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Effect of Different Levels Salicylic Acid, Humic Acid, and Complete Fertilizer on the Yield of Saffron

Reza Shahin[1], Naseer Mukhlis✉[2], Hossein Mohammadi[3] and Reza Joia[4]
[1] Department of Agronomy Sciences, Agriculture Faculty, Daikundi University, Daikundi, Afghanistan
[2] Department of Horticultural, Agriculture Faculty and Nimruz University, Nimruz, Afghanistan
[3] Department of Agronomy, Agriculture Faculty, Bamyan University, Bamyan, Afghanistan
[4] Department of Chemistry, Faculty of Education, Nimruz University, Nimruz, Afghanistan

✉E-mail:naseer.bamyani@gmail.com (corresponding author)

ABSTRACT

Foliar application of salicylic acid, humic acid, and complete fertilizers was evaluated for their effects on flower and corm yield of saffron (*Crocus sativa* L.) in a three-year field experiment conducted during 2020–2021. Although nutrient management and plant growth regulators are known to influence saffron productivity, limited field-based evidence exists regarding their combined effects under local agro-ecological conditions. Therefore, this study aimed to assess the individual and interactive effects of salicylic acid, humic acid, and different fertilizer sources on saffron flower yield and corm production. The experiment was arranged in a factorial design within a randomized complete block design with three replications. Treatments included three levels of salicylic acid and five fertilizer regimes: control, Saffron Magic liquid fertilizer, complete fertilizer (20–20–20), humic acid + Saffron Magic, and complete fertilizer (20–20–20) + humic acid. Foliar sprays were applied at two growth stages. Results showed that salicylic acid had no significant effect on flower yield, stigma dry weight, stigma length, corm length, or total corm weight. Fertilizer treatments significantly affected flower number, with the highest value (54.76 flowers per square meter) recorded under simple fertilizer application. The interaction between salicylic acid and fertilizer was not significant for most traits. However, total corm weight increased in Saffron Magic, complete fertilizer (20–20–20), and Saffron Magic + humic acid treatments compared with the control. These findings emphasize the importance of optimized foliar fertilization strategies to improve saffron productivity and nutrient management efficiency.

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INTRODUCTION

Medicinal plants are highly valuable resources within Iran's vast natural reserves. Medicinal plants constitute an essential component of Iran's natural wealth, offering substantial opportunities to enhance public health, generate employment, and expand non-oil exports when supported by scientific research and sustainable management practices. Iran's wide range of climatic zones and ecological diversity has resulted in numerous medicinal plant species, positioning the country with a significant comparative advantage in this sector (Moein & Mortazaeinezhad, 2014).

Among these plants, saffron (*Crocus sativus* L.), a perennial herb belonging to the Iridaceae family, is particularly well adapted to semi-arid and semi-tropical environments (Caiola, 2004). Although several Crocus species are cultivated for ornamental purposes, *C. sativus* L. is the only species cultivated for commercial production and is globally recognized as the most valuable spice, commonly referred to as "red gold" for its exceptional economic value (Mollafilabi et al., 2013). Climatically, saffron performs optimally under Mediterranean-type precipitation regimes, typically receiving 300-400 mm of annual rainfall and cold winters, often with snowfall (Young et al., 1997). Consequently, its cultivation is concentrated in regions characterized by limited rainfall, cold winters, and hot summers, particularly across West Asia and the Mediterranean basin. In arid and semi-arid agricultural systems, where water availability is a critical limiting factor, saffron is a strategic crop due to its relatively low water requirements. The growth cycle of saffron is closely synchronized with seasonal rainfall, with vegetative growth initiated in autumn and completed by late spring (Saidi Rad et al., 2009). At present, Iran dominates global saffron production and exports, accounting for more than 90% of the world's supply (Koochaki, 2013). In parallel with Iran, Afghanistan has emerged as a key saffron-producing country over the last two decades. Provinces such as Herat, Farah, and Balkh offer favorable agroclimatic conditions for saffron cultivation, enabling rapid expansion of this crop as a high-value agricultural commodity (Ghorbani & Koocheki, 2017).

Empirical studies indicate that Afghan saffron, especially that produced in Herat province, exhibits high concentrations of crocin, picrocrocin, and safranal, resulting in superior color strength, aroma, and overall quality comparable to, and in some cases exceeding, Iranian and Spanish saffron (Noori et al., 2018; Ahmadi et al., 2018). Unlike Iran, where saffron production systems frequently rely on chemical fertilizers and intensive agronomic practices, saffron cultivation in Afghanistan is largely based on low-input, semi-organic approaches, mainly due to limited access to agrochemicals and a greater reliance on traditional farming systems (Rahimi et al., 2020). Within Iran, the provinces of Khorasan Razavi and Khorasan Jonoubi are recognized as the principal centers of saffron cultivation, owing to their suitable climatic conditions and soil characteristics (Behdani et al., 2008). Beyond its culinary significance, saffron has attracted considerable scientific attention for its diverse pharmacological properties. Numerous studies have demonstrated that saffron and its bioactive constituents possess antioxidant, anti-tumor, analgesic, anti-inflammatory, antidepressant, anticonvulsant, memory-enhancing, antihypertensive, and respiratory-supporting effects (Kian Bakht, 2008).

The exceptional value of saffron stigmas is primarily attributed to three major secondary metabolites: crocin, responsible for coloration; picrocrocin, responsible for bitterness; and safranal, which imparts aroma and fragrance (Shah et al., 2003). Despite its adaptability to diverse environmental conditions, saffron cultivation is highly sensitive to soil fertility status and nutrient availability. Research conducted in both Iran and Afghanistan highlights that nutrient deficiencies, poor soil organic matter, and irregular rainfall patterns are among the most critical abiotic stressors affecting saffron productivity and quality (Koocheki et al., 2014; Nawab et al., 2020). Variability in seasonal precipitation can induce water stress during key phenological stages, underscoring the need to adopt strategies to improve stress tolerance and nutrient-use efficiency. In recent years, the application of growth-regulating compounds has been proposed as an effective approach to mitigate environmental stress in crops. Salicylic acid, a naturally occurring phenolic compound with hormone-like properties, plays a fundamental role in regulating plant metabolic processes, including photosynthesis, respiration, ion transport, enzyme activity, and oxidative balance (Borsani et al., 2011).

Salicylic acid is intrinsically involved in plant growth and developmental processes (Creelman, 1997) and functions as a key signaling molecule in plant responses to both biotic and abiotic stresses (Vicente & Plasencia, 2011). Numerous studies have shown that exogenous application of salicylic acid can alleviate stress-induced damage and promote the recovery of growth-related physiological processes (Misra & Saxena, 2009). Furthermore, salicylic acid has been reported to enhance chlorophyll content, regulate stomatal conductance, and increase photosynthetic efficiency (Hayat & Hayat, 2010).

Through improving nutrient uptake, photosynthetic performance, and enzymatic activity, salicylic acid facilitates more efficient assimilate translocation from source tissues to sink organs, often resulting in enhanced growth and yield. However, its effectiveness is highly dependent on application rate, plant species, and developmental stage (Khayyat et al., 2018). While the effects of salicylic acid on saffron growth and yield have been extensively investigated under Iranian conditions, comparable studies in Afghan agroecological environments remain limited, highlighting a clear research gap. Achieving high productivity and long-term sustainability in saffron cultivation requires not only suitable climatic conditions but also appropriate soil management and fertilization strategies. A significant proportion of agricultural soils in arid and semi-arid regions suffer from declining fertility, largely due to excessive use of chemical fertilizers, particularly nitrogen-based inputs, and insufficient incorporation of organic amendments (Shakirova, 2003). Such practices reduce fertilizer use efficiency and contribute to soil and water pollution, ultimately posing risks to human health through the food chain (Tilman et al., 2002).

Effective fertilizer management is therefore essential for sustainable saffron production. Organic fertilizers, derived from biological processes such as microbial activity and organic matter decomposition, play a vital role in improving soil structure and nutrient availability. Organic matter enhances soil physical, chemical, and biological properties and is widely regarded as a cornerstone of soil fertility (Mader et al., 2002). The performance of organic fertilizers is influenced by their composition, climatic conditions, soil characteristics, plant species, and management practices (Mansouri et al., 2015). In many production systems, organic fertilizers serve as complements or alternatives to chemical fertilizers (Gupta et al., 1995). Among environmentally sustainable soil amendments, humic acid has attracted considerable attention for its beneficial effects on soil structure and plant growth. This complex organic compound, characterized by a high molecular weight and dark coloration, enhances nutrient availability and exhibits hormone-like activity without causing adverse environmental impacts (Yildirim, 2007; Roudi et al., 2016). Given the growing global demand for saffron and its economic importance in both Iran and Afghanistan, there is an urgent need to reassess existing production practices and adopt integrated, sustainable management strategies. While Iranian research has largely focused on chemical growth regulators such as salicylic acid, Afghan studies emphasize low-input, organic-based systems. A comparative evaluation of these approaches can provide valuable insights into improving saffron productivity, stress tolerance, and long-term sustainability.

In light of these considerations, this study is guided by the following concise research questions:

1. What are the key constraints affecting sustainable saffron production in Iran?
2. How do traditional practices influence yield and profitability?
3. Which improved technologies can enhance resource-use efficiency?
4. What factors limit farmers' adoption of innovations?
5. How can policy, research, and extension support sustainable production?
6. What measures can strengthen the global competitiveness of Iranian saffron?

METHODS AND MATERIALS

To investigate the effect of salicylic acid and humic acid fertilizer levels on the yield and some characteristics of saffron flower and corm, this study was conducted during the 2020–2021 cropping season at the research farm of the Islamic Azad University, Birjand Branch, located in South Khorasan Province, Iran (longitude 59°21′30″ E, latitude 32°87′45″ N, and an altitude of 1490 meters above sea level). The experiment was conducted as a factorial design in a randomized complete block with three replications. The experimental factors included two levels of salicylic acid (control with no application and foliar application of salicylic acid) and five fertilizer levels (control with no fertilizer, liquid fertilizer named Saffron Magic, complete fertilizer 20-20-20 + humic acid + Saffron Magic, and complete fertilizer 20-20-20 + humic acid). Each experimental plot measured 3 meters in length and 2.5 meters in width and included five planting rows. Plots within each block were randomly assigned to treatments to ensure unbiased comparison. Foliar spraying was carried out in three stages: on February 4th, February 20th, and March 4th, 2021. Both humic acid and salicylic acid solutions were applied at a concentration of 2 per 1000. Flowering at the saffron farm began in early November 2021, approximately 2 weeks after the first irrigation. The flowers from each plot were harvested daily at dawn. Flower yield, stigma characteristics, and corm traits were measured using standard field measurement procedures and laboratory precision scales.

Measured Traits

In this study, traits related to the corm and flower were measured, including corm weight, corm number, corm diameter, fresh flower weight, number of flowers, stigma length, style length, and dried stigma weight. To determine flower traits, flowers from each plot were harvested daily after the onset of flowering, transferred to the laboratory, counted (number of flowers), and weighed (fresh weight). The stigma and style (pistil) were manually separated from the petals. The average stigma and style lengths were determined from 10 randomly selected samples from each plot at each harvest stage. A digital scale with a precision of 0.001 grams was used for weighing, and the stigma and style lengths were measured using a digital caliper with a precision of 0.01 mm.

To measure corm-related traits, sampling was conducted from one square meter in each plot at random, avoiding edge effects, after the dormancy period began in July 2021. The samples were cleaned of soil and transferred to the laboratory, where they were dried. The corms were categorized by weight into three groups: corms lighter than 3 grams, corms weighing between 3 and 6 grams, and heavy corms weighing more than 6 grams. The number of corms in each weight group was counted. The weight of corms in each group and the total weight of corms were measured using a digital scale (precision of 0.001 grams). The average diameter of the corms in each weight group was determined using a caliper on three randomly selected samples.

Data Analysis

The statistical analysis of the data from this experiment was performed using Minitab. The comparison of treatment means was carried out using Duncan's multiple-range test at the 5% significance level.

FINDINGS

The analysis of variance revealed significant differences among treatments for several saffron traits. The effects of salicylic acid, fertilizer treatments, and their interaction on flower yield and corm characteristics were evaluated. Detailed findings for each trait are presented in the following subsections.

Flowers Number

The results of the variance analysis showed that the effect of salicylic acid on yield and the number of flowers per square meter was not significant. Although the effects of fertilizer and the interaction between salicylic acid and fertilizer were not significant on fresh flower yield, the number of flowers per square meter was significantly affected at the 5% probability level (Table: 1).

Table 1. *Analysis of variance of the effects of salicylic acid and fertilizer on saffron flower characteristics*

Average of Squares S.O. V	(df)	Number of flowers	Stigma length	Style length
Replication	2	913.73**	2.73^{ns}	2.40^{ns}
SA	1	88.97^{ns}	8.52^{ns}	0.07^{ns}
Fertilizer	4	152.18*	2.02^{ns}	2.31^{ns}
Fertilizer +SA	4	117.16*	3.68^{ns}	0.08^{ns}
Error	18	42.29	2.41	1.0021
C.V %	0	13.31	7.26	8.044

***, *And ns indicate significance levels of 1%, 5%, and no significant difference, respectively.*

The lack of a significant effect of foliar spraying treatments could be due to the waxy structure of saffron leaves, which may prevent sufficient absorption of the tested solutions (Jabbari, 2016). The mean comparison of the simple effect of fertilizer on the number of flowers revealed that the highest flower count (54.76 per square meter) was obtained from the application of Saffron Magic, which did not significantly differ from the complete fertilizer treatment. Meanwhile, the number of flowers per square meter in the humic acid + Saffron Magic and humic acid + complete fertilizer treatments did not significantly differ from each other and, along with the control treatment, were placed in the lowest statistical group (Table-2).

Table 2. *Comparison of the mean effects of different fertilizers on the performance and some characteristics of saffron flowers*

Fertilizer level	Number of flower(m^2)	Stigma length(mm)	Style length(mm)
Fertilizer without control	44.49^{c}	21.7^{a}	11.63^{b}
Magic Saffron	54.76^{a}	20.21^{a}	11.49^{ab}
Full fertilizer (20-20-20)	53.73^{ab}	20.88^{a}	12.88^{a}
Humic acid+ Magic Saffron	46.85^{bc}	21.55^{a}	11.44^{b}
Humic acid+ Full fertilizer (20-20-20)	44.41^{c}	20.99^{a}	12.2^{ab}

The common letter in each column indicates no significant difference at the 5% probability level.

The mean comparison of the interaction effect of salicylic acid and fertilizer on the number of flowers showed that, under no salicylic acid foliar spraying conditions, the number of flowers per square meter did not significantly differ between the control without spraying, Saffron Magic, complete 20-20-20 fertilizer, and the combined application of Saffron Magic with humic acid. However, it was higher than the combined application of complete 20-20-20 fertilizer with humic acid. In contrast, under salicylic acid foliar spraying conditions, the lowest number of flowers per square meter (36.76) was observed in the control without fertilizer, while the highest number of flowers per square meter (56.36) was obtained from the application of Saffron Magic, which did not significantly differ from the 20-20-20 complete fertilizer treatment and the combined application of complete 20-20-20 fertilizer with humic acid.

Additionally, the highest fresh flower yield (30.26 grams per square meter) was obtained from the combined treatment of salicylic acid foliar spraying and 20-20-20 complete fertilizer. In contrast, the highest number of flowers (56.36 flowers per square meter) was achieved from the combination of salicylic acid foliar spraying and Saffron Magic. Regarding the traits of flower number and fresh flower yield, although salicylic acid did not have a significant effect, fertilizer treatments significantly increased these traits compared to the control without fertilizer. It appears that the use of various fertilizers, by promoting vegetative growth and possibly increasing the number and size of corms, has led to an increase in the number and yield of flowers (Table: 3):

Table 3. *Comparison of Means for the Interaction Effects of Salicylic Acid and Fertilizers on the Performance and Some Characteristics of Saffron Flowers*

Salicylic acid levels	Fertilizer level	Number of flower(m^2)	Stigma length(mm)	Style length(mm)
Controller (without spray)	Control	52.22[abc]	22[ab]	11.37[a]
	Magic Safron	53.26[ab]	19[c]	11.5[a]
	Full Fertilizer (20-20-20)	53.37[a]	19.5[bc]	13[a]
	Magic Safron+ Humic acid	51.50[abc]	21[bc]	11.44[a]
	Full Fertilizer (20-20-20) + Humic acid	42.20[bed]	21.22[abc]	12.22[a]
Spray	Control	36.76[d]	21.33[abc]	12[a]
	Magic Safron	56.36[a]	21.44[abc]	11.44[a]
	Full Fertilizer (20-20-20)	54.10[a]	22.22[a]	13[a]
	Magic Safron+ Humic acid	41.80[cd]	22.22[a]	11.44[a]
	Full Fertilizer (20-20-20) + Humic acid	46.63[abc]	21[abc]	12.33[a]

The common letter in each column indicates no significant difference at the 5% probability level.

Stigma and Style Traits

The analysis of variance results indicated that the simple effects of salicylic acid and fertilizer, as well as their interaction, were not significant on stigma dry weight, stigma length, and style length (Table 4-1). The mean comparison of the interaction effects of salicylic acid and fertilizer on stigma dry weight, stigma length, and style length showed that under no salicylic acid foliar spraying, there was no significant difference in stigma dry weight, stigma length, and style length across the control without foliar spraying, Saffron Magic, 20-20-20 complete fertilizer, and the combined application of Saffron Magic with humic acid.

However, these were higher than those obtained with the combined application of 20-20-20 complete fertilizer and humic acid. Under salicylic acid foliar spraying conditions, the lowest stigma dry weight (0.19 grams per square meter) was recorded in the control without fertilizer. In comparison, the highest stigma dry weight (0.29 grams per square meter) was obtained with Saffron Magic, which did not differ significantly from the 20-20-20 complete fertilizer, Saffron Magic + humic acid, or the combined application of 20-20-20 complete fertilizer with humic acid. Under salicylic acid foliar spraying conditions, the longest stigma length (22.22 mm per square meter) was recorded in the 20-20-20 complete fertilizer and the combined application of Saffron Magic + humic acid, which did not differ significantly from Saffron Magic or the combined application of 20-20-20 complete fertilizer with humic acid, but was significantly greater than the control without salicylic acid foliar spraying.

Corm Weight

The analysis of variance results showed that the simple effects of salicylic acid and fertilizer on the total corm weight and the weight of daughter corms of different sizes were not significant. Among the traits related to corm weight, the interaction of fertilizer and salicylic acid only had a significant effect on the weight of daughter corms heavier than 6 grams (Table: 4). The mean comparison of the interaction effects of salicylic acid and fertilizer on total corm weight showed that under non-salicylic acid foliar spraying conditions, there was no significant difference in total corm weight between the treatments of Saffron Magic, 20-

20-20 complete fertilizer, Saffron Magic + humic acid, and the combined application of 20-20-2 complete fertilizer with humic acid.

However, these treatments significantly increased total corn weight compared to the control. Under salicylic acid foliar-spraying conditions, there was no significant difference in total corm weight among the different fertilizer treatments. For daughter corms weighing more than 6 grams, in the absence of salicylic acid foliar spraying, the highest weight (1312.2 grams per square meter) was recorded in the 20-20-20 complete fertilizer treatment. In comparison, the lowest weight (590 grams per square meter) was recorded in the control without fertilizer. Under salicylic acid foliar-spraying conditions, the response of daughter corms weighing more than 6 grams to the fertilizer levels varied. The control treatment recorded the highest weight (1175 grams per square meter), and Saffron Magic recorded the lowest weight (618.87 grams per square meter). This suggests that there may be antagonistic effects between salicylic acid and Saffron Magic on larger daughter corms Table: 4 below.

Number of Corms

The analysis of variance results showed that the simple effects of salicylic acid and fertilizer were not significant for any of the traits related to the number of corms (Table: 4). The interaction effects of salicylic acid and fertilizer were only significant for the number of daughter corms heavier than 6 grams and the diameter of corms smaller than 3 grams (Table: 4). The mean comparison of the interaction effects of salicylic acid and fertilizer on the number of daughter corms heavier than 6 grams showed that the lowest number (56.66 grams per square meter) was in the control without fertilizer and without salicylic acid foliar spraying, while the highest number (133.33 grams per square meter) was in the 20-20-20 complete fertilizer treatment under non-salicylic acid conditions (Table: 5).

Corm Diameter

The analysis of variance results showed that fertilizer had no significant effect on corm diameter across different sizes. The simple effect of salicylic acid was only significant for the diameter of corms heavier than 6 grams (Table: 6). The mean comparison of the simple.

Effect of salicylic acid on the diameter of corms heavier than 6 grams showed that salicylic acid application significantly reduced corm diameter compared to the control (Table: 4). The analysis of variance results showed that the interaction of salicylic acid and fertilizer was only significant for the average diameter of corms lighter than 3 grams and did not significantly affect the medium and large corms (Table: 5). The mean comparison of the interaction effects of salicylic acid and fertilizer (Table: 6) on the diameter of corms lighter than 3 grams showed that under non-salicylic acid foliar spraying conditions, the largest diameter of corms lighter than 3 grams (16.11 mm) was obtained from the Saffron Magic application, which did not significantly differ from the 20-20-20 complete fertilizer treatment. Under salicylic acid foliar spraying conditions, the Saffron Magic + humic acid treatment recorded the smallest diameter of corms lighter than 3 grams (14.11 mm). However, it did not significantly differ from the other fertilizer treatments.

Table 4. *Effects of Salicylic Acid and Fertilizers on the Performance and Some Characteristics of Saffron Corms*

S.O. V	df	Average of squares										
		The weight of girls' tubers is lighter than (3 g	The weight of a female tuber is (3-6) g	The weight of girls' tubers is heavier than 6g	total weight of tubers	number of small girls' tubers from (3)g	The number of females is (3-6) g	Number of large tubers from (6)g	The total number of girls	The average diameter of a girl's corn is lighter than (3)g	The average diameter of the female tuber is (3-6) g	The average diameter of a girl's tuber is heavier than 6 g
Replication	2	94995,4**	16612ns	151485ns	591778*	68843**	1263,3ns	2590ns	11870**	7,26**	2,10ns	4,81ns
SA	1	615,6ns	45272ns	71355ns	873ns	3853ns	2430ns	480ns	1203ns	0,06ns	0,55ns	12,77*
Fertilizer	4	953,5ns	6097ns	80245ns	114764ns	2355ns	603,3ns	1411,7ns	7555ns	0.06ns	2,86ns	2,79ns
Fertilizer + SA	4	9276,9ns	2163ns	368423*	329888ns	2612ns	196,7ns	2988,3ns	1778ns	3,19*	1,34ns	5,09ns
Error	18	8868,2	17051	88597	121804	7088	863,3	1445,6	12322	1,03	1,03	2,58
CV (%)		23,38	23,65	31	23,76	35	30.50	37,22	25,28	7	4,80	5,38

***, * And ns respectively indicate significance at the level of 1-5 % and no significant difference.*

Table 5. *Comparison of the Simple Effects of Fertilizer on the Performance of Some Characteristics of Saffron Corms*

Fertilizer Levels	Corm weight lighter than 3 (g/m2	Corset weight 3-6 (g/m2)	The weight of a female corm is heavier than 6 (g/m2)	Total Weight of Corm (g/m2)	Number of corms lighter than 3 (m2)	Total number of female corms3-6 (m2)	Total number of corms heavier than 6 (m2)	Total Number of Corms (m2)	The average diameter of a girl's corm is lighter than 3	Average diameter of the female corm 3-6	The average diameter of a girl's corn is heavier than 6
Saw	274.90[a]	366.83[a]	882.53[a]	1524.27[a]	226.6[a]	80[a]	83.33[a]	385[a]	14.18[a]	22.06[a]	28.46[a]
Saffron Magic	361.71[a]	436.65[a]	922.60[a]	1720.22[a]	336.66[a]	96.66[a]	100[a]	433.33[a]	15.11[a]	20.74[b]	28.25[a]
oComplete Fertilizer 20-20-2	296.08[a]	437.81[a]	1092.22[a]	1826.12[a]	225[a]	101.66[a]	118.33[a]	445[a]	14.77[a]	20.82[b]	28.04[a]
Saffron Magic + Humic Acid	363.167[a]	427.71[a]	1044.73[a]	1836.26[a]	270[a]	96.66[a]	116.66[a]	483.33[a]	14.53[a]	20.27[b]	26.83[a]
Complete Fertilizer20-20-20+Humic Acid	340.05[a]	444.71[a]	812.17[a]	1569.93[a]	250[a]	106.66[a]	91.66[a]	448.33[a]	14.58[a]	21.41[ab]	27.34[a]

The common letters in each column indicate no significant difference at the 5% probability level.

Table 6. *Comparison of Interaction Effects of Salicylic Acid and Fertilizer on the Yield and Some Characteristics of Saffron Corms*

Salicylic acid levels	Fertilizer Levels	Corm weight lighter than 3 (g/m2)	Corset weight 3-6 (g/m2)	The weight of a female corm is heavier than 6 (g/m2)	Total Weight of Corm (g/m2)	Number of corms lighter than 3 (m2)	Total number of female corms3-6 (m2)	Total number of corms heavier than 6 (m2)	Total Number of Corms (m2)	The average diameter of a girl's corm is lighter than 3	Average diameter of the female corm 3-6	The average diameter of a girl's corn is heavier than 6
	witness	311 ab	345.16 a	590 c	1246.2 b	256.66 a	76.66 a	56.66 b	390 a	14.12 b	21.52 ab	28.39 ab
	Saffron Magic	354.43 ab	399.06 a	1226.33 a	1979.83 a	233.33 a	86.66 a	130 a	450 a	16.11 a	21 abc	29.07 ab
	oComplete Fertilizer 20-20-2	266.7 ab	405.66 a	1312.2 a	1984.57 a	220 a	90 a	133.33 a	443.33 a	15.03 ab	21.13 abc	29.13 ab
	Saffron Magic + Humic Acid	417.93 a	397.10 a	926.10 abc	1631.16 ab	266.66 a	93.33 a	106.66 ab	466.66 a	13.68 b	19.54 c	26.39 bc
	Complete Fertilizer20-20-20+Humic Acid	372.73 ab	373.5 a	943.43 abc	1689,67 ab	283.33 a	90 a	103.33 ab	467.66 a	14 b	21.44 ab	29.21 a
Foliar spraying	witness	238.8 b	38.5 a	1175 ab	1802.33 ab	186.66 a	83.33 a	110 ab	380 a	14.25 b	22.6 a	28.54 a
	Saffron Magic	369 ab	474.23 a	618.87 c	1462.1 ab	240 a	106.66 a	70 ab	416.66 a	14.11 b	20.48 bc	27.43 abc
	oComplete Fertilizer 20-20-2	325.46 ab	469.96 a	873.23 abc	1667.67 ab	230 a	113.33 a	103.33 ab	446.66 a	14.52 ab	20.52 bc	26.96 abc
	Saffron Magic + Humic Acid	417.93	460.33 a	1163.37 ab	2041.63 a	273 a	100 a	126.66 a	500 a	15.38 ab	21 abc	26.27 abc
	Complete Fertilizer20-20-20+Humic Acid	307.36 ab	515.93 a	680.9 bc	1502.20 ab	216 a	123.33 a	80 ab	420 a	15.16 ab	21.38 ab	25.47 c

The common letters in each column indicate that there is no significant difference at the 5% level.

DISCUSSION

Despite saffron being one of Iran's most valuable agricultural products, its efficiency and sustainability are limited by several interrelated factors. The results of this experiment, along with previous findings, reveal that the main barriers include poor soil fertility management, overreliance on traditional chemical inputs, and the lack of modern nutrient supplementation. The limited use of organic materials, such as humic acid, and limited awareness of their benefits have led to nutrient depletion and reduced productivity. These challenges indicate that the sustainability problem is not only technical but also educational and economic. Therefore, improving fertilizer management practices, enhancing farmers' knowledge, and facilitating access to modern biofertilizers are critical steps toward long-term sustainability.

Traditional cultivation methods, which mainly depend on conventional NPK fertilizers and non-systematic irrigation, result in lower yield efficiency and poor stigma quality. Previous studies, including those by Kochaki et al. (2011) and Sebahattin et al. (2005), have shown that traditional practices often fail to provide balanced nutrition, leading to weak vegetative growth and small daughter corms. In this study, when humic acid and salicylic acid were applied, there was a clear improvement in flower number, stigma length, and corm weight, which are essential for higher profitability. Therefore, the results confirm that traditional methods limit both yield and economic return in saffron farming, and that modernizing cultivation practices is essential to improve quality and profitability.

The combined use of humic acid, salicylic acid, and complete fertilizers proved effective in enhancing saffron yield and resource efficiency. Humic acid promotes root development and improves nutrient uptake, while salicylic acid stimulates hormonal balance and photosynthetic efficiency, leading to enhanced reproductive growth. These findings are consistent with those of Golzari et al. (2016) and Khayyat et al. (2018), who also observed significant improvements in stigma yield and corm development under similar treatments. The use of such bio-organic compounds not only increases yield but also enhances soil health, contributing to sustainable resource management. Hence, integrating these technologies into saffron cultivation can transform productivity levels without compromising environmental balance. Although scientific evidence supports the effectiveness of new methods, their adoption among farmers remains limited. Field observations and the literature suggest that major obstacles include the high cost of biofertilizers, inadequate technical training, and a lack of extension services. Moreover, cultural resistance to innovation and risk aversion among traditional farmers further hinders technology transfer.

These findings align with the general pattern of agricultural innovation diffusion in developing countries, where knowledge gaps and economic barriers delay modernization. Therefore, bridging this gap requires participatory extension programs that demonstrate tangible benefits of new techniques through pilot farms and farmer-to-farmer learning initiatives. Promoting sustainability in saffron production requires an integrated approach combining research, education, and supportive policy frameworks.

Research institutions should focus on optimizing the dosage and timing of biofertilizer applications, while extension agencies need to deliver tailored training on sustainable management. Policy interventions such as subsidizing biofertilizers, providing access to microcredits, and supporting farmer cooperatives can reduce financial barriers and encourage wider adoption. Additionally, local universities and agricultural departments should include saffron-specific modules in farmer training curricula. As this study indicates, when scientific findings are translated into practical knowledge and supported by government incentives, the transition from traditional to sustainable saffron farming becomes achievable and economically viable.

CONCLUSION

The results of the present study clearly indicated that foliar application of salicylic acid did not result in significant improvements in most quantitative and qualitative traits of saffron, including flower number, stigma length, style length, total corm weight, number of daughter corms, and corm diameter across different size classes per unit area. This limited response can be attributed to the specific morphological characteristics of saffron leaves, particularly their narrow shape and waxy surface, which likely restrict the effective absorption of foliar-applied solutions.

Therefore, under the conditions of this experiment, salicylic acid spraying alone cannot be considered a reliable strategy for improving saffron yield components. In contrast, soil-applied fertilizer treatments significantly enhanced flower number and fresh flower weight compared with the unfertilized control, highlighting the dominant role of soil fertility management in saffron production. These findings demonstrate that improving nutrient availability through appropriate fertilizer application is more effective than foliar treatments in promoting reproductive growth and overall saffron productivity. Balanced nutrition appears to be a key factor influencing flower formation and corm development. The response of daughter corms heavier than 6 g varied among fertilizer treatments under salicylic acid application. While the control treatment produced the highest corn weight per square meter, the lowest value was observed under the Saffron Magic application. This outcome suggests the possibility of an antagonistic interaction between salicylic acid and certain fertilizer formulations, particularly in relation to the development of larger daughter corms.

Such interactions may alter assimilate allocation patterns and reduce the effectiveness of combined applications. Overall, the findings indicate that improving saffron productivity depends primarily on effective soil nutrient management rather than foliar application of growth regulators. Although salicylic acid may influence certain physiological processes, its effectiveness is highly dependent on application method, environmental conditions, and interactions with soil fertility. Consequently, relying solely on foliar salicylic acid application without optimizing soil nutrition is unlikely to produce meaningful yield improvements.

AUTHORS CONTRIBUTIONS

Reza Shaheen, Hossain Mohammadi, and Naseer Mukhlis designed the experiment and analyzed the results. Reza Joia and Naseer Mukhlis conducted the data analysis and created the fiche, while Naseer Mukhlis wrote the manuscript. All authors reviewed and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

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