach to achieving high grain yields consistently across seasons.

The relationship between potassium humate, Zn, and N is intricate and can significantly influence plant growth. Potassium humate has been shown to boost the absorption and utilization of Zn in plants, resulting in enhanced growth and yield (Ozkutlu *et al.*, 2006; Kumar and Singh, 2017; Rahi *et al.*, 2021). Furthermore, potassium humate can mitigate nutrient imbalances and deficiencies that may arise in the presence of N (Petrus *et al.*, 2010; El-Naqma, 2020; Aljoubory and Al-Yasari, 2023). On the other hand, N plays a role in facilitating the efficient uptake of Zn by plants and utilizing potassium humate for improved growth and development (Nawaz *et al.*, 2012; Kumar and Singh, 2017; Montoya *et al.*, 2020; Aljoubory and Al-Yasari, 2023). This interplay between these elements underscores the importance of understanding their interactions for optimizing plant health and productivity.

IV. CONCLUSION

The impact of potassium humate, zinc spray, and nitrogen fertilization on maize yield and its components in Kharga oasis, Egypt, was found to be significant. The study revealed that the combination of potassium humate and zinc spray resulted in higher yields compared to other treatments. Additionally, the application of 300 kg/ha of nitrogen fertilizer also contributed to increased yields. Interestingly, there was no significant difference in yield when different levels of nitrogen (100, 200, and 300 kg/ha) were combined with potassium humate and zinc spray. These findings suggest that maize plants exhibited a clear response to the applied nutrients. However, it is worth noting that the highest application of nitrogen fertilizer led to a lower grain yield, indicating a potential loss of nitrogen fertilizers.

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