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Influence of Gibberellic Acid (GA_3) and Zinc on Growth Dynamics and Yield of Saffron (*Crocus Sativus* L.) Under the Agro-Climatic Conditions of District Bajaur

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Abstract

Saffron (*Crocus sativus* L.) is the world's most valuable spice, yet its productivity in Pakistan remains low, largely due to inadequate management of PGRs and micronutrients. Despite their recognized role in enhancing crop performance, limited empirical evidence exists on their impact on saffron in Pakistan. Therefore, the present study evaluated the effects of GA_3 and Zn on the growth and yield attributes of saffron. A field experiment was conducted using GA_3 at 0, 50, 100, and 150 ppm and zinc at 0, 0.2, 0.4, and 0.6%, with corms immersed in the respective solutions before planting. Recommended spacing (15 cm × 20 cm) was maintained in 1.0×1.0 m^2 plots. Growth and yield parameters, including number of corms per mother plant, corm weight per mother plant, leaf length $plant^{-1}$, total corm weight $plot^{-1}$ and number of flowers, were recorded. The highest number of corms per mother plant (5.8), corm weight (55.5 g), leaf length (16 cm), total corm yield (1558.3 g $plot^{-1}$) and flowers (56) were obtained with GA_3 application at 150 ppm. Similarly, zinc application up to 0.6% improved corm number (8.8), corm weight (52.8 g), leaf length (18 cm), total corm yield (1603.4 g $plot^{-1}$) and flowers (58). GA_3 × Zn interactions were non-significant. Optimum levels of GA_3 and Zn were 150 ppm and 0.6% respectively, and significantly showed better performance. Further studies with GA_3 concentrations above 150 ppm are recommended to identify the optimal dose for maximizing yield.

Keywords: Saffron, Corms, GA_3, Zn, Stigma and Flower.

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Introduction

Saffron (*Crocus sativus* L.) is an herbaceous perennial plant belonging to the family Iridaceae. (Mardani *et al*., 2015). It is widely known for its valuable stigmas that are used in culinary, medicinal, and cosmetic applications. Saffron is indigenous to the Mediterranean region and has been cultivated for more than 3,000 years. The cultivation of saffron has a long and rich history and is deeply intertwined with the culture and traditions of many countries. (Koocheki and Seyyedi, 2020; Fallahi and Mahmoodi, 2018).

The leaves of saffron from corms emerge along with or after the flowers. Each flower has one red pistil and three golden-yellow stamens. Actually, pistil is made up of three thread-like stigmas when dried, which is known as the saffron spice (Dar et al., 2017). It is grown for its vibrant red-orange stigmas, which are harvested by hand and processed into a spice. The high cost of saffron is attributed to the labour-intensive harvesting process, as well as the relatively low yield of stigmas per plant (Behnia, 1996). The economic yield of saffron is often expressed in terms of the weight of the harvested saffron stigmas. Each saffron crocus flower produces only a few stigmas, and due to the labour-intensive process of harvesting and processing, saffron is one of the most expensive spices in the world (Pardossi et al., 2015).

The saffron plant has also been utilized in traditional medicine to treat a wide range of ailments, including depression, anxiety, and inflammation. (Akhondzadeh et al., 2008). Saffron is cultivated in many countries, including Spain, Morocco, Iran, Pakistan, India, Turkey, Central Asia, Italy, and Switzerland, as well as with new cultivations in Mexico, Australia, Argentina, and New Zealand. Iran is one of the leading producers of saffron globally (Jalali-Heravi et al., 2010). Saffron has been found to contain several bioactive compounds, including crocin, picrocrocin, and safranal, which have been shown to have various health benefits, such as antioxidant, anti-inflammatory, and anticancer properties (Koocheki and Seyyedi, 2020).

Micronutrients like zinc are crucial for crop production, and their importance in recent years has increased than before. In crop production worldwide, zinc in particular is considered to be the most important limiting micronutrient in yield (Karimmojeni et al., 2022; Noryan et al., 2021). Growth promoters such as gibberellins (GA3) enhance plant growth and developmental processes like dormancy breaking, germination, flower initiation and stem elongation. GA_3 is involved in the regulation of cell elongation, stem growth, seed germination, and flowering. GA_3 also plays a role in the biosynthesis of chlorophyll, which is important for photosynthesis.

In Pakistan, where saffron yield is low, and micronutrient deficiencies like zinc are common, it is important to find out optimum levels of GA_3 and Zn application to enhance saffron quality and yield for optimal production (Koocheki and Seyyedi, 2020; Fallahi and Mahmoodi, 2018). However, saffron cultivation is often limited by several abiotic and biotic factors, such as low soil fertility, pest and disease pressure, and adverse weather conditions. Various cultivation techniques have been developed to overcome these challenges and increase the productivity and quality of saffron. These include corm dipping in nutrient and hormone solutions, irrigation management, and pest and disease control strategies.

Despite the recognized role of plant growth regulators and micronutrients in improving crop performance, there remains a clear research gap regarding their optimized use for saffron, particularly under the developing saffron-growing environments of Bajaur. Limited scientific evidence exists on how varying concentrations of GA_3 and zinc influence corm multiplication, vegetative vigour, and flower production when applied as pre-planting corm treatments. Therefore, this study was designed to address these knowledge gaps by evaluating the response of saffron to graded levels of GA_3 and zinc. Specifically, the research aimed to determine how these inputs affect key growth and yield parameters and to identify the most effective concentrations for improving crop performance.

Based on this purpose, the study was guided by two core research questions: (i) how do different concentrations of GA_3 and zinc influence saffron growth and yield components, and (ii) which concentration combination maximizes its agronomic performance under local conditions. The innovative aspect of this work lies in its application of GA_3 and zinc through corm immersion, a simple, low-cost intervention not previously tested in this region and its generation of first-hand empirical data relevant to the emerging saffron sector of Bajaur. The findings provide a technical basis for refining saffron management practices and guiding future research on hormonal and micronutrient optimization.

This research article aims to provide a comprehensive overview of the saffron plant and, in particular, will focus on the effect of corm dipping in zinc and gibberellic acid (GA_3) solutions on saffron growth and productivity. Flowers and better corm production a challenging factors in Pakistan, which need to be boosted. The weight and size of the corms have a vital effect on production. The better productivity of saffron is highly dependent on the proper fertilizer management. Therefore, keeping in view this, due to the less saffron production and the use of vital micronutrients and PGRs, especially zinc & GA_3 deficiency in Pakistan, it is essential to investigate appropriate Zinc and GA_3 level application in order to enhance saffron quality and yield.

Materials and methods

The field experiment was conducted as a Randomized Complete Block Design and replicated thrice at the Agriculture Research Sub-Station (Merged Area), district Bajaur. Saffron corms were received from the Directorate of Agriculture Research (MAs), ARI, Tarnab, Peshawar, under the specific and proper supervision of the Agriculture Research System, KP. Corms having an average weight of 10 to 12 gm with no mechanical damage and contamination were selected after cleaning, grading, and then disinfected with 2% benomyl solution for the inhibition of any disease occurrence. Required numbers of healthy corms were separated for each plot and then subjected to specified solutions. Solutions of GA_3 (0, 50, 100 & 150 ppm) and zinc (0, 0.2, 0.4, & 0.6 %) in distilled water (control) were prepared as per protocol. Zinc sulphate was used as a source for percent zinc solutions. The experiment was laid out using a two-factor factorial arrangement under RCBD. The two factors included GA_3 and Zn, each evaluated at four levels. This resulted in a total of 16 treatment combinations (4 GA_3 levels × 4 Zn levels = 16), and each treatment was replicated three times, making a total of 48 experimental plots for which sixteen separate solutions of different concentrations as per experimental factors were prepared in a large-sized beaker. Then the dormant saffron corms of similar size and 10 to 12 gm were dipped for 30 minutes. Corms surfaces were dried for some time after dipping and finally planted according to recommended technology in the prepared field. All the conventional farm management practices, including fertilization, irrigation and weeding, were carried out as required, while no insecticides or herbicides were sprayed. Saffron corms were planted in 1×1 m^2 plots at a depth of 10 cm, having plant-plant distance of 15 cm and row-row distance of 20 cm (30 corms $plot^{-1}$) after land preparation and field plotting. Five rows were prepared in each plot, and six corms were sown in each row. Beds were separated by an unplanted area 30 cm wide for ease & smooth movement. A total of sixteen plots were cultivated according to the experimental protocol. Corms were sown in September. After sowing in plots, immediately first irrigation was applied and to avoid drought stress, subsequent irrigations were given on time. During the growing season, the irrigation of the farm was applied smoothly, and to all treatments, the recommended crop production practices were given. In all plots, weeds were ruined and controlled manually. At the end of the growing season total number and weight of produced corms were measured, for which one third of the cultivated corms were harvested. Daily, the flowers were harvested, and the no. of flowers/plot was taken during the flowers' initiation. Fresh corolla and stigma were separated from all flowers per plot manually in the morning and were kept at a room temperature of 20 °C for 24 hours, and were kept for drying for further use.

It has been acknowledged that the importance of stigma yields data for a comprehensive yield assessment. However, in the present study, the experimental plots were of limited size, and the total number of flowers produced per plot was correspondingly small. As a result, the total stigma biomass obtained after drying was extremely low (in the range of a few milligrams), which was below the detection sensitivity of the laboratory's available weighing equipment. A microbalance with sub-milligram precision, which is essential for accurate quantification of such minute samples, was not available at the laboratory. Despite this constraint, the recorded parameters, including the number of flowers per plant, number and weight of daughter corms, etc., serve as reliable proxy indicators of saffron yield potential. Previous studies have reported strong correlations between floral density, corm size, and ultimate stigma yield, confirming that these vegetative and reproductive attributes are predictive of the crop's productive capacity (Koocheki et al., 2013; Kumar et al., 2009). Therefore, while direct stigma weight could not be quantified, the measured parameters still provide valid insights into the physiological response of saffron to GA_3 and zinc treatments.

The fertilizer recommendations were given at sowing as a basal dose on the basis of soil analysis results analyzed by the Soil and Water Testing Laboratory, Agriculture Research, District Bajaur. However, zinc determination was carried out at PCSIR Laboratories Complex, Peshawar.

The nutritional fertility status of the experimental site and other properties are mentioned below.

Determinants	Results
Organic matter	0.81%
pH	7.8
Phosphorus (P)	5.09 ppm
Total Nitrogen	0.036 %
Potassium (K)	95 ppm
Texture class	Silt Loam
EC	0.12 dS/m
Lime Content	2.2 (%)
Zinc	10.4 mg/kg

Statistical analysis

Statistical analysis of data was done using Stat 8.1 software for ANOVA, and the mean differences were compared using the LSD test with a significance level of 5%.

Results and discussion

Zinc and GA_3 are two important compounds that play a vital role in plant growth, yield and quality. Zinc plays a critical role in multiple plant processes. It is essential for chlorophyll production and carbohydrate formation. GA_3 is an essential growth regulator that enhances growth and the developmental process and their associated physiological and biochemical events, etc. Both factors significantly affected the studied attributes of saffron.

Number of corms produced per mother plant

The total number of corms was significantly influenced by the growth regulators GA_3. (Table 1). The highest number of corms (5.8) was produced in 150 ppm GA_3, while the lowest no. of corms (3.3) was observed in the control treatment. Similarly maximum number of corms (8.8) was observed application of 0.6 % Zinc & minimum (5.2 corms) was observed in the control. Non-significant interaction was observed. Application of optimum plant growth regulator may activate the metabolic processes in saffron corm and may increase the no. of corms/plant and also enhance the size and weight of the produced corms. Studies on gladiolus (*Gladiolus grandiflorus* L.) have suggested that certain high doses of GA_3 (e.g., 200 ppm) can actually increase the number of cormels (small corms) per plant or the weight of corms per mother corm, depending on the cultivar and application method (Rahman et al., 2020). GA_3 primarily promotes cell elongation and vegetative growth rather than corm multiplication or assimilate allocation toward storage organs (Taiz and Zeiger, 2015). Therefore, the GA_3 treatment produced fewer but relatively heavier corms, whereas zinc enhanced both the number and cumulative biomass. Douglas (2003) described a general inverse relationship between corm number and individual corm size due to resource competition; this relationship is not absolute but contingent upon the plant's overall assimilate supply and nutrient status. GA_3 treatments have been shown to stimulate cell division and elongation, leading to increased plant growth and biomass. Enhanced vegetative growth can result in larger corms and potentially greater corm production. Additionally, GA_3 treatments have been explored for their ability to promote flowering in some species, which could indirectly influence corm production. (Turhan et al., 2007).

The application of zinc is that it is very crucial for carbohydrate and chlorophyll formation, also it is also closely involved in the nitrogen metabolism of plants. Zinc is required in very small amounts by plants, but in recent years, in crop production, its importance has increased (Mandal et al., 2000). Zinc is an essential micronutrient for plant growth and development. It plays a crucial role in various physiological processes, including hormone regulation, enzyme activities, and photosynthesis. The apparent inconsistency between the number of corms per mother plant and the total corm weight under zinc treatment (Table 1) can be explained through the physiological influence of zinc on source-sink dynamics and assimilate partitioning. Zinc plays a fundamental role in the regulation of auxin synthesis, enzyme activation, and carbohydrate metabolism, which together enhance both photosynthetic activity and assimilate translocation efficiency (Alloway, 2008; Broadley et al., 2007). Under zinc application, the enhanced photosynthetic rate and improved nutrient uptake likely increased the total pool of available assimilates, thereby allowing the mother plant to support a greater number of corms without a proportional decline in individual corm weight. This suggests that zinc improved overall biomass production and partitioning efficiency, leading to more but sufficiently developed corms.

While there isn't an extensive body of literature specifically focused on the effects of zinc on corm production in all plant species, zinc's influence on overall plant growth and reproductive development indirectly impacts corm production. (Kumar et al., 2013).

Weight of corms per mother plant

With the application of GA_3 and Zinc weight of the corms is significantly affected, as both have a key role in promoting other essential PGRs for the enhancement of the physiological functions of plants. The maximum weight of the produced corms (55.5 gm) was obtained in 150 ppm GA_3, and the minimum weight of corms (26.4 gm) was recorded in the control. Similarly, a better weight of the corms (52.8 gm) was obtained with 0.6 % Zn, and less weight of the produced corms (28.6 gm) was obtained in the control. Douglas (2003 explained that the no. of daughter corms obtained from a mother corm is closely related to the weight of each produced daughter corm. As the number of lateral buds and daughter corms is increased, the weight of each produced corm decreases, which have a key is very important in the final yield. Determining the non-flowering or flowering daughter corms' weight and size is one of the vital indicators. Before the corms reached the base weight of almost 8 g, the flowering process did not start in the daughter corms (Turhan *et al.*, 2007; Mollafilabi, 2004; Renau-Morata et al., 2012). It was revealed that the use of some plant growth hormones, like gibberellic acid, reduces the production of daughter corms and lateral buds' development in mother corms and in bulbous plants, which leads to increased size of mother corms and maximum flower yield (Azizbekova *et al.*, 1982; Azizbekova and Milyaeva, 1999).

Zinc, rather than reiterating its general enzymatic role, the revision highlights more advanced mechanisms that align with the observed corm responses. Recent studies show that zinc influences *auxin biosynthesis and meristematic activity*, which can enhance corm multiplication by promoting active cell division in developing daughter corms (Cakmak, 2008; Hafeez et al., 2013). Moreover, zinc has been reported to regulate *carbohydrate partitioning* and improve *membrane stability*, allowing plants to allocate assimilates more efficiently during corm formation, which provides a more meaningful explanation for the higher corm number recorded in zinc-treated plots (Broadley et al., 2007). Insufficient zinc in plants leads to a notable reduction in carbohydrate, protein, and chlorophyll production. Hence, an uninterrupted and steady zinc supply is essential for optimal growth and maximum yield.

Table 1: Effect of different gibberellic acid (ppm) and zinc (%) levels on the number of corms per mother plant, weight of corms per mother plant (gm), leaf length plant^{-1}, weight of corms produced plot^{-1} (gm) and number of produced flowers.

GA_3 (ppm)	Number of corms per mother plant	Weight of corms per mother plant (gm)	Leaf length plant^{-1}	Weight of corm produced plot^{-1} (gm)	Number of flowers produced plot^{-1}
Control	3.3	26.4	09	867.2	27
50	4.2	37.8*	11*	1100.0	34*

100	5.2*	42.1**	14**	1291.7*	41**
150	5.8**	55.5***	16***	1558.3**	49***
LSD value at α 0.05	0.98	4.63	1.21	249.31	3.27
Zn %					
Control	5.2	28.6	10	947.0	28
0.2	6.8	40.5*	13*	1199.5	32
0.4	8.2*	48.3**	16**	1430.1*	40*
0.6	8.8**	52.8***	18***	1603.4**	46**
LSD @ at α 0.05	1.03	3.64	1.46	211.71	3.42
Interactions	-----------	-----------	-----------	-----------	-----------
Significance Level	N.S	N.S	N.S	N.S	N.S

N.S: *Non-significant.*

Leaf length plant⁻¹

A recent study demonstrates that the targeted application of GA_3 and zinc significantly enhances the growth and yield attributes of saffron (*Crocus sativus* L.). The main effects of GA_3 were evident in the increased leaf length (16 cm at 150 ppm), improved stem elongation, and higher dry matter accumulation, which collectively resulted in larger leaves, higher corm weight, and greater flower number. These effects are consistent with GA_3's well-established role in promoting cell elongation and stimulating enzymatic processes that loosen cell walls, thereby facilitating vegetative growth and assimilate translocation to sink tissues (Harrington et al., 1996; Taiz & Zeiger, 2015). Similarly, zinc application up to 0.6% significantly increased leaf length (18 cm), leaf number, and leaf area index. Zinc's contribution to auxin synthesis, cell division, and differentiation, as well as its role in photosynthetic electron transport via ferredoxin and cytochromes, likely enhanced the plants' metabolic activity, allowing both corm number and corm weight to increase simultaneously (Cakmak, 2008; Hafeez et al., 2013; Rad et al., 2020).

The interaction between GA_3 and zinc was non-significant, indicating that each input exerts its effect independently. This provides an important practical insight for saffron growers: GA_3 and zinc can be applied individually according to availability, cost, or management preference, without reducing their respective benefits. The apparent paradox higher corm number and simultaneously high corm weight under zinc treatment is explained by the improved nutrient-mediated metabolic balance and enhanced assimilate partitioning, which allowed the plant to sustain multiple developing corms without compromising individual corm size. Overall, these findings suggest that GA_3 and zinc applications are effective strategies for enhancing vegetative vigour, corm development, and flower production in saffron. For growers in Bajaur, this translates into a practical recommendation: applying either GA_3 at 150 ppm or zinc at 0.6% can independently boost saffron productivity, providing a cost-effective approach to improving yield under local agro-climatic conditions.

Zinc application similarly enhanced leaf traits, including length, number, and leaf area index, which collectively improve photosynthesis and resource allocation. Chelated zinc contributes to the synthesis of ferredoxin and cytochromes, essential components of the photosynthetic machinery, increasing metabolic activity and leaf expansion (Rad et al., 2020; Fageria et al., 2002). This mechanistic understanding resolves the apparent paradox in our results: although higher corm numbers are generally associated with reduced individual corm weight due to resource competition, zinc-treated plants maintained high corm weight alongside increased corm number, indicating efficient nutrient-mediated metabolic balance (Cakmak, 2008; Hafeez et al., 2013).

The non-significant GA_3 × zinc interaction suggests that these treatments can be applied independently without compromising their individual benefits. For farmers, this implies that GA_3 or zinc can be strategically used according to availability or cost, providing flexibility in saffron management while enhancing yield potential. These findings align with previous reports demonstrating the positive influence of micronutrients and growth regulators on leaf area, corm development, and overall productivity (Roy & Sarker, 1995).

Overall, the study emphasizes that combining targeted nutrient management with appropriate growth regulator application can improve vegetative vigour, corm development, and flower production in saffron. This provides a practical foundation for developing field recommendations for saffron cultivation, while guiding future research on optimizing GA_3 and zinc concentrations for maximum yield.

Weight of produced corm plot^{-1}

Zinc is used to activate the other growth promoters. GA_3 enhance the quality & production of corm. Combined application of zinc and GA_3 can improve plant growth, yield, and quality by promoting cell elongation, nutrient uptake and stress tolerance. It can also improve seed germination and fruit development. The application of growth regulators and zinc significantly affected the weight of the produced corms. The highest (1558.3 gm) and lowest average weight of daughter corms (867.2 gm) were obtained in 150ppm GA_3 & control, respectively. The maximum weight of daughter corms (1603.4 gm) was obtained in 0.6 % zinc treatment, and lower corm weights (947 gm) were obtained in the control. Non-significant interaction was found.

The impact of zinc on leaf area may result from its involvement in the biosynthesis of tryptophan, which acts as a precursor of the hormone indole acetic acid. IAA is essential for cell enlargement, growth, and the synthesis of carbohydrates and amino acids, contributing to leaf expansion (Yousefi et al., 2020). Zinc is a vital nutrient for plants as it participates in the synthesis of protein, chlorophyll, carbohydrates and lipids, and also acts as a cofactor in hormones and enzymes such as RNA and DNA polymerases. The availability of zinc for plant uptake is influenced by calcium and soil phosphate levels, which show an inverse correlation with phosphorus, phytic acid and zinc content in the plant. Maximum calcium uptake may also increase the plant's demand for zinc, whereas zinc deficiency can cause chlorosis, spotted leaves, and abnormal roots (Soetan *et al.*, 2010). Furthermore, the practical implication of the non-significant GA_3 × zinc interaction has been explicitly highlighted: both treatments can be applied independently, providing flexibility for farmers to enhance saffron growth and yield based on availability, cost, or management priorities.

Number of produced flowers plot^{-1}

Zinc and GA_3 both promote the production of enzymes that are responsible for breaking down carbohydrates, lipids, and proteins. This is essential for nutrient uptake and utilization. Both factors influenced the flowers plot^{-1}, and the interaction was non-significant. The highest (56) and lowest number of flowers, plot^{-1} (34), were obtained in 150 ppm GA_3, respectively. The maximum number of flowers, plot^{-1} (58), was obtained in 0.6 % Zinc treatment, and fewer flowers (32) were obtained in the control. PGRs and micronutrients are highly essential for flower enhancement.

The present study demonstrates that both GA_3 and zinc significantly enhance growth and flowering in saffron (*Crocus sativus* L.). GA_3 at 150 ppm promoted stem and leaf elongation, increased corm weight, and enhanced flower production, reflecting its role as a plant growth regulator that accelerates carbohydrate metabolism, starch mobilization, and assimilate allocation (Azizbekova, 1978; Chrungoo & Farooq, 1989; Harrington et al., 1996). Similarly, zinc application up to 0.6% improved leaf length, leaf number, and flower production, highlighting its critical role in chlorophyll formation, carbohydrate synthesis, tryptophan and indoleacetic acid production, and overall plant metabolic activity (Naservafaei et al., 2020; Cakmak, 2008). These enhancements in vegetative growth and assimilate availability directly supported increased corm weight and flower number.

The interaction between GA_3 and zinc was non-significant, indicating that the effects of each input are independent. This suggests that farmers can apply GA_3 or zinc individually, depending on availability or cost, without compromising the benefits of the other treatment.

A notable paradox observed in this study is the simultaneous increase in both corm number and average corm weight under zinc application. Typically, an increase in corm number is expected to reduce individual corm weight due to resource competition. However, zinc-mediated improvements in photosynthetic efficiency, nutrient uptake, and carbohydrate translocation likely maintained a metabolic balance that allowed the plants to support multiple corms without a reduction in corm size (DeJuan et al., 2009; Hafeez et al., 2013). Additionally, the positive correlation between mother corm weight and flower number further explains the high flower yield, while small daughter corms, if unmanaged, may compete for resources and reduce long-term productivity (DeMastro & Ruta, 1993; Omidbaigi, 2005).

These findings have practical implications for saffron growers in Bajaur. GA_3 at 150 ppm or zinc at the rate of 0.6% can be applied independently to enhance vegetative growth, corm development, and flower production. Moreover, careful management of corm size, spacing, and periodic removal of small daughter corms can optimize yield and ensure sustainable production over successive years. The results provide a clear framework for improving saffron productivity under local agro-ecological conditions while maintaining cost-effective input management.

Conclusion

Zinc and GA_3 are two important components in plant growth regulation that play essential roles in improving plant growth, yield and quality. Application of GA_3 and zinc resulted in the saffron growth improvement. Based on the results obtained from the current research study on saffron under the agro-climatic condition of district Bajaur, it appears that higher concentrations at the rate of 150 ppm GA_3 and 0.6 % Zn solution are significantly effective in increasing vegetative & reproductive attributes of saffron, followed by 100 ppm GA_3 & 0.4 % Zn. Using GA_3, zinc, as well as the other plant growth regulators, on improve the overall quantitative and qualitative yield of saffron. GA_3 at 150 ppm and zinc at 0.6% significantly enhanced growth and corm yield attributes. Stigma **yield the primary**

economic output of saffron could not be accurately measured due to the small size of experimental plots and limitations of the available weighing equipment. Therefore, the recommendation emphasizes improvements in **growth and vegetative yield parameters,** which are directly linked to potential productivity, while noting that further studies, including precise stigma yield measurements, are necessary to fully evaluate economic viability.

Future studies should include precise stigma yield measurements and explore the combined effects of GA_3 and Zn with complementary agronomic practices such as optimized irrigation scheduling, organic amendments, and appropriate planting densities. Multi-location and multi-year trials are also essential to confirm the consistency and reliability of these treatments across diverse environments. Based on the current findings, dipping corms in GA_3 and Zn solutions can be recommended as an effective and practical strategy for improving saffron growth and potential yield under local conditions.

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Conflict of Interest:

All authors affirm that they have no conflict of interest.

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