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Impact of GA_3 and $ZnSO_4$ on growth and quality flowering of Marigold (*Calendula officinalis*)

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ABSTRACT

An experiment was carried out at the nursery of the private farm Alaejaylat in Libya during the 2025 season to evaluate the impact of GA_3 and $ZnSO_4$ on marigold (*Calendula officinalis*) development and quality flowering. The experiment utilized a Randomized Complete Block Design (RCBD) with six treatments (control, GA_3 100 ml/l + $ZnSO_4$ 50 ml/l, GA_3 150 ml/l + $ZnSO_4$ 75 ml/l, GA_3 200 ml/l + $ZnSO_4$ 100 ml/l, GA_3 250 ml/l + $ZnSO_4$ 150 ml/l, and GA_3 300 ml/l + $ZnSO_4$ 200 ml/l) and three repetitions. Vegetative growth, including plant height, number of leaves, number of branches per plant, total fresh weight, and leaf area index; flowering parameters, including flower diameter, flower fresh weight, number of flowers, flower stalk length, and flowering period; and chemical composition, including nitrogen, phosphate, potassium, total carbohydrates, total chlorophyll, and carotene, were all examined. In comparison to the control treatment, which recorded the lowest mean values of these characteristics, the results showed that high concentrations of GA_3 300 ml/l + $ZnSO_4$ 200 ml/l recorded the highest values of all growth attributes, including plant height, number of leaves, number of branches/plant, total fresh weight and leaf area index, as well as flower diameter, flower fresh weight, number of flowers, flower stalk length and flowering period, nitrogen, phosphate, potassium, total carbohydrates, total chlorophyll, and carotene. According to the findings of the current study, foliar application of a micronutrient mixture plus GA_3 was shown to be the most effective in terms of the vegetative development, blooming, and yield characteristics of *Calendula officinalis*. This might help you get the most out of growing calendula.

Keywords: Marigold (*Calendula officinalis*), GA_3, Zn, vegetative growth, flowering parameters, chemical composition.

INTRODUCTION

Among the oldest plant species, ornamental and medicinal plants are a vital source of reasonably priced agricultural income. Floriculture and the production of medicinal plants have also experienced a recent surge. *Calendula officinalis* L., sometimes known as marigold, is a member of the Asteraceae family. Despite being native to the Mediterranean region, *C. officinalis* is grown all over the world, notably in China, Europe, and the US **(Soliman *et al.*, 2024).** *C. officinalis* is a winter annual herb known for its lovely and therapeutic blossoms. It features simple leaves, a lengthy root system with several secondary roots, a branching stem, and a maximum height of 70 to 90 cm. It blooms in the winter and spring. Two rows of hairy bracts encircle the inflorescence of the flower. Because of its beautiful and medicinal flowers, *C. officinalis* is a winter annual herb. It has a branching stem, a long root system with several secondary roots, simple leaves, and a maximum height of 70 to 90 cm winter and spring are when it blooms. The flower head's inflorescence is surrounded by two rows of hairy bracts **(Jan *et al.*, 2017).** Poland, Germany, Egypt, China, Russia, Hungary, and Bulgaria are just a few of the nations where *C. officinalis* is widely farmed **(Ruzmetov *et al.*, 2020).** In landscape gardening, *C. officinalis* is planted in beds and borders as an ornamental plant. Furthermore, the blossoms' striking yellow-to-orange hues make them desirable for usage as cut flowers **(Barut and Tansi, 2024).** On the other hand, *C. officinalis* is cultivated professionally for its medicinal properties. Flavonoids, coumarins, oleanolic acid, terpenoids, glycosides, carotenoids, and volatile oils are among the bioactive compounds present in flowers **(Ullah *et al.*, 2023).** The *C. officinalis* plant's flower is commonly used to treat gum disease, nourish the skin, and heal wounds. Additionally, it has hepatoprotective, anti-inflammatory, antioxidant, antihelminthic, antidiabetic, antibacterial, and anticancer properties **(Shahane *et al.*, 2023).** According to a recent study by **Zhang *et al.* (2024),** bioactive substances extracted from *C. officinalis* flowers, such as rutin, isorhamnetin 3-O-glucoside, 3, 4-dicaffeoylquinic acid, chlorogenic acid, and calenduloside E, act via PI3K and ERK signaling pathways to provide neuroprotective effects against Parkinson's disease.

The calendula flower blooms only once a year, during the winter. Calendula is commonly grown in beds, containers, and boxes, and it blooms three times a year during the spring and summer seasons for loose and cut blossoms. The flower is used to create garlands, bouquets, and vase preparations. It comes in a variety of colors, including orange and yellow. It serves as a source of scenery and color **(Khudus *et al.*, 2017).** Calendula is a member of the Asteraceae family and is commonly known as pot marigold, common marigold, English marigold, and garden marigold. Because of its lengthy blossoming cycle, the word Calendula is derived from the Lattin word "Kaendge," which indicates the first day of every month **(Dheeraj and Saravanan, 2018).** Calendulas come in a variety of colors and are used for vase arrangement, bouquets, and garlands **(Hasan, 2019).** The medicinal and industrial uses of calendula are also quite important. Bioactive substances such flavonoids, carotenoids, triterpenoids, and essential oils are present in the flowers. Because of its anti-inflammatory, antibacterial, wound-healing, and antioxidant qualities, extracts are frequently used in herbal remedies, cosmetics, ointments, and natural dyes **(Abou El-Ghait *et al.*, 2020).** Calendula petals are often utilized as natural colorants in food and animal feed. Plants naturally create hormones called cytokinins, which control various aspects of plant growth, such as cell division and leaf senescence. Benzyladenine is a synthetic cytokinin found in a number of commercial plant growth regulators (PGRs). In order to promote axillary branch development and increased floral synchrony, pinching the removal of the main shoot's apical bud is a frequent floricultural technique **(Thakare *et al.*, 2020).**

The blooms are said to be stimulant, antispasmodic, and emmenagogue, while the leaves are said to be re-solvent and diaphoretic. Due to their anti-inflammatory, antibacterial, and hypoglycemic properties, flower extracts are still crucial in phytotherapy even though most of these uses have been abandoned **(Shahane *et al.*, 2023).** Additionally, calendula is frequently used in topical cosmetic products because of its anti-inflammatory, wound-healing, and UV-B protective qualities **(Silva *et al.*, 2021).** The plant's secondary metabolite-related phytochemical composition is extremely rich and includes flavonoids, carotenoids, triterpenoid esters, and saponins **(Shahane *et al.*, 2023).** These substances have been extensively studied for their anti-inflammatory, antioxidant, and antimicrobial qualities. Because they are primarily responsible for the yellow/orange color of the petals, carotenoids are regarded as significant components of pot marigold flowers **(Bragueto *et al.*, 2019).** Extracts from pot marigold flowers are also utilized as food dyers due to their high content (1110–2760 µg total carotenoids/g fresh flowers) **(Kljak *et al.*, 2021).** Applications in food are another area of interest for polyphenols. Calcium alginate microparticles containing polyphenol-rich calendula extracts have recently been created as innovative natural food additives with antioxidant properties **(Savic Gajic *et al.*, 2022).** Additionally, because calendula extracts are poisonous to microorganisms like *Aspergillus niger* and *Penicillium sp.,* they have been suggested as novel natural food preservatives **(Pankiewicz and Podgorska-Kryszczuk, 2023).**

Small chemical compounds known as plant growth regulators (PGRs) have the ability to alter the quality and other characteristics of flowers. Plants either naturally produce them or synthesize them. Depending on its concentration and other inherent characteristics of the plant, GA_3 functions as both a stimulator and an inhibitor in growth metrics such as blossom weight and diameter **(Shrestha *et al.*, 2020).** The floriculture sector has changed as a result of the use of plant growth regulators. It can be applied to optimize advantage by overcoming limits related to growth, quality, and yield. In order to satisfy the increasing demand, flower farmers may be encouraged to cultivate calendula domestically by using GA_3 **(Shrestha *et al.*, 2020).** By reducing the action of ethylene, GA_3 reduces the senescence of flowers and promotes bloom production in most long-lived, cold-tolerant plants. The role of GA_3 in plants is not clear-cut, yet. In addition to increasing spike length, the number of flowers per spike, flower diameter, branch elongation, and vegetative development in the plant, the administration of GA_3 was found to dramatically reduce the number of days until flowering. Several studies have attempted to look into the function of GA_3 in growth and flowering in different plants **(Shrestha *et al.*, 2020).**

These days, the usage of growth regulators is crucial in lowering output, which alters and quantitatively boosts growth and development in little amounts. Flowers are pricey and used in various ways at social and religious events. Due to its extensive adaptability to a wide range of soil and climatic conditions, long flowering times, and beautifully colored, high-quality flowers. Growth regulators are employed in modest amounts to significantly improve the physiological processes of plants, perhaps leading to a significant improvement in yield and quality. According to **Kumar *et al.* (2014),** gibberellic acid has a significant impact on marigold development and flowering. In order to increase flower yield and facilitate cultivation, commercial plant growth regulators reduce apical dominance, delay vegetative growth, induce lateral buds, and produce a large number of flowers in a variety of crops **(Naidu *et al.*, 2014).** Similar to this, micronutrients in modest amounts affect flower crop growth, flowering, and yield quality. One mineral, zinc, encourages plants to store more carbohydrates through photosynthesis, which may be the cause of early flowering. The marigold crop reacts favorably to zinc and other micronutrients. Because zinc is involved in the manufacture of tryptophan, a precursor to auxin, it lowers the amount of auxin in plants. Marigold absorbs zinc in its ionic form **(Kumar *et al.*, 2010).** Since GA_3 is a component of florigen, which is primarily engaged in flower initiation in the plant system, early flower bud appearance following GA_3 treatment may be caused by early florigen production in GA_3-treated plants. Numerous researchers have also documented similar results regarding African marigold **(Palei *et al.*, 2016; Pragnyashree, 2017).** In order to satisfy the increasing demand, flower farmers may be encouraged to cultivate calendula domestically by using GA_3 **(Shrestha *et al.*, 2020).**

The main objective of this study is to investigate how GA_3 and $ZnSO_4$ affect the vegetative growth, flowering characteristics, and chemical comosition of marigold (*Calendula officinalis*) during the 2025 season.

MATERIALS AND METHODS

A field experiment was carried out in 2025 at the private farm of Tajoura-Libya evaluate the effects of $GA_3 + ZnSO_4$ on the growth, flowering, and chemical composition of *Calendula officinalis* under experimental settings.

Experimental Design

The experiment was conducted using a Randomized Complete Block Design (RCBD) with six treatments and three duplicates. The treatment's layout is as follows:

- Control
- GA_3 at 100 ml/l + $ZnSO_4$ 50 ml/l
- GA_3 at 150 ml/l + $ZnSO_4$ 75 ml/l
- GA_3 at 200 ml/l + $ZnSO_4$ 100 ml/l
- GA_3 at 250 ml/l + $ZnSO_4$ 150 ml/l
- GA_3 at 300 ml/l + $ZnSO_4$ 200 ml/l

The studied characters:

The following growth attributes were studied:

A) Vegetative growth:

- **Plant height (cm):** From 10 days after spraying until 100 days later, plant height was measured every ten days. Plant height was measured in centimeters using a meter scale from ground level to each plant's growing tip.
- **Number of leaves/plant:** The total number of leaves in the plant at the 50% flowering stage was counted to collect observations on the number of leaves per plant. The average number of leaves per plant was determined by adding the successive values; dead and decaying leaves were not counted.
- **Number of branches/ plant:** All of the branches of the chosen plants were counted in order to determine the average number of branches per plant.
- **Plant fresh weight (g):**
- **Leaf area index (cm^2):** Using an AM350 leaf area meter, a non-destructive method was used to determine the leaf area index. Square centimeters (cm2) were used to express the results.

B) Flowering parameters:

- **Flower diameter (cm):** Five flowers were chosen at random from each treatment plot to measure the diameter of each fully opened bloom, and the average flower diameter was computed.
- **Fresh weight of flower (g):** Each observational plant's single blossom was weighed using an electronic balance, and average results were computed and reported in grams.
- **Number of flowers/Plant:** The number of buds on a plant at ten-day intervals was used to determine the total number of blooms per plant.
- **Flower stalk length (cm):**
- **Flowering period (days):** The period of flowering was determined by counting the number of days between the initial and last flowering dates. The number of days needed for blossoming was noted by treatment.

C) Chemical analysis:

Chemical measurements: Using a colorimetric technique described by **AOAC, (2005),** the amount of total chlorophyll in leaves and total carotenoids was calculated as mg/100g fresh weight from flower petals. **Dere *et al.* (1998)** used spectro-photometric methods to quantify the total carotenoids in fresh petals (mg/g f.w.) in the acetone extract. The total carbohydrates (%) in the dry leaves were calculated using the phenol-sulfuric acid technique **(Dubois *et al.*, 1956).** According to **FAO (1980),** the micro-Kjeldahl device was used to calculate the percentage of total nitrogen in dry samples. **Jackson, (1976)** colorimetric approach was used to quantify the amount of phosphorus. The flame photometer, as described by **Brown and Lilleland (1946),** was used to measure potassium.

- **Statistical analysis**

Following a preliminary test for homogeneity of error variances as described by **Gomez and Gomez (1984),** statistical analysis was carried out using analysis of variance (ANOVA) appropriate for randomized complete block design (RCBD). The treatment means were compared at the 0.05 level of probability using the LSD test.

RESULTS AND DISCUSSIONS

A) Vegetative growth

The results displayed in **Table (1) and Fig. (1)** demonstrated that the administration of a high concentration of GA_3 + $ZnSO_4$ significantly affected the vegetative growth of Marigold (*Calendula officinalis*), including plant height, number of leaves, number of branches, total fresh weight, and leaf area index. However, results showed that high concentration of GA_3 at 300 ml/l+ $ZnSO_4$ 200 ml/l recorded the higher values of plant height (42.49 cm), number of leaves (174.28/ plant), number of branches (27.79/ plant), total fresh weight (447.55 g) and leaf area index (3.01 cm^2), followed by GA_3 at 250 ml/l+ $ZnSO_4$ 150 ml/l which recorded plant height (35.08 cm), number of leaves (151.32/ plant), number of branches (25.27/ plant), total fresh weight (384.20 g) and leaf area index (2.84 cm^2), as compared to control treatment which recorded the lower values of plant height (17.49 cm), number of leaves (89.58/ plant), number of branches (15.33/ plant), total fresh weight (302.32 g) and leaf area index (2.18 cm^2), respectively.

The results of this study indicated that a greater concentration of GA_3 treatment (350 ppm) was associated with the highest plant height. The favorable benefits of GA_3 are more noticeable at lower concentrations, which may be the result of increased chlorophyll content **(Arora *et al.*, 2012)** leading to enhanced photosynthetic activity, which further aided the maximum synthesis and use of phom assimilates. Additionally, **Khodakovskava *et al.* (2012)** observed that applying GA_3 at 350 ppm boosted the height of 26 Calendula plants. Additionally, Brassic Jance plants treated with 300 ppm of GA_3 had higher average plant heights **(Arora *et al.*, 2012).** Gibberellic acid (GA_3), which causes shoot elongation, may be the cause of the height increase **(Stepanova *et al.*, 2007).** The application of GA_3 at 250 ppm was found to be superior in terms of plant height, plant spread, number of branches, and leaf area index, according to the results **(Malik and Rather, 2017).** As the quantity of GA_3 grew, so did the number of branches per plant. A notable rise in the number of branches per plant may be the result of increased vegetative development, particularly in the plant's height, as a result of applying optimal GA_3, which causes more lateral branches. **Sunitha *et al.* (2007)** have earlier documented this in African marigold. After 30 days, the calendula crop was sprayed with a 100 ppm concentration, increasing the plant's productivity **(Arora *et al.*, 2012)** reported that the application of GA_3 increased the average number of secondary branches (36%), but there was a decrease in main branches up to 9% at 100 ppm and 25% at 350 ppm.

Growth hormones influence the expression of several genes that interact intricately to control leaf number **(Gonzalez *et al.*, 2010).** Leaf abscission is controlled by the plant hormone ethylene. Inhibition of ethylene activity has been found to lessen the occurrence of abscisson **(Seif *et al.*, 2011). Khodakovskaya *et al.* (2012)** found that tomato plants treated with 100 ppm GA_3 also had more leaves.

Higher concentrations of GA_3 may have accelerated cell elongation and multiplication, which may have stimulated plant development and, thus, increased plant height **(Benny *et al.*, 2017).** Gibbrellin may have a growth-promoting impact via raising the tissues' auxin levels or by improving the conversion of tryptophane to IAA, which led to cell division and elongation. Consequently, there was an increase in plant height **(Mishra, 2017),** which was consistent with the results of **Palekar *et al.* (2018)** in China aster. The application of GA_3 may have produced more leaves because of rapid development and differentiation **(Benny *et al.*, 2017).** The maximum number of branches per plant with GA_3 spray may be caused by the fact that GA_3 is well known for its prominent translocation and transcription mechanism of protein synthesis, as well as stimulation of cell division and elongation, while increasing the flexibility of cell walls and the synthesis of energy-rich phosphates, leading to an increased number of productive branches **(Deepti *et al.*, 2021).** The hyperelongation of internodal length and consequent increase in nodal count on the main axis may be the cause of the rise in branches with GA_3 therapy. As a result, these nodes produced more latent buds, which may have been the source of the main branches **(Delvadia *et al.*, 2009).** Increased leaf area leads to more photosynthesis and the buildup of more carbohydrates in the plant body, which aids in early flowering, bud initiation and opening, and an increase in the number of flowering and flower buds, all of which eventually result in higher yield. Additionally, the results are consistent with those of **Singh and Sharma (2004)** for calendula, **Nair *et al.* (2002) and Dalal *et al.* (2009)** for gerbera, **Priyanka and Singh (2012)** for tuberose, **Singh (2004)** for California poppy, and **Prashanth *et al.* (2006)** for floribunda rose cv. "Iceberg". **Dheeraj and Saravanan (2018)** found that applying GA_3 at 300 ppm produced the highest number of flowers per plant as well as the highest yield of flowers per plant.

The application of the micronutrient $ZnSO_4$ has a significant impact on plant height because it promotes cell division, multiplication, and differentiation, which increases photosynthesis and food material translocation. It also improves the plant's root system, which increases water and nutrient absorption and utilization. Additionally, micronutrients participate in a number of physiological processes and activate a number of enzymes, including catalase, carbonic dehydrogenase, and tryptophan synthases. **Kakade *et al*. (2009)** in China aster, **Balakrishnan (2005)** in marigold, and **Ahmad *et al.* (2010)** in rose all reported similar findings.

The findings suggested that the foliar application of zinc may be promoting metabolic activity with a stimulating effect on cell wall loss, increased cell elongation along with cell enlargement and differentiation, leading to increased photosynthesis and food material translocation, which may increase the number and length of leaves. In Gerbera, **Bashir *et al.* (2013); Pal *et al.* (2016)** both reported similar outcomes.

Micronutrients like zinc sulfate ($ZnSO_4$), which is a necessary component of several dehydrogenases, proteinases, and peptidases and is closely linked to hormone growth, may be the cause of the increased number of Branches. These factors all contributed to cell division, multiplication, and differentiation, which increased photosynthesis and food material translocation, which in turn increased the number of branches, **Pal *et al*. (2016)** in Gerbera verified the aforementioned outcome.

Table (1): Impact of GA_3 and $ZnSO_4$ on vegetative growth of marigold (*Calendula officinalis*) in 2025 season.

Treatments	Plant height (cm)	No. of leaves	No. of Branches/ plant	Total fresh weight (g)	Leaf area index (cm^2)
Control	17.49	89.58	15.33	302.32	2.18

GA_3 100 ml/l+ $ZnSO_4$ 50 ml/l	27.26	96.68	17.27	342.76	2.41
GA_3 at 150 ml/l+ $ZnSO_4$ 75 ml/l	30.38	102.82	19.86	353.99	2.47
GA_3 at 200 ml/l+ $ZnSO_4$ 100 ml/l	33.39	117.11	23.95	372.60	2.66
GA_3 at 250 ml/l+ $ZnSO_4$ 150 ml/l	35.08	151.32	25.27	384.20	2.84
GA_3 at 300 ml/l+ $ZnSO_4$ 200 ml/l	42.49	174.28	27.79	447.55	3.01
L.S.D$_{(0.05)}$	**5.84**	**25.95**	**3.37**	**10.43**	**0.26**

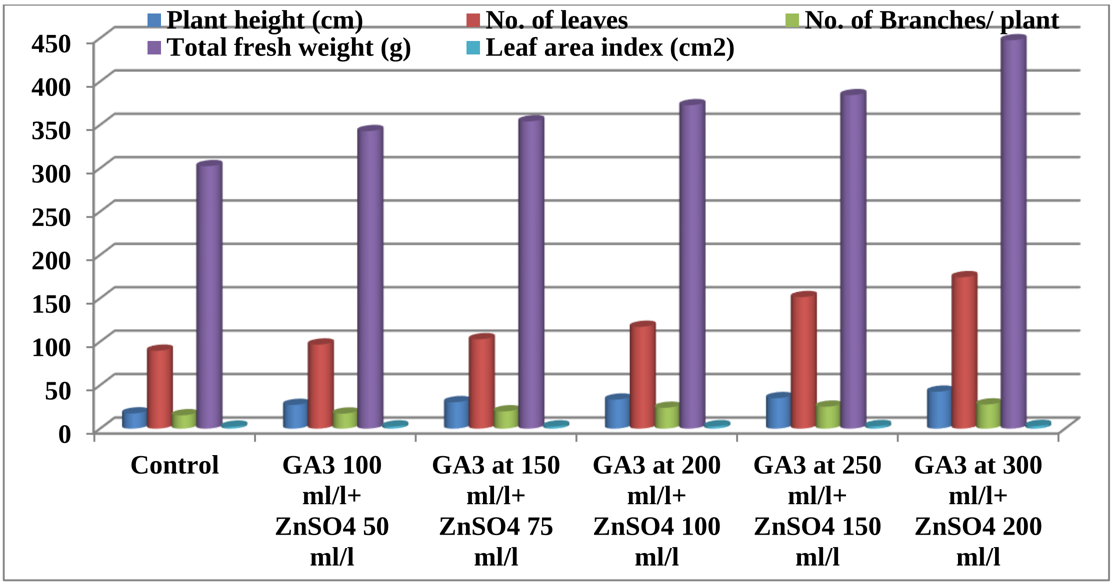

Fig. (1): Impact of GA_3 and $ZnSO_4$ on vegetative growth of Marigold (*Calendula officinalis*) in 2025 season.

B) Flowering parameters

The results displayed in **Table (2) and Fig. (2)** demonstrated that the administration of a high concentration of GA_3+ $ZnSO_4$ significantly affected the flowering parameters of Marigold (*Calendula officinalis*), including flower diameter, fresh weight of flower, number of flowers/plant, flower stalk length and flowering period, during 2025 season. However, results showed that high concentration of GA_3 at 300 ml/l+ $ZnSO_4$ 200 ml/l recorded the higher values of flower diameter (5.89 cm), fresh weight of flower (5.64 g), number of flowers/plant (39.38), flower stalk length (29.74 cm) and flowering period (155.85 days), followed by GA_3 at 250 ml/l+ $ZnSO_4$ 150 ml/l which recorded flower diameter (5.67 cm), fresh weight of flower (5.39 g), number of flowers/plant (32.85), flower stalk length (27.09 cm) and flowering period (153.26 days), as compared to control treatment which recorded the lower values of flower diameter (4.75 cm), fresh weight of flower (4.61 g), number of flowers/plant (17.59), flower stalk length (16.98 cm) and flowering period (143.56 days), respectively.

The elongation of the flower's cells may be connected to the rise in floral diameter. Additionally, it has been shown that gibberellins strengthen the sink of sections that are actively developing **(Kuri *et al.*, 2018).** The creation of more branches with a decent number of developed flowers on the branches is the primary cause of the increased number of blooms. The increased number of flowers per plant may be the result of the plant producing more laterals at an earlier stage of development and having more time to accumulate carbohydrates for flower bud differentiation as a result of the plant's increased reproductive efficiency **(Kumar *et al.*, 2018).** The increased number of flowers on each stem may be the result of the plant producing more laterals during a previous stage of growth and having more time to accumulate carbohydrates for flower bud differentiation as a result of increased reproductive efficiency **(Sathappan, 2018).** The fact that GA_3 increases the plants' efficiency in terms of photosynthetic activity, nutrient absorption and translocation, and better assimilate partitioning into reproductive organs may be the reason for the increase in fresh weight of flowers in GA_3-treated plants **(Sindhuja and Prasad, 2018).** According to **Kumar *et al.* (2014),** GA_3's higher performance is attributable to its involvement in improving cell division and elongation, which encourages stronger vegetative and floral growth and increases flower yield. Due to increased meristematic region size, improved cell division and enlargement, promotion of protein synthesis, and increased dry matter, plants that get gibberellic acid in the ideal ratio may have higher-quality flowers **(Kasturi and Shekhar, 2017).** Gibberellins may promote cell elongation by boosting the mobilization of starch in cotyledons through enhanced amylase activity caused by the hydrolysis of starch resulting from the formation of GA_3 **(Kaur *et al.*, 2000).**

The reason for this outcome is that GA_3 promoted cell elongation and division. Additionally, GA_3 causes meristematic tissue development to occur earlier. Additionally, GA3 reduces the amount of ABA in plant shoots, which results in early flowering and flower initiation **(Phengphachanh *et al.*, 2012**). Gibberellins' ability to shorten the juvenile phase may also contribute to early flowering **(Palei *et al.*, 2016).** Additionally, it increases the amount of carbohydrates in the plant's body, which causes early flower bud initiation and bud opening. Research on calendula by **Sardoei and Shahdadneghad (2014); Dheeraj and Saravanan (2018)** also revealed similar findings. The increased number of flowers could be the result of the plant producing more laterals in the early stages of growth, which would allow adequate time for the buildup of carbohydrates for flower bud differentiation due to the plant's increased reproductive efficiency **(Kumar *et al.*, 2014).** According to **Sharifuzzaman *et al.* (2011),** the application of GA_3 may enhance the number of flowers because it increases the number of cells, which in turn increases the number and area of leaves. More blooms may have been created as a result of increased photosynthate synthesis and accumulation that was redirected to the sink. **Kumar *et al.* (2012),** who observed a significant increase in the quantity of blooms when plants were treated with GA_3 at 150 ppm in carnations, corroborate these findings. **Zalewska and Antkowiak (2013)** observed that *Ajania pacificaas* flower bud growth was increased by double application with GA_3.

Zinc and other micronutrients encourage photosynthesis to store more carbohydrates, which may help flowers bloom earlier. **Senthamizhselvi (2000); Jadhav (2004)** observed similar findings in Gerbera. This could be because more food material was produced, which led to an increase in quality criteria like blossom diameter and stalk length. Similar findings in tuberose were also reported by **Nag and Biswas (2003); Hardeep *et al.* (2003).** The outcome may be attributed to micronutrients like zinc, which aid in controlling the semi-permeability of cell walls, allowing more water to enter flowers and boosting iron synthesis, which increases flower weight and size. **Nag and Biswas (2003)**; **Hardeep *et al.* (2003)** similarly observed similar outcomes in tuberose. When zinc was applied, the plants recovered from chlorosis and developed healthy green leaves. This led to increased assimilate synthesis and floral development partitioning, which may ultimately boost flower production and yield. **Pal *et al.* (2016)** in Gerbera and **Nath and Biswas (2002)** in tuberose have reported similar findings. Gibberellins' capacity to alter plants' photoperiodic needs, which are crucial for floral anthesis, may be the cause of earlier anthesis when GA_3 is applied. Similar findings were reported in African marigold by **Kumar *et al.* (2015); Mithilesh *et al.* (2014).**

Advanced bud development and promoting flowering in GA_3-treated plants may be the cause of the longer flowering period. The availability of GA_3 under treatments may be the cause of the longer bloom length; hence, the flowering period may have grown dramatically. In African marigold, **Mithilesh *et al.* (2014), Kumar *et al.* (2015); Pragnyashree (2017)** reported similar findings. Gibberellins' ability to encourage cell proliferation and elongation in the flower bud region, along with the large amounts of carbohydrates translocated in the developing flowers, may be the cause of the notable rise in flower stalk length. **Pragnyashree (2017), Dalal *et al.* (2009); Tyagi and Kumar (2006)** reported the longest flower stalk length in African marigold as a result of GA_3 treatment. The increased girth of the flower stem may be the result of GA_3's stimulation of cell proliferation and cell elongation. The availability of GA_3 under treatments may be the cause of the longer bloom duration; hence, the lowering period may have increased considerably. Numerous studies have also observed similar results with the African marigold cv. Pusa Narangi Gainda **(Tyagi and Kumar 2006; Ramesh Kumar *et al.*, 2010).** There may be more flowers since there are more branches. The plant produced more flowers per plant as a result of the lateral branches growing as the apical dominance of the plant was reduced. This result is consistent with **Ramesh *et al.* (2010); Palei *et al.* (2016); Tyagi and Kumar (2006).** The development of more and larger blooms may be the cause of the rise in fresh weight of flowers per plant with GA_3. This could be explained by the cell's quick synthesis, enlargement, elongation, and quick transfer of assimilates to sink when phytohormones are present. **Mithilesh *et al.* (2014), Palei *et al.* (2016); Pragnyashree (2017)** observed similar outcomes for African marigold cv. Pusa Narangi Gainda.

According to **Tripathi *et al.* (2003),** spraying French marigold with GA_3 at doses of 100, 200 and 300 ppm improved flower output per plant. According to **Balakrishnan *et al.* (2007),** the delivery of nutrients at varying levels causes a rapid rise in cell size, which is reflected in the size and weight of the flowers in African marigolds. This may be because a longer growing season increases both the number of flowers per plant and the number of harvests per plant. Increased micronutrient levels in leaves may have contributed to the plants' ability to generate more blooms by aiding in photosynthesis, IAA breakdown, auxin synthesis, and protein synthesis **(Muthumanikam *et al.*, 1999).** Crop lifespan may be extended by vegetative growth and cell division, cell expansion, enhancement of protein synthesis with increased apical dominance, and optimal GA_3 concentration. The intensification of the sink may have drawn photosynthetes to the lower, increasing cell division and elongation of GA_3, which may have been exploited to produce high-quality flowers in African marigold. This outcome closely aligns with the results of **Ramdevputra *et al.* (2009); Tyagi *et al.* (2006).**

Zinc used topically is essential for plant growth, according to **Bharracharjee (1993).** Zinc is involved in the processes of photosynthesis, indole acidic acid metabolism, protein synthesis, and auxin synthesis. Cell division, development, and respiration caused the fresh flower weight to reach its maximum **(Khosa *et al.*, 2011).** Similar findings were reported by **Sharma *et al.* (2013),** who came to the conclusion that foliar zinc spray improved the fresh flower weight of gladiolus. **(Shah and others, 2015)** observed that the greatest fresh weight of marigold was obtained with a 0.5% zinc sulphate application.

Table (2): Impact of GA_3 and $ZnSO_4$ on flowering parameters of marigold (*Calendula officinalis*) in 2025 season.

Treatments	Flower diameter (cm)	Fresh weight of flower (g)	No. of flowers/ Plant	Flower stalk length (cm)	Flowering period (days)
Control	4.75	4.61	17.59	16.98	143.56
GA_3 100 ml/l+ $ZnSO_4$ 50 ml/l	5.10	4.97	20.69	19.01	146.66
GA_3 at 150 ml/l+ $ZnSO_4$ 75 ml/l	5.29	5.20	26.58	21.53	149.38
GA_3 at 200 ml/l+ $ZnSO_4$ 100 ml/l	5.46	5.32	29.68	25.09	151.97
GA_3 at 250 ml/l+ $ZnSO_4$ 150 ml/l	5.67	5.39	32.85	27.09	153.26
GA_3 at 300 ml/l+ $ZnSO_4$ 200 ml/l	5.89	5.64	39.38	29.74	155.85

L.S.D$_{(0.05)}$	**0.16**	**0.17**	**2.07**	**0.86**	**13.00**

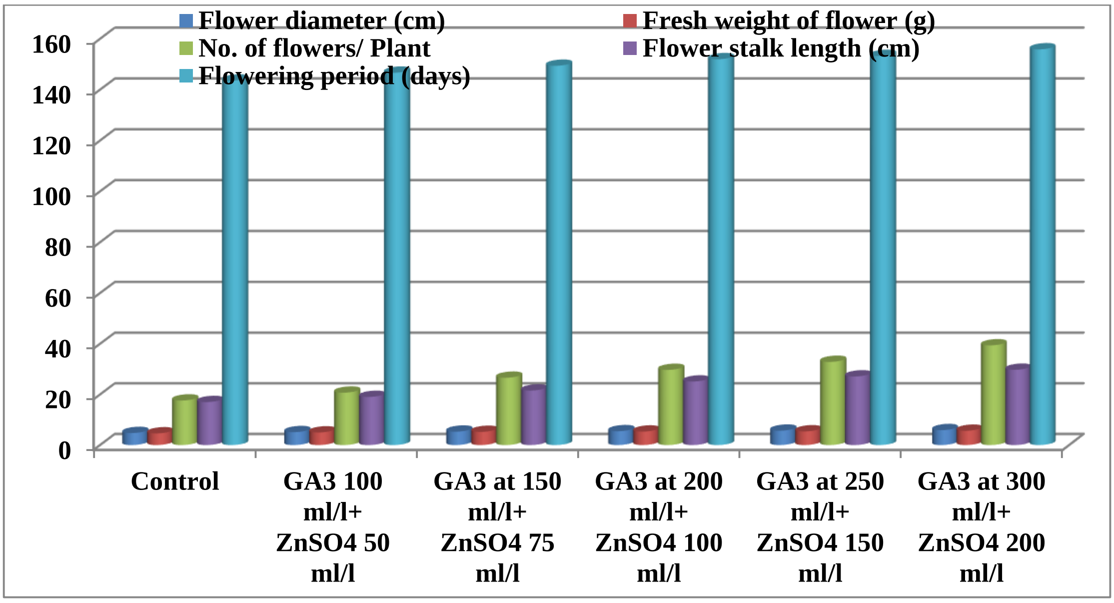

Fig. (2): Impact of GA_3 and $ZnSO_4$ on flowering parameters of marigold (*Calendula officinalis*) in 2025 season.

C) Chemical composition

The results displayed in **Table (2) and Fig. (2)** demonstrated that the administration of a high concentration of GA_3 $ZnSO_4$ significantly affected the chemical composition of Marigold (*Calendula officinalis*), including nitrogen, phosphorus, potassium, total carbohydrates, total chlorophyll and carotein during 2025 season. However, results showed that high concentration of GA_3 at 300 ml/l+ $ZnSO_4$ 200 ml/l recorded the higher values of nitrogen (2.82 %), phosphorus (0.37%), potassium (2.35 %), total carbohydrates (2.28 mg/g), total chlorophyll (2.24 mg/100g f.w.) and carotein (16.64 mg/100g f.w.), followed by GA_3 at 250 ml/l+ $ZnSO_4$ 150 ml/l which recorded nitrogen (2.28 %), phosphorus (0.32%), potassium (1.93 %), total carbohydrates (51.05 mg/g), total chlorophyll (2.13 mg/100g f.w.) and carotein (15.41 mg/g), as compared to control treatment which recorded the lower values of nitrogen (1.95 %), phosphorus (0.22%), potassium (1.26 %), total carbohydrates (30.51mg/g), total chlorophyll (1.24 mg/100g f.w.) and carotein (7.14 mg/100g f.w.), respectively.

When compared to control plants, treated plants with any dosage of micronutrient mixture often produced the highest quantities of the aforementioned records. These findings could be explained by the micro-elements' beneficial effects on the majority of metabolic activities, including the synthesis of ribosomes, proteins, carbohydrates, and phosphate RNA **(Mostafa *et al.*, 1997).** In this regard, **Hassanain *et al.* (2006)** on chamomile plants, **Rady *et al.* (2005)** on amaryllis plants, **Ebtsam *et al.* (2006)** on *Polianthes tuberosa*, and **Naguib *et al.* (2007)** on *Ruta graveolens*.

The creation of rough endoplasmic reticulum, which offers the proper substrate for growing polyribosome and mRNA, may be the cause of plant growth regulators' increased protein content **(Kaber, 1987).** These findings are consistent with research on *Asparagus sprengeri* by **Ebtsam and Rady (2005),** *Calendula officinalis* by **Azzaz *et al.* (2007),** *Hemerocallis auantiaca* by **Ismaeil and Youssef, (2008),** *Solidags Hybrida* by **Kazaz and Karaguzel (2010),** and *Palanites aegyptiaca* plants by **Mostafa and Abou-Alhamd, (2011).** They came to the conclusion that spraying GA_3 at any concentration had clear boosting effects on the chemical composition of plants.

Table (3): Impact of GA_3 and $ZnSO_4$ on chemical composition of Marigold (*Calendula officinalis*) in 2025 season.

Treatments	N (%)	P (%)	K (%)	Total Carbohydrates (mg/ g)	Total chlorophyll (mg/ 100 g f.w.)	Caroten (mg/100g f. w.)
Control	1.95	0.22	1.26	30.51	1.24	7.14
GA_3 100 ml/l+ $ZnSO_4$ 50 ml/l	2.15	0.24	1.37	37.19	1.57	12.51
GA_3 150 ml/l+ $ZnSO_4$ 75 ml/l	2.20	0.26	1.41	40.19	1.69	13.12
GA_3 200 ml/l+ $ZnSO_4$ 100 ml/l	2.23	0.29	1.54	46.86	1.88	14.37
GA_3 250 ml/l+ $ZnSO_4$ 150 ml/l	2.28	0.32	1.93	51.05	2.13	15.41
GA_3 300 ml/l+ $ZnSO_4$ 200 ml/l	2.82	0.37	2.35	54.01	2.24	16.64
L.S.D$_{(0.05)}$	**0.09**	**0.02**	**0.07**	**4.58**	**1.08**	**0.82**

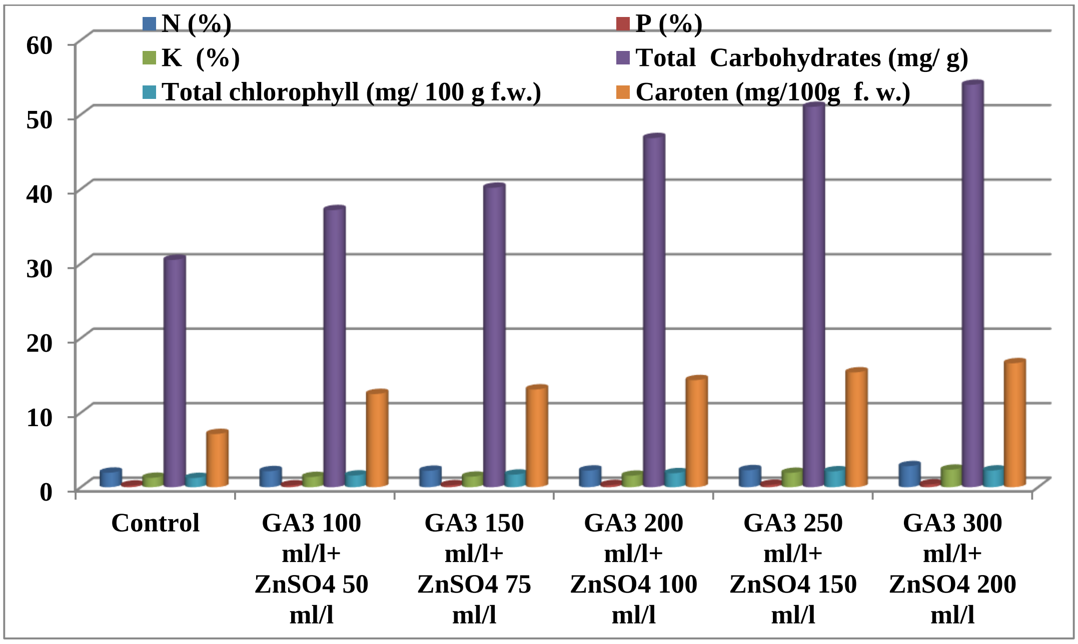

Fig. (3): Impact of GA_3 and $ZnSO_4$ on chemical composition of marigold (*Calendula officinalis*) in 2025 season.

Conclusion:

Gibberellins are a crucial regulator of plant growth and development, particularly when it comes to the photoperiodic regulation of flowering. Gibberellic acid is essential for the growth and development of plants. It has been shown to be the most effective in improving flower crops' vegetative and blooming characteristics. Additionally, zinc is involved in the synthesis of RNA, the absorption of phosphorus, and the synthesis of carbohydrates. It has been observed that zinc plays a crucial role in the growth and development of plants and is a necessary component of many enzymes. Zinc is a crucial micronutrient for plants and is essential to many of their functions. Zinc plays a significant role in the formation of ribosomes and aids in the synthesis of proteins in plants. Zinc interacts with other elements and is an active nutrient in many biological and chemical processes, which increases the intake of other elements. Zinc, which is essential for plant growth, is also linked to auxin synthesis.

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