Impact of Zinc Application on Growth, Yield, and Quality of African Marigold in Semi-Arid Conditions

ABSTRACT

Marigold is a widely cultivated, hardy flower crop known for its adaptability.Among the various intercultural practices in marigold cultivation, foliar application of zinc plays a critical role in enhancing yield and quality,however, standardization of this practice is necessary to optimize commercial production.Hence, the investigationaimed tostandardize foliar zinc application for improving productivity in African marigold (PusaNarangiGainda) at Rajasthan Agricultural Research Institute, Jaipur, during 2020-21, and 2021-22.Two concentrations of zinc sulphate ($ZnSO_4$), Z_1 (0.2%), and Z_2 (0.5%), were applied at 35 and 65 days after transplanting (DAT) in a factorial randomized block design with three replications. Results indicated that Z_1 ($ZnSO_4$ 0.2%) was most effective in increasing plant height, and promoting early bud initiation, and flower opening, while Z_2 ($ZnSO_4$ 0.5%) significantly enhanced plant spread, primary branching, leaf dimensions, plant biomass, root-to-shoot ratio, flower diameter, and yield parameters such as flower mass and number.Z_2also improved quality traits like chlorophyll and xanthophyll content. Statistical analysis revealed significant differences among treatments, suggesting that the application of $ZnSO_4$ at 0.5% may be recommended for optimizing growth, yield, and quality in commercial marigold cultivation,thereby enhancing productivity and profitability.

Keywords: Growthattributes, Flowers,Marigold,Micronutrient,Quality traits.

1. Introduction

Marigold is a homegrown plant in South and Central America, particularly Mexico. It is a member of the Tagetes genus in the Asteraceae family(Kumar and Sharma, 2013 [22]). Among the 33 reported species of this genus, the three species most frequently cultivated are *Tageteserecta* L. (African marigold), *Tagetespatula* L. (French marigold), and *Tagetestenuifolia* L. (Striped marigold)(Joshi *et al.*, 2007[14]; Kumar and Sharma, 2013[22]). African marigoldis a diploid species of marigold (2n=24)predominantly used as a gardening plant, both in urban and rural areas for bedding and for growing in pots.This is a major flower crop grown widely in North India for their aesthetic values and income generation. For marketable purposes, the quality of flower plays a crucial role which can be fluctuated by the high and low concentration of Zn (Gupta and Kumar, 2015)[10].Its application alleviates the quality flower production and foliar application of micronutrients directly affects the growth, quality, and yield of plants

(Girwani*et al.*,1990[9];Kumar and Sharma, 2013 [22]).Foliar application of micronutrient zinc (0.05-0.1ppm) in optimum concentration expanding plant height, number of flowers, flower diameter, stalk length, and flower yield (Balakrishnan *et al.*, 2007)[2]. It is well known that zinc acts as a co-factor of many enzymes, and affects numerous biological processes such as photosynthetic reactions, nucleic acids metabolism, protein and carbohydrate biosynthesis, this is because of the fact that, zinc in plant play a vital role due to its requirements in the synthesis of tryptophan which is a precursor of IAA (Indole acetic acid). Zincaccelerates the biological mechanism and these are consisting of proteins, and enzymes. Foliar application of micronutrients on leaves *i.e.* functional green factories thathelps in the effective photosynthesis and produce the essential compounds required for the plant growth. These nutrients pass to the plant body easily where it is required and nourish the flower quality (Shukla *et al*. 2007[32]; Gupta and Kumar, 2015[10]). Therefore, in the present research an attempt was made to investigatethe effect ofzincon plant growth, flower quality, and yield related traits in order to get higher yields and economic returns per unit area.

2. Materials and Methods

The current study was carried out in the Division of Horticulture, Rajasthan Agricultural Research Institute, located in Durgapura, Jaipurduring October to January seasons of 2020-21 and 2021-22, respectively. It was set up in a factorial randomized block design with three replications.This location is geographically positioned at 750 47’ East longitudes, 260 51’ North latitude, and has an altitude of 390 m over the mean sea level which issituated in the state Rajasthan’s Jaipur district.This area is in Rajasthan's semi-arid Eastern Plain Zone, or Agroclimatic Zone IIIa.This area usually experiences extremes in temperature during the summer and winter due to its semi-arid environment. Temperatures can go as high as 49^0C in the summer and as low as 0^0C in the winter.Frost is a common wintertime phenomenon. 52 to 92% relative humidity is the range throughout which it shifts. Summers, and winters are almost entirely dry.The 120 x 60 x 10 cm raised beds were used to spread the marigold seeds. The seedlings, which were put in lines with a 40 x 40 cm spacing, were 30 days old, uniform in height, robust, and strong with 5–6 leaves. Five randomly chosen and labelled plants per plot were used to collect the databefore harvesting while after harvest five flowers from each plant were taken for recording quality parameters. In order to evaluate the importance of variance in data derived from different growth, yield, and quality characteristics, the Fisher (1950)[6]factorial randomized block design technique was utilized to apply analysis of variance.The statistical analysis was done using the opstat software package (Sheron *et al.*, 1998)[31].

3. Results and Discussion

3.1 Impact of zinc application on plant vegetative growth characteristics

3.1.1 Impact of zinc on plant height

Table 1 presents the results of the current experimental design with respect to the vegetative growth characteristics of the plants. It is evident that the Z_2 ($ZnSO_4$ 0.5%) treatment significantly changed the plant height (67.2 cm and 70.6 cm), while the Z_1 (ZnSO4 0.2%) treatment showed the merest gain in plant height (51.2 cm and 54.6 cm) in 2020-21 and 2021-22, respectively. The combined results from the two years indicated that treatment Z_2 and Z_1 had the greatest (68.9 cm), and moderate (52.9 cm) gains in plant height, respectively. Plant height percentage increased by 76.19 percent when Z_2 (ZnSO4 0.5%) treatment was applied compared to Z_1 (ZnSO4 0.2%) during the pooled mean at 65 DAT.While minimal plant height increase was seen by the treatment Z_1 ($ZnSO_4$ 0.2%) (51.2 cm and 54.6 cm in 2020-21, and 2021-22, respectively), the Zn foliar application at 65 DAT considerably improved the plant height (67.2 cm and 70.6 cm) when treated with Z_2 ($ZnSO_4$ 0.5%) at maximal level. The largest (68.9 cm), and smallest (52.9 cm) increases in plant height were found in treatments Z_2 and Z_1, respectively, according to pooled data for both years. In the first and second years, as well as in the pooled mean at 65 DAT, the application of Z_2 ($ZnSO_4$ 0.5%) yielded the highest mean plant height (30.24%) compared to Z_1 ($ZnSO_4$ 0.2%) treatment.The synthesis of tryptophan, a precursor of indole acetic acid (auxin), which is accelerated by zinc, and aids in the plant's maintenance of apical dominance, polarity, and growth, may be the cause of the rise in plant height observed in marigold when zinc sulphate is applied appropriately (Kumar and Arora, 2000[21]).

3.1.2 Impact of zinc on plant spread

The information also showed (Table 1), that foliar Zn spraying applied at 35 and 65 DAT significantly affected the increase in plant spread. The application of treatment Z_2 ($ZnSO_4$ 0.5%) resulted in the greatest increase in plant (N-S) spread (27.8 and 29.0 cm), while treatment Z_1 ($ZnSO_4$ 0.2%) produced the merest gain in plant spread (17.0 cm and 19.8 cm) in 2020-21, and 2021-22, respectively. The largest (28.4 cm), and smallest (18.4 cm) increases in plant spread were observed with treatments $Z_{2,}$ and Z_1, respectively, according to pooled data. In the pooled mean at 65 DAT, the application of Z_2 ($ZnSO_4$ 0.5%) treatment increased the plant spread percent to an intensity of (54.34 %) over Z_1 ($ZnSO_4$ 0.2%).It was seen from the data that the plant spread (N-S) was increased by application of foliar spray Zn 65 DAT (observation time) had significant effect on increment in plant spread. The maximum addition in plant (N-S) spread (44.8 and 46.8 cm) was recorded with application of treatment Z_2 ($ZnSO_4$ 0.5 %) and minimum raise in plant spread was recorded by the treatment Z_1 ($ZnSO_4$ 0.2 %) (34.0 cm and 37.6 cm) in 2020-21 and 2021-22 respectively. Pooled data for both the years showed that outside (45.8 cm) and slightest (35.8 cm) augmentation in plant spread was recorded in treatment Z_2 and Z_1 respectively.Application of Z_2 ($ZnSO_4$ 0.5%) treatment enhanced the plant spread percent to the extent of (27.93 %) over Z_1 ($ZnSO_4$ 0.2%) during pooled mean at 65 DAT. In plants, zinc is necessary element of cell component of various cell membranes which guidance in cell membrane maintenance and induce cell division that emanate enhanced vegetative growth.

3.1.3 Impact of zinc on number of primary branches per plant

It wasobserved that, the effect of foliar application of Zn 35 and 65 DAT (observation recorded) was significant in terms of number of primary branches per plant are presented in Table 1. The foliar application of various Zn level showed significant effects on increment of number of primary branches. The higher gain in number of primary branches (10.0, 11.0, and 10.0) was observed in treatment Z_2 ($ZnSO_4$ 0.5 %) in 2020-21 and 2021-22 with pooled mean, followed by treatment Z_1 ($ZnSO_4$ 0.2 %) slightest (5.0, 8.0 and 6.0) during both years as well as in pooled mean, respectively. The improved number of primary branches per plant to the breadth of (66.66 %) was observed in Z_2 ($ZnSO_4$ 0.5 %) over Z_1 ($ZnSO_4$ 0.2 %) treatment during pooled mean at 65 DAT.The data showed that numberof primary branches per plant as affected by foliar application of Zn after 65 days (observation recorded) are presented in Table 1,the foliar application of various Zn level showed significant effects on increment numberof primary branches. The best boost in primary branches (14.80, 16.72 and 15.76) was observed in treatment Z_2 ($ZnSO_4$ 0.5 %) in 2020-21, and 2021-22 with pooled mean, followed by treatment Z_1 ($ZnSO_4$ 0.2 %) with little gain (10.00, 13.52, and 11.76) during both years as well as in pooled mean, respectively. Using Z_2 ($ZnSO_4$ 0.5 %) treatment instead of Z_1 ($ZnSO_4$ 0.2 %) treatment, the number of primary branches per plant increased to a degree of (34.01%) during the pooled mean at 65 DAT. Plants may be having more branches because of stimulated cell division, which results in increased biomass and vegetative growth. In conclusion, plants spread because of the ordered accumulation of carbohydrates brought about by photosynthesis (Chattopadhayay*et al.*, 2001)[3].

3.1.4 Impact of zinc on leaf length

Based on the data shown in Table 1, it was determined that foliar treatment of different Zn levels at 35 and 65 DAT (observation recorded) had a substantial impact on the increase in leaf length in plants. Applying treatment Z_2 ($ZnSO_4$ 0.5%) over both years resulted in the largest increase in leaf length (6.4, 6.1,and 6.2 cm), as well as in the pooled mean, respectively. The smallest leaf length (4.3, 4.9,and 4.6 cm) was seen under Z_1 ($ZnSO_4$ 0.2%) in both the individual year and the pooled analysis, respectively.During the pooled mean at 65 DAT observed, treatment Z_2 ($ZnSO_4$ 0.5 %) lengthens leaves to a duration of (34.78%) compared to Z_1 ($ZnSO_4$ 0.2 %).Data regarding foliar application of different Zn levels at 65 DAT (observation noted) shown a considerable effect on plant leaf length increment, which is verified by the data. The application of treatment Z_2 ($ZnSO_4$ 0.5 %) throughout both years resulted in the highest gather in leaf length (13.7, 13.8,and 13.8 cm), as well as in the pooled mean, respectively. Nonetheless, the lowest leaf length (7.6, 8.6 and 8.1 cm) was recorded under Z_1 ($ZnSO_4$ 0.2%) in the pooled analysis and for each individual year. During the pooled mean at 65 DAT observed, treatment Z_2 ($ZnSO_4$ 0.5 %) increases leaf length per plant to the extent of (70.37 %) above Z_1 ($ZnSO_4$ 0.2 %).The expansion of materials used in photosynthesis may be the cause of the larger length and width of plant leaves (Yadav *et al.*, 2002[35]).

3.1.5 Impact of zinc on leaf width

According to a study of the results (Table 1), foliar application of different Zn levels at 35 and 65 DAT had a substantial impact on the increase in leaf width in the plant. Applying treatment Z_2 ($ZnSO_4$ 0.5%) during both years resulted in an outside increment in leaf width of 4.86, 5.24,and 5.05 cmas well as an increase in the pooled mean, correspondingly. Nonetheless, the smallest increases in leaf width (2.76, 4.04,and 3.40 cm) were observed in the pooled study and individual year under Z_1 ($ZnSO_4$ 0.2 %). According to the pooled mean at 35 DAT observed, the percentage increase in plant leaf width under treatment ($ZnSO_4$ 0.5 %) was determined to be (48.52 %) larger than treatment Z_1 ($ZnSO_4$ 0.2 %). It was also observed that the foliar application of different Zn levels at 65 DAT had a substantial impact on the increase in leaf width in plants. The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) for both years as well as in the pooled mean, respectively, was associated with the greatest increase in leaf width (7.78, 8.50,and 8.14 cm). The smallest increase in leaf width, however, was observed under Z_1 ($ZnSO_4$ 0.2%) in the pooled analysis and during the individual year, respectively, at 3.68, 5.30, and 4.49 cm. According to the pooled mean at 65 DAT observed, the percentage increase in plant leaf width under treatment (ZnO_4 0.5 %) was determined to be (81.29 %) larger than treatment Z_1 ($ZnSO_4$ 0.2

%).Application of zinc approximately increased the number of leaves per plant which could be due to induced cell division with extra accumulation of photosynthesis materials (Paradhan*et al.*, 2007[26]). The increment in plant leaf area might be due to storage of further carbohydrates favored by zinc application which arm help in reducing juvenile phase of plants (Jauhari*et al.*, 2005[13]).This could be due to application of micro nutrient (zinc) favors in storing spare carbohydrates in leaves that helps in induced cell division process (Mir *et al.*,2007[24]).

3.1.6 Impact of zinc on leaf area

The findings in Table 1,further highlights the fact that foliar application of different Zn levels at 35 and 65 DAT had a substantial impact on the increase in leaf area in the plant. With the administration of treatment Z_2 ($ZnSO_4$ 0.5 %) over both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, an outside increase in leaf area (27.8, 29.8,and 28.8 cm^2) was noted. The smallest increase in leaf area (21.7, 24.6,and 23.1 cm^2) was observed under Z_1 ($ZnSO_4$ 0.2%) in the pooled analysis and over the individual year, respectively. Nevertheless, under treatment Z_2 ($ZnSO_4$ 0.5%) as opposed to treatment Z_1 ($ZnSO_4$ 0.2%) under pooled mean at 65 DAT, a final increase in plant leaf area percentage (24.67%) was detected.The plant's ability to increase its leaf area was significantly impacted by the foliar treatment of different Zn levels at 65 DAT. The application of treatment Z_2 ($ZnSO_4$ 0.5%) over both the years (2020-21 and 2021-22) as well as in the pooled mean, respectively, resulted in the best accretion in leaf area (47.5, 47.7, and 47.6 cm^2). The lowest increase in leaf area (41.4, 42.5,and 42.0 cm^2) was observed in the individual year and pooled study under Z_1 ($ZnSO_4$ 0.2 %). Nonetheless, under treatment Z_2 ($ZnSO_4$ 0.5%) as opposed to treatment Z_1 ($ZnSO_4$ 0.2%) under the pooled mean at 65 DAT, a greater increase in the percentage of plant leaf area (13.33%) was found.The widening of leaves could be due to stimulated cell division in plant parts including leaves so increment in plant fresh and dry weight (Reddy and Chaturvedi 2009)[29].

3.1.7 Impact of zinc on fresh weight

According to Table 1,of the current study, foliar spraying of different Zn levels had a substantial impact on the plant's increase in fresh weight at harvest. In the years 2020-21, and 2022-22, as well as in the pooled mean, the administration of treatment Z_2 ($ZnSO_4$ 0.5%) yielded the highest results in terms of plant fresh weight (289.25, 290.39,and 289.82 g), respectively. The smallest increases in plant fresh weight (199.15, 201.19,and 200.17 g) were, however, recorded under Z_1 ($ZnSO_4$ 0.2%), in both the individual year and the pooled study. When treatment Z_2 ($ZnSO_4$ 0.5%) was applied foliar, the plant fresh weight increased (44.78%) in comparison to treatment Z_1 ($ZnSO_4$ 0.2%) during the pooled mean.

3.1.8 Impact of zinc on dry weight

It differs with the data showing that foliar spray of different Zn levels demonstrated substantial effect on plant dry weight attainment (at harvest), as measured by (Table 1). When treatment Z_2 ($ZnSO_4$ 0.5%) was applied, the outside capture in plant dry weight (88.45, 91.08, and 89.77 g) as well as the pooled mean were recorded, respectively, for the two years (2020–21, and 2021-22). The lowest plant dry weight collection, however, was recorded under Z_1 ($ZnSO_4$ 0.2%) in the individual year and in the pooled analysis, weighing 56.35, 59.88, and 58.12 g, respectively. On the other hand, foliar spraying of treatment Z_2 ($ZnSO_4$ 0.5 %) showed a higher percentage of plant dry weight (54.45%) than treatment Z_1 ($ZnSO_4$ 0.2 %).

3.1.9 Impact of zinc on total plant biomass

According to Table 1, which presents the data for total plant biomass (at harvest), foliar spraying of different Zn levels had a substantial impact on the total biomass gathered in the plant (at harvest). In the years 2020-21 and 2022-22, as well as in the pooled mean, the application of treatment Z_2 ($ZnSO_4$ 0.5%) yielded the best results in terms of plant biomass (76.85, 79.19, and 78.02 q/ha). The Z_1 ($ZnSO_4$ 0.2 %) group showed the lowest increases in plant biomass (44.75, 47.99, and 46.37 q/ha) in both the individual year and the pooled study, respectively. When treatment Z_2 ($ZnSO_4$ 0.5%) was applied topically, plant biomass increased (68.25%) in comparison to treatment Z_1 ($ZnSO_4$ 0.2 %).

3.1.10 Impact of zinc on plant root-shoot ratio

The data on plant root-shoot ratio (at harvest) as affected by (Table 1), the foliar application of various Zn levels showed significant effect on total root-shoot ratio increment in plant (at harvest). The high boost in plant root-shoot ratio (0.185, 0.192 and 0.189) was first year and pooled results similarly, recorded with application of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020-21, and 2021-22) as well as in pooled mean, respectively. However, low addition in plant root-shoot ratio (0.144, 0.150, and 0.147) noted similarly under Z_1 ($ZnSO_4$ 0.2 %) during individual year and in pooled analysis, respectively. However, maximum increases percentage plant root-shoot ratio foliar application of treatment Z_2 ($ZnSO_4$ 0.5 %) (28.57 %) was observed compared to treatment Z_1 ($ZnSO_4$ 0.2 %) during investigation of pooled analysis.It was noticed that, escalation plant biomass and root-shoot ratio which resulted in considerable alteration of root form foliar application of Zn, but with only a small depression in shoot growth compared with Z_1 ($ZnSO_4$ 0.2 %), plant receiving an extensive supply to all parts of the root system (Eid *et al.*, 2010)[4].The findings of Khosa *et al.* (2011)[19], Katiyar *et al.* (2012)[17], Memon *et al*. (2013)[23], Gupta and Kumar (2015)[10], Patel *et al.*(2000)[27], and Vanlalruati*et al.* 2019[34]were in co-relation with the above results.

3.2Impact of zinc application on plant floral growth characteristics

3.2.1 Impact of zinc on number of days to first flower bud initiation

According to Table2, which presents data on the impact of days to first flower bud initiation, foliar application of different zinc levels significantly affected the number of days to first flower bud initiation increment in plants. The pooled results, which were obtained with application of treatment Z_2 ($ZnSO_4$ 0.5 %) over both the years (2020-21, and 2021-22) as well as in the pooled mean, respectively, showed minimal days to first flower bud initiation (30.0, 31.0, and 30.0) in the first year. The maximum days to the beginning of the first flower bud (34.0, 35.0, and 34.0) were seen in a similar manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled study. Nonetheless, the Z_2 treatment ($ZnSO_4$ 0.5%) showed the closest days of bud initiation, which was (13.33%) fewer than the Z_1 treatment ($ZnSO_4$ 0.2 %).

3.2.2Impact of zinc on number of days to first flower opening

The first flower opening was prompted by (Table2), which demonstrated that foliar application of different Zn levels had a substantial impact on the plant's days before first flower opening. The first year had the earliest days to first flower opening (37.0, 38.0,and 37.0), and the pooled findings showed comparable results, recorded with application of treatment Z_2 ($ZnSO_4$ 0.5 %) in the pooled mean and both of the years (2020–21, and 2021-22), respectively. On the other hand, Z_1 ($ZnSO_4$ 0.2 %) showed comparable results for the highest days to first flower opening (42.0, 44.0, and 44.0) in both the individual year and the pooled study. The earliest flower opening was observed on the smallest days under Z_2 ($ZnSO_4$ 0.5 %), which was 13.95 % lower than treatment Z_1 ($ZnSO_4$ 0.2 %).However, these yield attributes were realized compared to Z_1 ($ZnSO_4$ 0.2 %). The foliar application of Z_2 ($ZnSO_4$ 0.5 %) treatments of zinc in marigold were symbolic effect on early days to flower opening from date of transplanting. This can be the attributing factor for the positive influence of optimum dose of zinc on reducing juvenile phase of the plant (Khan *et al.*, 2017[18];Yadav *et al.*, 2002[35]).

3.2.3Impact of zinc on number of days to 50 % flowering

According to Table 2, foliar application of different zinc levels significantly affected the number of days to 50% flowering increment in the plant. The pooled results, which were obtained with the administration of treatment Z_2 ($ZnSO_4$ 0.5 %) for both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, showed that the minimum days to 50% flowering (47.0, 48.0,and 47.0) was observed in the first year. Nonetheless, the maximum days to 50% flowering (51.0, 52.0, and 51.0) were seen in a comparable manner under Z_1 ($ZnSO_4$ 0.2%), both in the individual year and in the pooled analysis. On the other hand, Z_2 ($ZnSO_4$ 0.5%) showed 50% blooming on the earliest days, which was 8.51 % less than Z_1 ($ZnSO_4$ 0.2%) treatment.

3.2.4Impact of zinc on flower diameter

The data pertaining to the impact of plant flower diameter, as indicated by Table2, demonstrated a substantial effect on the increase in bloom diameter in plants when different Zn levels were applied topically. The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) over both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, was associated with the superlative capture in plant flower diameter (6.8, 6.6,and 6.7 cm) in the first year and pooled findings. The smallest collection of plant blossom diameter (4.7, 5.4,and 5.1 cm) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled study. When Z_2 ($ZnSO_4$ 0.5%) was applied to marigolds, the increase in bloom diameter was 31.37% more than when Z_1 ($ZnSO_4$ 0.2%) was applied.The increase in diameter of flower can be due to more accumulation of carbohydrates that guidance in induced cell division producing higher diameter of flower and other plant parts (Ali*et al.*, 2019)[1].

3.2.5Impact of zinc on flower stalk length

The results demonstrated the impact of plant flower stalk length(Table 2), which demonstrated a substantial effect of foliar application of different zinc levels on the increase in flower stalk length in plants. The first year exhibited the largest gather in plant flower stalk length (8.21, 8.47,and 8.34 cm), and the pooled results, when applied with treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020-21, and 2021-22) as well as in the pooled mean, were similarly reported. The smallest length of plant flower stalks (6.10, 7.27, and 6.69 cm) were observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled study. The length of the flower stem increased by 25.75 percent when Z_2 ($ZnSO_4$ 0.5 %) foliar spray was applied compared to Z_1 ($ZnSO_4$ 0.2 %) treatment in pooled mean.The increase in flower stalk length per flower can be due to application of zinc sulphate Z_2 ($ZnSO_4$ 0.5 %)

causes extra accumulation of carbohydrates that helps in induced cell division producing higher flower stalk length in marigold flower (Kumar *et al.*,2004[20]).

3.2.6Impact of zinc on length of ray floret

According to Table 2, which presents data on the influence of zinc on ray floret increment, foliar administration of different amounts of zinc had a substantial effect on the length of the flower on the plant. The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, was associated with the greatest increase in plant flower length of ray floret (2.19, 2.86,and 2.53 cm) in the first year and pooled findings. The smallest addition to the ray floret length (1.69, 2.26,and 1.98 cm) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2%), both in the individual year and in the pooled study. When Z_2 ($ZnSO_4$ 0.5%) was applied to marigold, the length of the ray florets increased.

3.2.7Impact of zinc on fresh flower weight

According to the findings in Table 2, foliar application of different doses of zinc had a significant effect on the increase in fresh flower weight in the plant. The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020-21, and 2021-22) as well as in the pooled mean, respectively, was associated with an outside increase in plant flower fresh weight (6.61, 7.41,and 7.01 g) in the first year and pooled results similarly. The smallest increase in plant flower fresh weight (4.51, 5.30,and 4.91 g) washowever, observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2%), both in the individual year and in the pooled study. Compared to treatment Z_1 ($ZnSO_4$ 0.2 %), treatment Z_2 ($ZnSO_4$ 0.5 %) increased fresh flower weight to the warble by 42.76 %.The justification behind increased fresh weight of flower adequacy due to the optimum concentration of zinc Z_2 ($ZnSO_4$ 0.5 %) involved in RNA metabolism and ribosomal content that steer to stimulate carbohydrate, protein and DNA content. Which helps in the synthesis of tryptophan which acts as growth raise substance (Halder *et al.*,2007)[11].

3.2.8Impact of zinc on dry flower weight

According to Table 2, which lists the effects of plant dry flower weight, foliar treatment of different zinc levels had a substantial impact on the increase in floral dry weight in plants. First-year and pooled results, which were obtained with application of treatment Z_2 ($ZnSO_4$ 0.5 %) for both the years (2020-21, and 2021-22) as well as in the pooled mean, respectively, showed the outstanding accretion in plant flower dry weight (1.36, 1.41,and 1.39 g). The smallest increase in plant flower dry weight (0.95, 0.85,and 0.90 g) was seen in the individual year and in the pooled analysis, respectively, under Z_1 ($ZnSO_4$ 0.2 %). When treatment Z_2 ($ZnSO_4$ 0.5%) was applied, the dry flower weight increased by 54.44 percent compared to treatment Z_1 ($ZnSO_4$ 0.2%) during pooled mean.Treatment Z_2 ($ZnSO_4$ 0.5 %) foliar spray plays a vital role in production of abundant growth and ultimately restore the biomass of plant which results in increased dry weight of flower (Pratap *et al.*,2007)[28].

3.2.9Impact of zinc on number of ray floret per flower

The data indicate that foliar treatment of different zinc levels showed substantial effect on number of ray florets per flower (Table 2). The use of treatment Z_2 ($ZnSO_4$ 0.5 %) over both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, yielded the ultimate outcomes in plant number of ray florets per flower (195.0, 198.0,and 197.0). Nonetheless, the smallest plant number of ray florets per flower (139.0, 142.0,and 141.0) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2%), both in the individual year and in the pooled analysis. The increase in marigold ray floret count brought about by the applicationof Z_2 ($ZnSO_4$ 0.5 %) was to the breadth of (39.71 %) over Z_1 ($ZnSO_4$ 0.2 %).The increase in number of ray florets and length of ray floret per flower might be due to further production of tryptophan which acts as a precursor of auxin. Higher production of auxin helps to increase in abundant growth by suppressing the juvenile phase of plant (Katiyar*et al.* 2012)[17].

3.2.10Impact of zinc on weight of flower per plant

Additionally, it is evident from Table 2, data on the weight of flowers per plant that foliar treatment of different Zn levels had a substantial impact on the increase in weight of flowers per plant. The first year's maximum flower weight collected (536.53, 541.52,and 539.03 g) was recorded in the pooled data, along with the application of treatment Z_2 ($ZnSO_4$ 0.5 %) in both the 2020-21, and 2022-22 years, as well as in the pooled mean, respectively. Nonetheless, limited collection in floral weight per plant (296.43, 301.32,and 298.88 g) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled analysis. When treatment Z_2 ($ZnSO_4$ 0.5%) was applied, the weight of flowers per plant increased and it wasover treatment Z_1 ($ZnSO_4$ 0.2 %).

3.3 Impact of Zn application onflower yield and quality characteristics

3.3.1 Impact of zinc on number of flowers per plant

According to Table 3, results on the influence of flowering time per plant, foliar application of different Zn levels significantly affected the number of flowers per plant increase in the plant. The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, yielded the highest attainment in plant number of flowers per plant (64.0, 67.0,and 65.0) and pooled results alike. Nonetheless, the minimal capture in terms of blooms per plant (54.0, 55.0,and 54.0) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled study. Compared to treatment Z_1 ($ZnSO_4$), treatment Z_2 ($ZnSO_4$ 0.5%) increased the quantity of flowers per plant to a duration of 20.37 %.

3.3.2 Impact of zinc on number of flowers per plot

The data presented in Table 3, indicates that the quantity of flowers per plot increment in the plant was significantly affected by the foliar treatment of varying zinc levels.The administration of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, was associated with the greatest increases in the number of flowers per plot plant (848.0, 853.0,and 851.0) in the first year of the pooled findings. Nonetheless, a negligible increase in the quantity of flowers per plot plant (692.0, 724.0,and 708.0) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2 %) in both the individual year and the pooled study. When treatment Z_2 ($ZnSO_4$ 0.5 %) was applied to the area of (20.19 %) greater than treatment Z_1 ($ZnSO_4$ 0.2 %), the quantity of flowers per plot was much higher.The increased in yield of flowers per plot due to application of zinc sulphate can be because of the fact that zinc sulphate escalation the vegetative growth and leads to extra production of food material, which in turn utilized for preferred development of buds and flowers which can be results in increased number of flowers and flower yield (Kakade*et al.*, 2014[15]).

3.3.3 Impact of zinc on flower yield per hectare

It was further documented from data quoted in effect of flower yield per hectare as influenced by (Table 3), that, foliar application of various zinc levels showed significant effect on flower yield per hectare increment in plant.The higher raise in flower yield per hectare (195.38, 197.09, and 196.24 q/ha) was first year and pooled results similarly, recorded with application of treatment Z_2 ($ZnSO_4$ 0.5 %) during both the years (2020-21, and 2021-22) as well as in pooled mean, respectively. However, tiniest augmentation in flower yield per hectare (113.06, 114.74, and 113.90 q/ha) noted similarly under Z_1 ($ZnSO_4$ 0.2 %) during individual year and in pooled analysis, respectively. The increases in flower yield under application of foliar spray Z_2 ($ZnSO_4$ 0.5 %) was registered to the tune of (72.29 %) over treatment Z_1 ($ZnSO_4$ 0.2 %) in pooled mean.The treatments of zinc Z_2 ($ZnSO_4$ 0.5 %) were symbolic effect on weight of flowers per plant and flower yield. This could be due to the fact that zinc sulphate increases the arable growth and leads to extra production of food material, which in turn utilized for exceeding flower yield Also similar to above present verdicts agreement with studies of Hembrom and Singh, 2015[12] and Singh *et al.*,2018[33].

3.3.4 Impact of zinc on flower yield per hectare

According to Table 3, of the current study, foliar spraying of different Zn levels had a substantial impact on net return (Rs./ha). The use of treatment Z_2 ($ZnSO_4$ 0.5%) for both the years (2020-21 and 2021-22) as well as in the pooled mean, respectively, yielded the highest net return (266699, 270114,and 268407 Rs./ha). The least amount of net return (104309, 107656,and 105983 Rs/ha) was seen under Z_1 ($ZnSO_4$ 0.2%), though. The higher values of net returns under these treatments could be ascribed to the higher flower yield of marigold crop obtained under these treatments. Similar results were also found by Balakrishnan *et al.* 2007[2]; Sainath *et al.* 2014[30] and Ganesh *et al.* 2013[7].

3.3.5 Impact of zinc on shelf life of flower

According to Table 3, data on the impact of flower shelf life, foliar treatment of different Zn levels significantly increased the flower's shelf life in the plant. The first year had the highest accrual in flower shelf life (3.0, 7.0,and 5.0)and pooled results showed comparable results, with treatment Z_2 ($ZnSO_4$ 0.5 %) applied during both the years (2020-21, and 2021-22) as well as in the pooled mean, respectively. Nonetheless, a lesser increase in flower shelf life (3.0, 4.0, and 4.0) was observed in a comparable manner under Z_1 ($ZnSO_4$ 0.2%), both in the individual year and in the pooled study. When Z_2 ($ZnSO_4$) was applied, the flower's considerable maximum shelf life was observed. This increased to an expansion of (48.97%) over treatmentZ_1 ($ZnSO_4$ 0.2 %).

3.3.6 Impact of zinc on vase life of flower

According to data compiled from Table 3, which shows how foliar application of different Zn levels influences flower vase life, there is a considerable effect on the increase in flower vase life in plants. The first year and pooled findings, which were obtained with the application of treatment Z2 (ZnSO4 0.5 %) for both the years (2020–21, and 2021-22) as well as in the pooled mean, respectively, yielded the highest vase life of the flower (14.0, 13.0, and 13.0). The smallest acquisition in flower vase life (10.0, 13.0, and 11.0) was observed in a comparable manner under Z1 (ZnSO4 0.2 %) in both the individual year and the pooled analysis, though. Compared to treatment Z1 (ZnSO4 0.2 %), the improved vase life of the flower under treatment Z_2 (ZnSO4 0.5 %) was recorded to the tune of 17.10 %.This could be due to foliar application of treatment Z_2 ($ZnSO_4$ 0.5 %) varietal character on the other hand it could be due to the fact that zinc sulphate increases the vase life of flower and leads to higher production of food material, which in turn utilized for more shelf life of flower (Nagaraju*et al.* 2002[25]).

3.3.7 Impact of zinc on chlorophyll content

The results in Table 3, which shows how foliar application of different Zn levels affects a plant's chlorophyll content, indicates a considerable impact on the increase in chlorophyll content in plants. The first year had the highest chlorophyll content (1.750, 1.830,and 1.790 mg/gm), and pooled findings showed comparable results, with treatment Z_2 ($ZnSO_4$ 0.5 %) applied in both the 2020-21, and 2022–22 years, as well as in the pooled mean, respectively. The plant's lowestchlorophyll content (1.150, 1.200,and 1.175 mg/gm) were, however, seen in a similar manner under Z_1 ($ZnSO_4$ 0.2%) in both the individual year and the pooled analysis. The warble of (52.34%) showed an increase in chlorophyll content in leaves when foliar spray Z_2 ($ZnSO_4$ 0.5%) was applied, compared to treatment Z_1 ($ZnSO_4$ 0.2 %).

3.3.8 Impact of zinc on xanthophyll content

These findings are consistent with the xanthophyll content in plant as depictedin Table 3, which indicated that foliar application of different Zn levels had a substantial impact on the increase of xanthophyll content in plant. The application of treatment Z_2 ($ZnSO_4$ 0.5 %) for both the years (2020-21, and 2021-22) as well as in the pooled mean, respectively, was associated with the highest increase in xanthophyll content in plants (5.03, 5.10, and 5.07 mg/gm), according to first year and pooled data. However, under Z_1 ($ZnSO_4$ 0.2%), there was a slight increase in the plant's xanthophyll content (3.45, 3.60, and 3.53 mg/gm) in both the individual year and the pooled study, respectively. Treatment Z_2 ($ZnSO_4$ 0.5%) application increased the amount of xanthophyll in marigold flowers by 43.62 percent compared to treatmentZ_1 ($ZnSO_4$ 0.2 %).Treatment Z_2 ($ZnSO_4$ 0.5 %) foliar spray mainly energy levels of organic compound are erected by synthesis of phosphate esters and prepared for subsequent reactions in leaves and flowers so increases the chlorophyll and xanthophyll content in flowers (Balakrishnan *et al.*, 2007)[2]. These results also in corroboration with the findings of Ganga *et al.* 2014[8], Fahad *et al.* 2014[5] and Karuppaiah 2019[16].

4. Conclusion

The final findings from the present research showed that the Zn foliar application treatment was best for increasing plant height, early flower bud initiation, and early flower opening. On the other hand, the Z_2 ($ZnSO_4$ 0.5%) foliar spray treatment was best for increasing plant spreading, primary branches per plant, leaf length, leaf width, leaf area, plant fresh weight, plant dry weight, total biomass, root-shoot ratio, 50% flowering, flower diameter, stalk, ray floret length, fresh and dry flower weight, quantity and mass of flowers on each plantand flower yield. Additional improved quality characteristics included shelf life, vase life, and chlorophyll and xanthophyll content in marigold, all of which help to yield good net returns. Thus, it may be concludedand farmers cultivating African marigold crop may be advised to apply ZnSO4 @ 0.5% as a foliar spray which might help improve yield and quality attributes in commercial African marigold cultivation.

Disclaimer (Artificial intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Table: 1 Effect of zinc on plant vegetative growth characteristics of African marigold

Treatments	Plant height (cm)			Plant spread (cm)		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Z_1-$ZnSO_4$ 0.2 %	51.2	54.6	52.9	34.0	37.6	35.8
Z_2-$ZnSO_4$ 0.5 %	67.2	70.6	68.9	44.8	46.8	45.8
SEm$\pm$	0.62	0.66	0.32	0.34	0.37	0.17
CD (P=0.05)	1.75	1.86	0.88	0.97	1.05	0.49
Treatments	**Number of primary branches per plant**			**Leaf length (cm)**		
Z_1-$ZnSO_4$ 0.2 %	10.00	13.52	11.76	7.6	8.6	8.1
Z_2-$ZnSO_4$ 0.5 %	14.80	16.72	15.76	13.7	13.8	13.8
SEm$\pm$	0.62	0.66	0.31	0.10	0.11	0.05
CD (P=0.05)	1.75	1.86	0.86	0.27	0.31	0.15
Treatments	**Leaf width (cm)**			**Leaf area (cm^2)**		
Z_1-$ZnSO_4$ 0.2 %	3.68	5.30	4.49	41.4	42.5	42.0
Z_2-$ZnSO_4$ 0.5 %	7.78	8.50	8.14	47.5	47.7	47.6
SEm$\pm$	0.03	0.04	0.02	0.32	0.37	0.16
CD (P=0.05)	0.08	0.11	0.04	0.90	1.04	0.44
Treatments	**Plant fresh weight (g)**			**Plant dry weight (g)**		
Z_1-$ZnSO_4$ 0.2 %	199.15	201.19	200.17	56.35	59.88	58.12
Z_2-$ZnSO_4$ 0.5 %	289.25	290.39	289.82	88.45	91.08	89.77
SEm$\pm$	2.29	2.29	1.29	0.72	0.72	0.44
CD (P=0.05)	6.46	6.45	3.61	2.02	2.03	1.24

Treatments	Plant total biomass (q/ha)			Plant root-shoot ratio		
Z_1-$ZnSO_4$ 0.2 %	44.75	47.99	46.37	0.144	0.150	0.147
Z_2-$ZnSO_4$ 0.5 %	76.85	79.19	78.02	0.185	0.192	0.189
SEm$\pm$	0.72	0.72	0.37	0.012	0.012	0.006
CD (P=0.05)	2.02	2.03	1.04	0.033	0.033	0.016

Table: 2 Effect of zinc on plant floral growth characteristics of African marigold

Treatments	First flower bud initiation (DAT)			First flower opening (DAT)		
	2020-21	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**
Z_1-$ZnSO_4$ 0.2 %	34.0	35.0	34.0	42.0	44.0	44.0
Z_2-$ZnSO_4$ 0.5 %	30.0	31.0	30.0	37.0	38.0	37.0
SEm$\pm$	0.23	0.25	0.12	0.23	0.25	0.12
CD (P=0.05)	0.65	0.71	0.32	0.65	0.71	0.34
Treatments	**50 % flowering (DAT)**			**Flower diameter (cm)**		
Z_1-$ZnSO_4$ 0.2 %	51.0	52.0	51.0	4.7	5.4	5.1
Z_2-$ZnSO_4$ 0.5 %	47.0	48.0	47.0	6.8	6.6	6.7
SEm$\pm$	0.41	0.45	0.20	0.05	0.07	0.04
CD (P=0.05)	1.14	1.28	0.57	0.15	0.21	0.10
Treatments	**Flower stalk length (cm)**			**Length of ray floret (cm)**		
Z_1-$ZnSO_4$ 0.2 %	6.10	7.27	6.69	1.69	2.26	1.98
Z_2-$ZnSO_4$ 0.5 %	8.21	8.47	8.34	2.19	2.86	2.53
SEm$\pm$	0.05	0.07	0.04	0.03	0.03	0.01
CD (P=0.05)	0.15	0.21	0.10	0.08	0.08	0.04
Treatments	**Fresh flower weight (g)**			**Dry flower weight (g)**		
Z_1-$ZnSO_4$ 0.2 %	4.51	5.30	4.91	0.95	0.85	0.90
Z_2-$ZnSO_4$ 0.5 %	6.61	7.41	7.01	1.36	1.41	1.39
SEm$\pm$	0.06	0.07	0.04	0.01	0.01	0.02
CD (P=0.05)	0.16	0.20	0.12	0.04	0.04	0.05
Treatments	**Number of ray florets per flower**			**Weight of flowers per plant (g)**		

Z_1-$ZnSO_4$ 0.2 %	139.0	142.0	141.0	296.43	301.32	298.88
Z_2-$ZnSO_4$ 0.5 %	195.0	198.0	197.0	536.53	541.52	539.03
SEm$\pm$	1.33	1.33	0.71	1.63	1.63	1.96
CD (P=0.05)	3.74	3.74	1.98	4.59	4.59	5.82

Table: 3 Effect of zinc on floweryield and quality characteristics of African marigold

Treatments	**Number of flowers per plant**			**Number of flowers per plot**		
	2020-21	**2021-22**	**Pooled**	**2020-21**	**2021-22**	**Pooled**
Z_1-$ZnSO_4$ 0.2 %	54.0	55.0	54.0	692.0	724.0	708.0
Z_2-$ZnSO_4$ 0.5 %	64.0	67.0	65.0	848.0	853.0	851.0
SEm$\pm$	0.94	0.94	0.47	4.91	5.38	3.64
CD (P=0.05)	2.66	2.65	1.32	13.86	15.19	10.39
Treatments	**Flower yield (q/ha)**			**Net return (Rs/ha)**		
Z_1-$ZnSO_4$ 0.2 %	113.06	114.74	113.90	104309	107656	105983
Z_2-$ZnSO_4$ 0.5 %	195.38	197.09	196.24	266699	270114	268407
SEm$\pm$	1.98	1.98	1.02	1961	2172	1128
CD (P=0.05)	5.58	5.58	2.86	5532	6129	3154
Treatments	**Shelf life of flower (days)**			**Vase life of flower (days)**		
Z_1-$ZnSO_4$ 0.2 %	3.0	4.0	4.0	10.0	13.0	11.0
Z_2-$ZnSO_4$ 0.5 %	3.0	7.0	5.0	13.0	14.0	13.0
SEm$\pm$	0.07	0.09	0.04	0.07	0.09	0.04
CD (P=0.05)	0.20	0.25	0.10	0.20	0.25	0.12
Treatments	**Chlorophyll content (mg/gm)**			**Xanthophyll content (mg/gm)**		
Z_1-$ZnSO_4$ 0.2 %	1.150	1.200	1.175	3.45	3.60	3.53
Z_2-$ZnSO_4$ 0.5 %	1.750	1.830	1.790	5.03	5.10	5.07
SEm$\pm$	0.007	0.007	0.009	0.01	0.01	0.02
CD (P=0.05)	0.021	0.021	0.025	0.03	0.04	0.07