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Growth and Productivity of Maize (*Zea mays*) Using Gibberellic Acid 3 (GA3) with Different Planting Distances in a Clay Condition at Cabagan, Isabela, Philippines

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ABSTRACT

Maize is a global staple food widely used as animal feed, biofuel, and a raw material in various industries. Gibberellic Acid 3 (GA3) is crucial in regulating plant growth. This study aimed to evaluate the impact of GA3 concentrations and planting distances on maize productivity, providing insights to optimize production for quality and profitability. The experiment was conducted at the ISU Compound, Cabagan, Isabela, from March to July 2023. It is a 4 × 2 factorial in a Randomized Complete Block Design (RCBD) with eight treatment combinations and three replications. Factor A consisted of four GA3 concentrations (control, 175 mL, 200 mL, and 225 mL), while Factor B included two planting distances (20 cm × 20 cm and 20 cm × 25 cm). Data were analyzed using two-way ANOVA and Tukey's LSD at a significance level of $P < 0.05$. Results indicated that GA3 application significantly influenced plant height (PH), demonstrating that higher concentrations of GA3 promoted greater vegetative growth, while the other parameters were not significantly affected. Meanwhile, the computed yield (CY) was significantly affected by planting distance and the interaction effect between GA3 concentration and spacing. The combination of 175 mL GA3 application with a 20 cm × 25 cm planting distance resulted in the highest yield, suggesting that this treatment enhances maize productivity while maintaining efficient plant spacing. Thus, it is recommended for optimizing maize production, ensuring better growth performance, and higher economic returns.

Keywords: Distance of planting, gibberellic acid 3, maize, tassel

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INTRODUCTION

Maize (*Zea mays*) is the third-largest plant-based food source in the world, serving as a primary food source for both humans and animals. Despite its importance, farmers and the agricultural sector face persistent challenges related to low productivity. Various strategies have been proposed to address this issue and enhance maize productivity, with the adoption of plant growth regulators like Gibberellic Acid 3 (GA3) emerging as a promising study area. Maize experiences several factors, such as environmental conditions, pest infestations, and nutrient deficiencies, contributing to reduced productivity. Thus, it is imperative to research to identify viable approaches to enhance maize productivity and increase yields (Singh, 2010; Turner et al., 2014).

Department of Agriculture Regional Field Office III, six hundred thousand (600,000) farms household depend on maize as their major source of livelihood and in line with this, Isabela and Bukidnon are the top maize producing province in the Philippines contributing a total production of 1.1 million metric tons and 0.8 million metric tons (Salazar et al., 2021). Reyes et al. (2009) stated that the province of Isabela was named the top maize producer in the country. It had consistently been a top producer throughout the years, with a proportion of national output ranging from 9 to 16 percent. All over the Philippines, the estimated production based on the standing crop from April to June 2024 is projected to decrease to 1.19 million metric tons. This represents a 19.1 percent decline from the actual production of 1.47 million metric tons recorded during the same period in 2023 (Philippine Statistics Authority, 2024). Due to dry periods at the beginning of the year and flooding in September and December, Isabela was forced to settle for second place in the race for grain output.

On the other hand, one of the approaches proposed to enhance maize productivity is using plant growth regulators, such as Gibberellic acid. GA3 is a naturally occurring plant hormone that promotes plant growth and development, and it has been shown to enhance the growth and yield of maize crops (Gao et al., 2020; Al-Shaheen & Soh, 2018). However, the effect of GA3 application is influenced by other factors, such as planting distance. While GA3 is known for its potential to enhance crop growth and development by improving parameters such as stem elongation, leaf expansion, and overall plant vigor (Camara et al., 2018; Anjum et al., 2017; Mahender et al., 2015), its efficacy can vary depending on plant spacing in the field. Proper planting distance is essential because it affects light interception, nutrient availability, and the overall microclimate around each plant. Inadequate spacing can lead to competition among plants for resources, potentially reducing the impact of GA3 application on individual plants. Conversely, optimal spacing can ensure that each plant receives adequate resources, maximizing the benefits of GA3 in promoting growth and increasing yields (Noda-Leyva & Martin-Martin, 2017). Despite this, the interaction between the GA3 application and different planting distances, particularly in specific soil conditions like clay, has not been thoroughly investigated. Furthermore, one study investigated the impact of exogenous GA3 application on maize under salinity stress. GA3 application improved plant growth by enhancing chlorophyll content, reducing sodium (Na^+) accumulation, and increasing potassium (K^+) concentration. It improved photosynthetic efficiency and ionic balance, leading to better growth and yield under stress conditions. In contrast, the combined effects of GA3 and foliar application on maize seedlings under varying salinity levels enhanced antioxidant enzyme activities, reduced oxidative damage, and nutrient uptake, and modulated stress responses and metabolic processes (Mukarram et al., 2021; Shahzad et al., 2021). Additionally, research on the application of GA3 and mepiquat chloride (M.C) as growth regulators showed that foliar application of 100 ppm GA3 significantly increased grain yield by 33% compared to the control and mitigates salt stress by enhancing chlorophyll content, soluble protein levels, and ion balance, thereby improving overall plant health and productivity (El-Nwehy & Afify, 2023).

Maize has become popular among farmers due to its superior qualities, such as improved yield, resistance to pests and diseases, and adaptability to various environmental conditions (Frank et al., 2013). However, the productivity of maize can be further enhanced by optimizing cultivation practices, including applying growth regulators such as GA3 and appropriate planting distance.

Thakur et al. (2018) investigated the impacts of GA3 and planting distances on sweet william (*Dianthus barbatus* L) growth and yield. Their findings suggest that applying GA3 alongside planting distance increased yield, flowering, and plant height. Nevertheless, by identifying the most efficient cultivation methods, this study assesses how Gibberellic Acid 3 (GA3) and various planting distances influence maize productivity, aiming to offer insights for optimizing production in terms of quality and profitability.

METHODOLOGY

Study Area

The experiment was conducted at the Experimental Field Area of the College of Agricultural Sciences and Technology at Isabela State University, Cabagan Campus (ISUC), located in Cabagan, Isabela, Philippines, at coordinates 17.4144° N latitude and 121.7670° E longitude. The study was carried out during the summer season, from March to July 2023, when the climatic conditions during the study period were marked by variations in rainfall, temperature, and relative humidity, which influenced maize growth and development. Insufficient precipitation was recorded during the 1st, 5th, 8th, and 12th weeks after sowing, with an average rainfall of only 1.32 mm. Temperature patterns showed an average minimum temperature of 24.77°C and a maximum temperature of 35.21°C from the 1st to the 9th week after sowing. However, during the critical reproductive stages (10th to 14th weeks after sowing), temperatures slightly increased, averaging a minimum of 25.78°C and a maximum of 35.56°C. These conditions persisted through the later stages of crop development. During the reproductive (dough) stage at 13 weeks after sowing, an average rainfall of 1.38 mm was recorded. This low water availability was not ideal, as it limited water absorption, potentially leading to smaller and immature kernels.

Experimental Design, Soil Sampling and Treatments

The field experiment encompassed an area of 341 square meters divided into three blocks, each subdivided into eight equal plots, each measuring 3 meters by 3 meters. There were 1.0-meter alleyways between the blocks and plots. Soil samples were collected from 6 to 8 inches, with composite samples representing the entire experimental area prepared after removing debris, weeds, and topsoil. The collection process involved using a shovel, bolo, and post-hole digger, and the samples were transported in pails. These samples were then pulverized and air-dried for seven days. Uniform 1-kilogram samples were obtained using the quartering technique and sent to the Department of Agriculture-Soil Laboratory-Cagayan Valley Research Center (DA-SL-CVRC) in San Felipe, Ilagan, Isabela, for analysis. Based on the soil analysis recommendations, both inorganic and organic fertilizers were applied. Organic fertilizers included carbonized rice hull and vermicompost, administered at 450 grams per plot. The inorganic fertilizers used were Urea (46-0-0), Muriate of Potash (0-0-60), and Complete Fertilizer (14-14-14), applied at rates of 58.5 grams, 31.5 grams, and 256.95 grams per plot, respectively.

The experiment was structured as a 4 × 2 randomized complete block design (RCBD), incorporating a two-factorial approach to assess the impact of different treatments on crop growth under varying stress conditions. Factor A focused on evaluating the effects of varying concentrations of gibberellic acid (GA3) with four distinct treatments: (1) A1: without GA3 (WOG), (2) A2: 175 mL of GA3 per hectare (175GA3), (3) A3: 200 mL of GA3 per hectare (200GA3), and (4) A4: 225 mL of GA3 per hectare (225GA3). The control group (A1) was essential in establishing a baseline for comparison, as no GA3 was applied to this treatment. This allowed the researchers to isolate and quantify the specific influence of GA3 application on maize growth and yield. The decision to exclude GA3 in the control group was crucial for understanding the natural growth response of maize under the given environmental conditions. By comparing the untreated plants (WOG) with those subjected to different GA3 concentrations, the researchers could assess how much GA3 influenced key growth parameters such as plant height, biomass accumulation, flowering time, and grain yield. Without a control group, it would be challenging to determine whether observed differences were due to GA3 application or other environmental or genetic factors. Additionally, including a control group aligns with experimental best practices, ensuring that any potential benefits or drawbacks of the GA3 application are accurately measured. It also provides practical insights into whether the GA3 application is necessary under field conditions, helping to inform future agronomic recommendations. Factor B investigated the effects of planting distance on crop growth, with two treatments: (1) B1: 20 cm × 20 cm (PD20) and (2) B2: 20 cm × 25 cm (PD25). This factor aimed to understand how spacing influenced the growth parameters and overall yield of the crops.

Planting, Planting Materials, Care, and Maintenance of Plants

The necessary materials for the study were obtained from multiple sources. Complete Fertilizer (14-14-14), Urea (46-0-0), Muriate of Potash (0-0-60), and insecticides were procured from Agricultural Supply in Ugad Cabagan, Isabela. The maize seed variety used in the study was NK6410, selected for its maturing characteristics 100-105 days after planting (DAP) and its potential yield of 12 metric tons per hectare (MT/ha). This variety is suitable for a wide range of regions, including the Cagayan Valley (Lower Vega), Ilocos Region, Central Luzon, South Luzon, Bicol Region, and Mindanao Low Elevation. NK6410 is renowned for its Class A grain quality, good standability, and ease of dehusking and harvesting. GA3 was sourced from an authorized online retailer. The ISUC nursery provided vermicast, a hand tractor, a wheelbarrow, garden tools, placards, pegs, a meter stick, and a sprayer. Land preparation involved plowing the field twice with a four-wheeled tractor, followed by a final harrowing one week before planting. After removing debris and weeds, the soil was further conditioned using a hand tractor. The experimental site was divided into three columns and eight rows, creating plots that measured 3 by 3 meters, marked with basic farming tools. The soil was then levelled using a garden rake in preparation for planting. Maize seeds were planted in furrows at 2–5 cm. Each subplot contained 10 rows and 13 hills, with 130 seeds per plot (2 seeds per hill). There was a 20 cm interval between hills and a 25 cm gap between rows. Due to poor germination, particularly with the NK6410 variety, to ensure uniform plant density, an alternative approach to replanting is to initially sow multiple seeds per hill and thin excess seedlings after germination. GA3 was applied via foliar spraying at 30 DAS, diluting each concentration in 115.2 mL of water. Irrigation was conducted every five days using a submersible pump. Weed management was performed manually using a hand trowel, while initial infestations of fall armyworm were controlled through hand-picking. At maturity, maize cobs were harvested by hand, followed by manual threshing to remove the husks and separate the kernels. The kernels were sun-dried until they attained a 12%–14 % moisture content.

General Observation and Collection of Data

The data collection process was comprehensive, encompassing a range of growth parameters to provide a holistic view of the crop performance under the different treatments. The samples are randomly selected, 10 per plot, in all the parameters, such as Plant height

(PH), which was measured from the base of the culm to the tip of the highest leaf using a meter stick, 10 days after the GA3 application, to assess the initial response of the plants to the hormone. Leaf count (LC) was recorded post-GA3 application to gauge the vegetative growth stimulated by the treatments. The ear length (EL) was measured from the base to the tip of the de-husked maize cobs to determine the effect of the treatments on reproductive growth. Ear diameter (ED) was measured using a caliper, providing insights into the physical development of the maize ears. Computed yield (CY) was determined by weighing the harvested marketable dry kernels from each treatment and converting the weight to a per-hectare basis, offering a standardized measure of productivity. Biomass yield (BY) was obtained by weighing the fresh uprooted maize plants, including the ears, to assess the overall biomass produced. The kernels weight at 1000 (KW) were measured after drying and randomly selecting kernels from each treatment, providing a detailed understanding of kernel weight and potential yield quality.

Data Analysis

The analysis was conducted using a two-factorial analysis of variance (ANOVA) to evaluate the effects of GA3 application and different planting distances on the growth parameters of maize. This method was chosen because it allows for assessing both main effects and interactions between the factors. Before performing ANOVA, key assumptions—normality of residuals, homogeneity of variances (Levene's test), and independence of observations—were checked to ensure the validity of the analysis. Tukey's Honestly Significant Difference (HSD) test was used as a post-hoc analysis to determine significant differences among treatment means. Tukey's HSD was selected for its ability to control the family-wise error rate while performing multiple comparisons, making it suitable for detecting pairwise differences among treatments without inflating the Type I error rate. The results were reported as mean ± standard deviation (SD), with statistical significance at $P < 0.05$. This rigorous statistical approach ensured that the conclusions drawn from the study were robust, providing valuable insights into the effects of GA3 application and planting distance on maize growth under varying conditions.

RESULTS AND DISCUSSION

Plant Height (cm)

In the study on maize in PH, as shown in Table 1, the application of different gibberellic acid (GA3) concentrations was analyzed and compared using ANOVA. The findings revealed that treatments with 175 mL, 200 mL, and 225 mL of GA3 per hectare (175GA3, 200GA3, 225GA3) resulted in significantly increased plant heights of 105.2 ± 3.06 cm, 112.2 ± 10.02 cm, and 108.0 ± 5.84 cm, respectively. These heights were statistically similar but

Table 1
Effects of various parameters in different concentrations of GA3 in maize

FACTOR A	PH (cm)	LC (cm)	EL (cm)	ED (mm)	BY (g)	KW (g)	CY (kg/ha)
WOG	83.3 ± 18.19[b]	7.70 ± 0.66	11.83 ± 0.38	36.97 ± 0.83	2696.67 ± 188.71	280.50 ± 6.13	2477.78 ± 152.68
175GA3	105.2 ± 3.06[a]	8.45 ± 0.10	11.44 ± 0.01	36.03 ± 0.11	2439.00 ± 68.96	281.60 ± 6.96	2260.74 ± 64.35
200GA3	112.2 ± 10.02[a]	8.37 ± 0.02	11.74 ± 0.29	34.99 ± 1.15	2489.83 ± 18.13	266.17 ± 8.21	2332.22 ± 7.13
225GA3	108.0 ± 5.84[a]	8.90 ± 0.55	10.78 ± 0.67	36.56 ± 0.42	2406.33 ± 101.63	269.50 ± 4.88	2229.63 ± 95.46

Note. g: kilogram, ha: hectare, WOG: Without GA3, 175GA3: 175 mL of GA3 per hectare, 200GA3: 200 mL of GA3 per hectare, 225GA3: 225 mL of GA3 per hectare, PH: plant height, LC: leaf count, EL: ear length, ED: ear diameter, BY: biomass yield, CY: computed yield and KW: kernel weight of 1000. The different factors are presented along with their respective standard deviations (SD) using the mean ± standard deviation, followed by different subscript letters (e.g., a, b) used to denote significant differences at a 5% probability level

markedly different from the control group (WOG), which had a significantly lower plant height of 83.3 ± 18.19 cm. This suggests that the application of GA3 promotes substantial growth in maize height. The increased plant height observed in maize treated with GA3 can be attributed to several mechanisms. GA3 stimulates cell elongation and division in the internodes, increasing stem length and overall plant height. This hormone activates gene expression in cell wall loosening and expansion, facilitating cell growth. Additionally, the GA3 application can improve nutrient uptake efficiency, providing the necessary resources for sustained growth. GA3 also interacts with other plant hormones, such as auxins and cytokinins, to regulate growth processes, ensuring balanced and optimal growth. Moreover, GA3 helps mitigate stress conditions, allowing plants to grow vigorously even under suboptimal environmental conditions. These findings align with previous research, which reported that GA3 significantly enhances plant height in tomatoes and corn, highlighting the growth-promoting effects of GA3 across different plant species (El-Sayed et al., 2014; Hadi et al., 2010).

In a study comparing the effect of different planting distances on maize in PH, as shown in Table 2, two different planting distances were tested: 20 cm × 20 cm (PD20) and 20 cm × 25 cm (PD25). The mean plant heights recorded were 101.74 ± 0.47 cm and 102.68 ± 0.47 cm, respectively. Results indicated no significant difference in plant height at 30 days after sowing (DAS) between the different planting distances. Similar findings were reported by Jiang et al. (2020), who found that planting density did not significantly affect plant height in maize.

In Table 3, the results presented the PH under different treatments involving the application of gibberellic acid (GA3) at varying concentrations and planting distances. Upon analysis, it is evident that there are fluctuations in plant height across the treatments. For

Table 2
Response of two different distances of planting in various parameters

FACTOR B	PH (cm)	LC (cm)	EL (cm)	ED (mm)	BY (g)	KW (g)	CY (kg/ha)
PD20	101.7 ± 0.47	7.93 ± 0.27	11.50 ± 0.05	35.92 ± 0.22	2288.50 ± 219.46	219.67 ± 24.71	2147.04± 178.06[b]
PD25	102.6 ± 0.47	8.46 ± 0.27	11.40 ± 0.05	36.35 ± 0.22	2727.42 ± 219.46	269.08 ± 24.71	2503.15 ± 178.06[a]

Note. kg: kilogram, ha: hectare, CY: computed yield, PH: plant height, LC: leaf count, LE: ear length, ED: ear diameter, BY: biomass yield, KW: kernel weight, PD20: 20 cm × 20 cm planting distance and PD25: 20 cm × 25 cm planting distance. The different factors and their respective standard deviations (SD) are presented using the mean ± standard deviation

Table 3
Interaction effects of different distances of planting applied with various concentrations of GA3

TREATMENT	PH (cm)	LC (cm)	EL (cm)	ED (mm)	BY (g)	KW (g)	CY (kg/ha)
WOG + PD20	163.5± 12.08	6.40± 1.84	11.87± 0.42	37.57± 1.56	2724.67± 287.97	286.00± 11.63	2494.81± 169.72[ab]
175GA3 + PD20	134.3± 17.08	8.07± 0.17	11.80± 0.35	35.36± 0.65	2668.67± 231.97	275.00± 0.63	2460.74± 135.65[ab]
200GA3 + PD20	161.7± 10.32	8.50± 0.26	12.20± 0.75	35.90± 0.11	2389.33± 47.37	285.67± 11.30	2265.93± 59.16[b]
225GA3 + PD20	147.9± 3.55	8.40± 0.16	10.68± 0.77	36.15± 0.14	2488.57± 51.87	277.00± 2.63	2255.56± 69.53[b]
WOG + PD25	149.1± 2.28	8.40± 0.16	10.55± 0.90	34.45± 1.56	2296.00± 140.70	283.00± 8.63	2195.56± 129.53[b]
175GA3 + PD25	156.6± 5.22	8.33± 0.09	11.02± 0.43	35.52± 0.49	2683.67± 246.97	249.33± 25.05	2827.41± 502.32[a]
200GA3 + PD25	147.5± 3.92	8.77± 0.53	11.39± 0.60	35.76± 0.25	1174.00± 1262.69	264.00± 10.38	1631.85± 693.24[c]
225GA3 + PD25	150.6± 0.82	9.03± 0.79	12.08± 0.63	37.37± 1.36	3068.67± 631.97	275.00± 0.63	2468.89± 143.80[ab]

Note. kg: kilogram, ha: hectare, CY: computed yield, WOG: without GA3, 175GA3: 175 mL of GA3 per hectare, 200GA3: 200 mL of GA3 per hectare, 225GA3: 225 mL of GA3 per hectare, PH: plant height, LC: leaf count, EL: ear length, ED: ear diameter, BY: biomass yield, KW: kernel weight, PD20: 20 cm × 20 cm planting distance and PD25: 20 cm × 25 cm planting distance. The different factors are presented along with their respective standard deviations (SD) using the mean ± standard deviation, followed by different subscript letters (e.g., a, b) used to denote significant differences at a 5% probability level

instance, under the same planting distance of PD20, the WOG + PD20 treatment exhibited the tallest plants with a mean height of 163.53 ± 12.08 cm, while the 175GA3 + PD20 treatment showed the shortest plants with a mean height of 134.37 ± 17.08 cm. Conversely, under the PD25 planting distance, the tallest plants were observed in the 175GA3 + PD25 treatment with a mean height of 156.67 ± 5.22 cm, whereas the shortest plants were in the 200GA3 + PD25 treatment with a mean height of 147.53 ± 3.92 cm. Interestingly, despite the variations observed, the ANOVA results indicate that the different planting distances did not significantly influence the mean PH at 30 days after sowing (DAS). The effect of GA3 on PH lies in its ability to promote cell division and elongation. GA3 stimulates the production of enzymes that loosen cell walls, allowing cells to expand more readily. This leads to increased internode length, which directly contributes to taller plants. However, the observed fluctuations in plant height across different GA3 concentrations and planting distances suggest that the response to GA3 is not linear and may be influenced by other factors such as nutrient availability, light, and the inherent genetic characteristics of the maize variety used. The tallest plants in the WOG + PD20 treatment could be attributed to the absence of exogenous GA3, allowing the plants to rely on their endogenous GA3 levels, which might be sufficient for optimal growth under the given conditions.

Leaves Count

The data presented in Table 1 (LC) highlights the impact of gibberellic acid (GA3) application on leaf count (LC) in maize, offering insights into how this plant growth regulator influences vegetative development. Upon analysis, it becomes evident that the GA3 application generally led to an increase in leaf count compared to the control (WOG, without GA3). Specifically, treatments with 175GA3, 200GA3, and 225GA3 resulted in higher mean leaf counts of 8.45 ± 0.10, 8.37 ± 0.02, and 8.90 ± 0.55, respectively, while the WOG treatment exhibited a mean leaf count of 7.70 ± 0.66. The increase in leaf count with GA3 application has practical implications for crop management and productivity. Leaves are essential for photosynthesis, the process by which plants convert light energy into chemical energy. Thus, more leaves generally mean a higher photosynthetic capacity and potentially greater biomass production (Taiz et al., 2015; Liu et al., 2010).

The results presented in Table 2 (LC) illustrate the effect of planting distance on LC in maize. Upon analysis, it is evident that there is a difference in leaf count between the two planting distances studied. Specifically, the mean leaf count for the PD20 planting distance was 7.93 ± 0.27, whereas for the PD25 planting distance, it was 8.46 ± 0.27. Despite this observed numerical difference, the Analysis of Variance (ANOVA) results indicated that the mean leaf count at 45 days after sowing (DAS) was not significantly affected by the different planting distances. The numerical increase in leaf count from PD20 to PD25 suggests that wider planting distances may provide plants with more space and resources to develop additional leaves. This finding implies that altering the planting distance could potentially enhance the photosynthetic capacity and overall vigor of maize plants. More leaves typically mean increased surface area for photosynthesis, which is crucial for the plant's energy production and growth (Lambers et al., 2019; Taiz et al., 2015).

Table 3 under LC presents the results of the effect of different treatments. Upon analysis, it is evident that the treatments and the planting distances do not impact leaf count in maize.

As per the analysis, different concentrations of GA3 and different planting distances had no significant impact on LC.

Length of Ear (cm)

Table 1 presents the effects of GA3 on the ear length (LE) of maize, revealing variations among the different treatments. Upon analysis, the control group (WOG) exhibited the longest ear length, with a mean of 11.83 ± 0.38 cm, followed closely by the 200GA3 treatment at 11.74 ± 0.29 cm. The 175GA3 treatment resulted in a slightly shorter ear length of 11.44 ± 0.01 cm, while the highest concentration (225GA3) produced the shortest ear length at 10.78 ± 0.67 cm. These findings suggest that applying GA3 at certain concentrations does not necessarily lead to an increase in ear length compared to the control, and excessive GA3 may even have adverse effects on ear development. Ear length is important in the yield component, as it directly influences the number of kernels per ear, a primary determinant of overall grain yield. A longer ear generally provides more space for kernel formation, leading to higher potential grain production. However, the non-linear response observed in this study suggests that while moderate GA3 application may support growth, excessive concentrations could disrupt natural hormonal balances, possibly leading to inefficient ear development. This trend is supported by the findings of a study by Gohil et al. (2023), which reported that higher GA3 concentrations did not necessarily increase ear length in maize. Their study observed a maximum ear length of 12.17 cm, indicating that excessive GA3 application may have a diminishing or negative effect on ear development.

The results in Table 2 illustrate the effect of Factor B, representing different planting distances, on maize ear length (LE). The findings indicate a minimal difference between the two planting distances, with PD20 producing a mean ear length of 11.50 ± 0.05 cm and PD25 showing a slightly shorter mean ear length of 11.40 ± 0.05 cm. These results suggest that modifying the planting distance from PD20 to PD25 has a marginal effect on ear length, implying that maize plants experience similar growth conditions within this range. Planting distance influences intraspecific competition for essential resources such as sunlight, nutrients, and water, impacting maize growth and yield parameters. However, in this study, the slight variation in ear length suggests that the tested planting distances provided sufficient space for maize plants to access the necessary resources without significant competition. Similar findings were reported by Yang et al. (2024), who observed that moderate adjustments in planting density had negligible effects on ear length when environmental conditions were optimized. Bi et al. (2024) highlighted that certain maize genotypes exhibit inherent resilience to planting density variations, allowing them to maintain consistent ear size even under different spacing conditions. The results of the present study align with these findings, suggesting that the observed differences in LE may be more influenced by genetic potential rather than by planting distance alone. Environmental factors such as soil fertility, moisture availability, and temperature fluctuations may also contribute to the minor variations in ear length, as supported by Ullah, Saqib, Khan et al. (2024), who found that planting distance did not significantly affect ear diameter, reinforcing the idea that within this spacing range, maize plants maintained similar growth patterns.

Table 3 presents the effects of varying gibberellic acid (GA3) concentrations and planting distances on maize ear length (LE). The data indicate that both factors influence ear development, though the impact varies across treatments. Under a planting distance of 20 cm (PD20), the control group without GA3 (WOG + PD20) exhibited a mean ear length of 11.87 ± 0.42 cm. The application of 175 mL GA3 per hectare (175GA3 + PD20) resulted in a comparable ear length of 11.80 ± 0.35 cm. Interestingly, increasing the GA3 concentration to 200 mL per hectare (200GA3 + PD20) led to a slight increase in ear length (12.20 ± 0.75 cm), while the highest concentration of 225 mL per hectare (225GA3 + PD20) resulted in a reduced ear length of 10.68 ± 0.77 cm. At a wider planting distance of 25 cm (PD25), the control group (WOG + PD25) had a mean ear length of 10.55 ± 0.90 cm. The 175GA3 + PD25 treatment showed an increased ear length of 11.02 ± 0.43 cm, and the 200GA3 + PD25 treatment further increased ear length to 11.39 ± 0.60 cm. Notably, the 225GA3 + PD25 treatment exhibited the longest ear length in this group, measuring 12.08 ± 0.63 cm. Comparing these findings with existing literature reveals both consistencies and divergences.

For instance, a study by Ullah, Saqib, Zaman et al. (2024) demonstrated that exogenous application of compounds like melatonin and sodium nitroprusside can mitigate stress effects in maize, leading to improved growth parameters, including ear length. While their focus was on stress mitigation rather than GA3 application, the positive impact on ear length aligns with the observed benefits of moderate GA3 concentrations in our study. Additionally, Ullah, Saqib, Khan et al. (2024) explored the role of sodium nitroprusside in plants and its interaction with phytohormones under various conditions. Their findings highlight the complexity of hormone interactions in plant development. This underscores the importance of optimizing hormone applications, such as GA3, to achieve desired agronomic outcomes without inducing adverse effects.

Ear Diameter (mm)

Table 1 presents the results of the effect of Factor A, likely representing different treatments on the ED in maize. There are variations in ED among the different treatments. The WOG exhibited the largest ED with a mean of 36.97 ± 0.83 mm, followed by the 225GA3 treatment with a mean of 36.56 ± 0.42 mm. However, treatments with 175GA3 and 200GA3 had slightly smaller ED, with means of 36.03 ± 0.11 mm and 34.99 ± 1.15 mm, respectively. The result indicated no significant difference in the ear diameter of maize based on the different concentrations of GA3. Several factors could contribute to these observed differences. The physiological response to GA3 may vary depending on the concentration applied, with higher concentrations potentially causing adverse effects on ear development.

Table 2 illustrates the impact of Factor B, which likely represents different planting distances, on ED in maize. There is a slight variation in ED between the two planting distances. The mean ear diameter for the PD20 planting distance is 35.92 ± 0.22 mm, whereas for the PD25 planting distance, it is slightly larger at 36.35 ± 0.22 mm. These results suggest that altering the planting distance from PD20 to PD25 may have a minimal impact on ear diameter in maize. The observed difference, while statistically significant, is relatively small, indicating that planting distance alone may not be a major determinant of ear diameter variability in maize.

Table 3 provides a comprehensive view of the effect of different treatments on ED in maize, in combination with different GA3 concentrations and planting distances. Upon thorough analysis, it is evident that the interaction of the treatments has a discernible impact on ear diameter. Comparing GA3 concentrations within the same planting distance reveals noteworthy differences in ED. For instance, under the PD20 planting distance, the treatment WOG + PD20 exhibits the largest ear diameter with a mean of 37.57±1.56 mm, while treatments with GA3 (175GA3 + PD20, 200GA3 + PD20, 225GA3 + PD20) generally show slightly smaller ED ranging from 35.36 ± 0.65 mm to 36.15 ± 0.14 mm. Similarly, under the PD25 planting distance, the control treatment WOG + PD25 displays a smaller ED of 34.45 ± 1.56 mm, whereas treatments with GA3 (175GA3 + PD25, 200GA3 + PD25, 225GA3 + PD25) exhibit larger ED ranging from 35.52 ± 0.49 mm to 37.37 ± 1.36 mm.

Biomass Yield (g)

BY obtained per plant applied with different concentrations of GA3 is shown in Table 1. WOG gave the highest BY with a mean of 2696.67 ± 188.71 g, followed by 200GA3 with 2489.83 ± 18.13 g, 175GA3 with 2439.00 ± 68.96 g, and 225GA3 with a mean of 2406.33 ± 101.63 g, respectively. However, the table showed that the mean of BY (fresh) was not significantly affected by the different concentrations of GA3. Table 2 represents the BY as affected by planting distances. The highest mean BY was recorded in PD25 with a mean value of 2727.42 ± 219.46 g, while PD20 exhibited the lowest mean BY with a value of 2288.50 ± 219.46 g. However, the results showed that the different planting distances did not significantly affect the mean biomass yield (fresh). Table 3 provides a detailed impact of different treatments, specified by Treatment, in conjunction with distinct planting distances and GA3 concentrations, on maize BY measured in grams. Upon thorough analysis, it becomes apparent that GA3 and the planting distances have notable effects on BY in maize.

When comparing treatments, there are considerable variations. For instance, under the PD20 planting distance, the control treatment WOG + PD20 exhibits a biomass yield of 2724.67 ± 287.97 g, while treatments with GA3 (175GA3 + PD20, 200GA3 + PD20, 225GA3 + PD20) generally display lower biomass yields ranging from 2389.33 ± 47.37 g to 2668.67 ± 231.97 g. Similarly, under the PD25 planting distance, there are significant differences in biomass yield among treatments. The control treatment WOG + PD25 shows a biomass yield of 2296.00 ± 140.70 g, while treatments with GA3 (175GA3 + PD25, 200GA3 + PD25, 225GA3 + PD25) exhibit a wider range of biomass yields, from 1174.00 ± 1262.69 g to 3068.67 ± 631.97 g. However, the results showed no significant difference in the effects of the different treatments.

Weight of 1000 Kernels (g)

Table 1 illustrates the impact of different concentrations of GA3 on the weight of KW. The application of GA3 at a concentration of 175 ppm resulted in the highest mean kernel weight (281.60 ± 6.96 g), slightly surpassing the control group (280.50 ± 6.13 g). Higher concentrations of GA3 (200 ppm and 225 ppm) were associated with reduced kernel weights, suggesting a potential inhibitory effect at elevated levels. However, the results indicated that these differences were not statistically significant, implying that GA3 application did not markedly influence kernel weight under the conditions tested. Similarly, variations in planting distance (PD) showed that the PD20 spacing yielded the heaviest kernels (219.67 ± 24.71 g), followed by PD25 (269.08 ± 24.71 g). Despite these observations, ANOVA results demonstrated no significant effect of planting distance on kernel weight. Furthermore, the combined treatments of GA3 application and planting distance did not exhibit significant interactions affecting kernel weight, as evidenced by the range of weights observed across different treatment combinations. The study investigating the impact of GA3 on maize under different planting dates found no significant effect on grain yield and 1000-seed weight, suggesting that factors such as planting date and environmental conditions may modulate the responsiveness of maize to GA3 application (Naghashzadeh et al., 2009). Conversely, GA3 application, particularly at optimal concentrations, can enhance growth parameters and yield attributes, including plant height, number of grains per cob, and weight (Singh et al., 2018). The lack of significant effects observed in this study could be attributed to several factors, including environmental conditions, maize variety, and the specific concentrations of GA3 used. It is possible that the maize variety employed in this experiment exhibits a limited response to GA3, or that the environmental conditions during the study were not conducive to expressing the potential benefits of GA3 application. Additionally, the timing and method of GA3 application could influence its efficacy.

Computed Yield (kg/ha)

The results in Table 1 demonstrate the impact of different concentrations of GA3 on computed yield (CY) per hectare. The WOG achieved the highest yield at 2477.78 ± 152.68 kg per hectare, followed by the 200GA3 treatment with a mean yield of 2332.22 ± 7.13 kg per hectare. The 175GA3 treatment yielded 2260.74 ± 64.35 kg per hectare, while the 225GA3 treatment had the lowest yield at 2229.63 ± 95.46 kg per hectare. Despite these differences in yield, the results indicated that the mean CY was not significantly affected by the different concentrations of GA3. These findings align with previous studies that examined the role of GA3 in maize productivity. GA3 application has been shown to enhance vegetative growth and biomass accumulation, yet its direct impact on final yield varies depending on environmental conditions and nutrient availability (Akter et al., 2014). Similarly, Shahzad et al. (2021) reported that while GA3 treatments increased maize height and biomass, yield improvements were not always statistically significant.

Table 2 focuses on the effect of planting distances on CY, showing that the PD25 planting distance resulted in the highest CY at 2503.15 ± 178.06 kg per hectare. This was higher than the yield for the PD20 planting distance, with a weighted mean CY of 2147.04 ± 178.06 kg per hectare. Results revealed that the mean computed yield per hectare was significantly affected by the different planting distances. These consistent results show that wider spacing in maize planting allows better root expansion and reduces competition for resources, resulting in higher yields (Shao et al., 2018; Gao et al., 2010). Conversely, overly dense planting (such as PD20) can lead to increased competition for light, nutrients, and water, negatively impacting yield (Postma et al., 2021).

Table 3 explores the interactive effects of varying GA3 concentrations and planting distances on CY. The highest yield was obtained from the 175GA3 + PD25 treatment, which yielded 2827.41 ± 502.32 kg per hectare. This was significantly higher than the WOG + PD20 treatment yield, which produced 2494.81 ± 169.72 kg per hectare. The yields from other treatment combinations ranged from 1631.85 ± 693.24 kg to 2827.41 ± 502.32 kg. The significant interaction between GA3 application and planting distance highlights the importance of optimizing both factors for maximum maize productivity. Rademacher (2015) demonstrated that growth regulators like GA3 can be more effective when combined with optimal plant spacing, as the availability of resources and reduced intra-species competition amplify the effects of growth-promoting hormones. This study's findings suggest that a GA3 concentration of 175 mL combined with a planting distance of 25 cm is the most effective combination for maximizing maize yield. Mahender Singh et al. 2018 investigated the effects of various gibberellic acid (GA3) concentrations on maize yield. The findings revealed that applying GA3 resulted in the highest grain yield, with 3,522 kg/ha during the kharif season and 4,277 kg/ha during the rabi season. This suggests that while GA3 application positively influences maize yield, increasing the concentration beyond a certain point does not lead to significant yield improvements.

CONCLUSION

Based on the comprehensive analysis of the results presented across various tables, it can be concluded that both gibberellic acid (GA3) application and planting distance have significant effects on various growth parameters of maize, including plant height and computed yield. GA3 application, particularly at a concentration of 175GA3, generally resulted in favorable plant height and yield outcomes. However, the influence of GA3 on other parameters, such as ear diameter and biomass yield, varied depending on the concentration used. Additionally, planting distance played a crucial role, with wider distances favoring higher plant height and yield performance. Interactions between the GA3 application and planting distance enhance the yield capability of the hybrid corn, highlighting the importance of considering both factors in optimizing maize cultivation practices. While the short-term benefits of GA3 application are evident, repeated use of growth regulators may have cumulative impacts on soil health and long-term maize productivity. Continuous application of GA3 could alter soil microbial communities, nutrient dynamics, and soil fertility, which may affect subsequent cropping cycles. Therefore, sustainable use strategies, such as periodic soil assessments and integrated nutrient management, should be explored to mitigate negative long-term effects. Further in-depth investigation is recommended using other varieties of maize to determine if there are varietal differences in the response to GA3 application and different planting distances. Additionally, maize planting is recommended at the beginning of the wet season to ensure sufficient moisture during the germination and early growth stages, further optimizing crop establishment and yield potential.

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