Bulgarian Journal of Agricultural Science, 31 (No 1) 2025, 139–149

Separate and combined effects of Super Absorbent Polymers (SAP), organic (Seaumic), and nano-fertilizers (Lithovit®-Forte and nano-chelate Super Plus ZFM++) on the performance of small and medium-sized saffron (*Crocus oreocreticus*) corms

W. Hourani[1,2*], Z. El Sebaaly[1,2], Z. Allaw[2], V. Koutev[1] and Y. N. Sassine[1,2]

[1] *University of Forestry, Faculty of Agronomy, Department of Agronomy, 1797 Sofia, Bulgaria*
[2] *Lebanese University, Faculty of Agriculture, Department of Plant Production, Beirut, Lebanon*
[*] *Corresponding author:* wissam.hourani@st.ul.edu.lb

Abstract

Hourani, W., El Sebaaly, Z., Allaw, Z., Koutev, V. & Sassine, Y. N. (2025). Separate and combined effects of Super Absorbent Polymers (SAP), organic (Seaumic), and nano-fertilizers (Lithovit®-Forte and nano-chelate Super Plus ZFM++) on the performance of small and medium-sized saffron (*Crocus oreocreticus*) corms. *Bulg. J. Agric. Sci., 31*(1), 139–149

Amelioration in saffron production and quality has been reported as a result of using organic fertilizers, nanofertilizers and Super Absorbent Polymers (SAP). The study investigated the separate and combined effects of various fertilizers (Seaumic, nano-chelate Super Plus ZFM++, Lithovit®-Forte) and SAP on the performance of small-sized (SS: 4–6 g) and medium-sized (MS: 6–8 g) saffron corms. Fertilizers applied with SAP hastened leaf emergence by 4.3–10.8 days for SS corms compared to their use without SAP, and flowering date by 11.8–20.6 days in SS corms and 16.3–22.8 days in MS corms, compared with control. Harvest was the earliest in MS/Seaumic and MS/Seaumic/SAP (20.8 and 20.0 DAP, respectively). Compared to control, leaf number of MS corms increased by 5.3 and 3.8 because of Lithovit®-Forte applied with and without SAP, respectively.

Seaumic and Lithovit®-Forte showed superior effect on leaf length than nano-chelate Super Plus ZFM, whether applied with or without SAP. Improvement in flower number per m^2 reached 65.1% in MS/Seaumic/SAP compared to control. Without SAP, Seaumic and nano-chelate Super Plus ZFM improved dry stigma yield by 43.9 and 33.7% in SS-corms and 60 and 50.7% in MS-corms, respectively, and with SAP, they improved it by 71.4 and 72.3% in SS-corms and 90.4 and 79.6% in MS-corms, respectively. The highest fresh stigma yield, dry stigma yield, yield of daughter corms, and number of daughter corms were in MS/Seaumic/SAP (2.01 g/m^2, 1.11 g/m^2, 850 g/m^2, and 73.5, respectively). The majority of treatments affected crocin and picrocrocin contents (higher than control), but not safranal. Saffron production can be optimized by applying Seaumic or Nano-chelate Super Plus ZFM with SAP.

Keywords: SAP; nano and organic fertilizers; replacement corms; stigma yield; saffron derivatives; C*rocus oreocreticus*

Introduction

The most expensive spice is produced from saffron (*Crocus sativus* L.); a monocotyledonous herbaceous triploid plant, belonging to the family Iridaceae and usually cultivated as perennial crop (Fallahi et al., 2014; Kothari et al., 2021). The center of origin of saffron is assumed to be Greece and/or Iran (Shokrpour, 2019). A red spice is produced from the saffron flower and is primarily used in food because of its color, flavor and aroma (José Bagur et al., 2017; Cid-Pérez et al., 2021). The main bioactive ingredients responsible for the color, aroma, and bitterness of saffron are crocin, safranal, and picrocrocin, respectively (Zhang et al., 2019). Besides, saffron has many other uses in pharmaceutical, cosmetic, perfume, and textile dye industries (Menia et al., 2018).

Saffron growth starts with sprouting, followed by cataphylls and flower appearance, plant appearance and development, development of daughter corms, plant senescence, and corm dormancy (Lopez-Corcoles et al., 2015). The size of maternal corm plays a crucial role on saffron phenology and production (Arslan et al., 2007; Nassiri Mahallati et al., 2007; Çavuşoğlu et al., 2009; Koocheki & Teimouri, 2014; Tavakkoli et al., 2014; Ghobadi et al., 2015).

Despite the low fertilizer requirements of saffron, fluctuations in saffron flower yield are mostly caused by soil characteristics that are impacted by fertilizers and soil amendments (Temperini et al., 2009; Nehvi et al., 2010). According to Dourandish et al. (2019), the majority of fertilizers used in saffron fields are chemical ones, and using too much of them can harm the quality of the soil and water used for farming and limit saffron harvest. On the other hand, interest in organic fertilization in saffron production has been growing (Fallahi & Mahmoodi, 2018) because they are more secure and have less adverse impact on the environment (Ebrahimi et al., 2022). They are essential for enhancing the nutritional condition of plants and the soil's characteristics, securing long-term sustainability and fruitful economic returns in the fields (Chen et al., 2018). For instance, the use of animal and farmyard manure (Amiri, 2008; Kirmani et al., 2014; Alipoor Miandehi et al., 2015; Shariatmadari et al., 2018), vermicompost (Rezaie et al., 2019), and humic acid (Koocheki et al., 2015; Osmani Roudi et al., 2015; Mollafilabi & Khorramdel, 2016; Ahmadi et al., 2017; Golzari Jahan Abadi et al., 2017) had a favorable impact on the growth and yield indices in saffron. Furthermore, the use of nanofertilizers may increase the effectiveness of nutrient use, lessen nutrient waste, replenish soil fertility, boost crop output, and maintain ecosystem health (Chhipa, 2017). Earlier studies have reported a positive effect of nanofertilizers on saffron flowering and production traits, like flower number, stigma length, fresh and dry stigma weights, and dry stigma yield (Azarpour et al., 2013; Baghai & Maleki Farahani, 2013; Amirnia et al., 2014; Maleki Farahani & Aghighi Shahverdi, 2015; Seghatoleslami & Sabzekar, 2016; Mahmoodi et al., 2021).

Super absorbent polymers (SAPs) are hydrophilic chemicals with significant potential for maintaining water and nutrients for plant growth by enhancing soil water retention and nutrient use efficiency (Fallahi et al., 2015). Consuming SAP was reported as a method to improve saffron growth and production traits (Wu et al., 2008; Islam et al., 2011; Fallahi et al., 2014; 2016; 2017; Zarch et al., 2020) and a viable alternative for enhancing saffron flowering in regions under drought stress (Fallahi et al., 2017). However, the application of SAP with nanofertilizers was less reported. Khoshpeyk et al. (2022) observed an improvement in flower and stigma yield of saffron because of using SAP together with nanosilicon.

Therefore, the present study investigated the separate and combined effects of SAP and various fertilizers (nano and organic fertilizers) on phenology, production and quality of saffron of different corm sizes.

Materials and Methods

Experimental site

The experiment was conducted in the village of Douma, Batroun, North Lebanon, situated at an altitude of 1100 m.a.s.l, longitude of 35.834583, and latitude of 34.219683. Douma region is characterized by a Mediterranean climate, cold and rainy in winter, hot and dry in summer, with an average annual rainfall of approximately 800 mm. Prior to experiment initiation, soil analysis conducted on soil samples collected at 0 to 30 cm depth showed that the soil was sandy clay loam, with 5.04% organic matter, 0.4 mS.cm^{-1} EC, 0.41% total nitrogen, 462.4 ppm available phosphorus, 529.5 ppm available potassium, and 7.6 pH.

Experimental treatments

Sixteen treatments were the subject of study investigating the separate and combined effects of nano-chelate Super Plus ZFM++, Lithovit®-Forte, Seaumic, and SAP on the performance of small-sized (SS: 4–6 g) and medium-sized (MS: 6–8 g) saffron corms of the species *Crocus oreocreticus*. The experimental design was a randomized complete block design, with five blocks, sixteen treatments per block, with 25 replicates per treatment. Treatments were as follows: SS/Seaumic, SS/ZFM++, SS/LIForte, SS/SAP, SS/Seaumic/SAP, SS/ZFM++/SAP, SS/LIForte/SAP, MS/Seaumic, MS/ZFM++, MS/LIForte, MS/SAP, MS/Seaumic/SAP, MS/ZFM++/SAP, MS/LIForte/SAP, compared to two controls (SS and MS: non-treated corms).

Planting and products application

Field was plowed 30 cm deep into the soil, and before planting, weeds were removed manually, to reduce competition for water and nutrients with saffron corms. Likewise, the rows were prepared keeping 20 cm between them. During the first week of August, corms were planted distant of 15 cm in each row. Saffron irrigation used a localized drip system with a distance of 20 cm between the irrigation lines and 15 cm between the emitters of the same line. The first irrigation was done at the time of planting and the second irrigation 15 days later in order to facilitate the sprouting of the corms (Zarch et al., 2020). Transmitters with a flow rate of 4 l/h were used. Each irrigation was conducted for 1.5 h. Tested fertilizers were applied by fertigation at following doses; Lithovit®-Forte (1 kg/ha as a 0.5% suspension; 0.5 kg of Lithovit per 100 l of water), Seaumic (2 l/ha) and nano-chelate Super Plus ZFM++, (3 l/ha). Seaumic contained 67% Humic acid, 4.5% Fulvic acid, 10.5% K_2O, 1.6% Alginic acid, 0.1% P_2O_5, 0.3% Micro elements (Cu+Zn+Fe+B+Mo), 0.2% Mannitol, 100 ppm Betaine, 10 ppm Cytokinin, 50 ppm Giberellin, and 1% Amino acid. Lithovit®-Forte was composed of 60% Calcium Carbonate, 35% Calcium Oxide, 12% Silicon Dioxide, 1% Magnesium Oxide, 1% Iron, and 0.02% Manganese. Nano-chelate Super Plus ZFM++ contained 8% Zinc, 5% Iron, 3% Manganese, 1.5% Magnesium, 1% Calcium, 0.4% Copper, and 0.02% Boron. The SAP was applied at the time of saffron planting below and beside of mother corms (Fallahi et al., 2017). The used SAP was made of potassium polyacrylate based polymer and was applied at a rate of 40 kg/ha.

Data collection

Saffron phenology was evaluated through daily observations in terms of the date of occurrence of the following phenological events; date of leaf appearance, date of flowering, and the date of harvest. The date of leaf appearance was recorded as soon as the first leaf started to develop on saffron corms. Also, the date of flowering corresponded to the date when first flower developed on saffron corms. The date of harvest corresponded to the first harvest of every treatment. Whole, fully-open flowers were plucked by hand close to the ground level and harvested every 1–2 days. The total number of flowers harvested from every treatment was counted and then calculated per unit of area (m^2). At the same day of harvest, stigmas were removed from the flowers using sterile tweezers, and the yellow stalk was kept behind. Collected stigmas of every treatment were weighed and their fresh weight was calculated per unit area (m^2). Thereafter, stigmas were dried in an air-flow oven for 24 h at a constant temperature of 30°C based on the method suggested by McGimpsey et al. (1997). The weight of dry matter collected from each treatment corresponded to the stigma dry yield, which was then calculated by unit of area (m^2). Leaves developing on planted corms were counted and average leaf number was calculated per treatment. Leaf length was assessed on a sample of 15 corms per treatment (three representative corms per block). For determination of pigments, crocins, picrocrocin, and safranal, samples of 0.5 g dry stigma were collected per each treatment. Samples were analyzed following the ISO 3632 standard by measuring E1% of an aqueous saffron extract at 442, 330 and 257 nm using a 1 cm pathway cell on a Shimadzu UV-Visible 1100 spectrophotometer (Vida et al., 2012). Moreover, after leaf withering, corms were dug up from soil and the number and weight of daughter corms per square meter was recorded.

Results and Discussion

Saffron phenology and leaf development

Results (Table 1) showed that treated corms of small (4–6 g) and medium sizes (6–8 g) recorded significantly earlier dates of leaf appearance compared to non-treated corms, except in the treatment (SS/SAP). Kumar et al. (2008) had earlier reported a direct relationship between the size of the mother corm and the emergence of saffron leaves. In the current study, this was only applicable when corms were subjected to a combined treatment of fertilizers and SAP; recording significantly earlier dates of leaf appearances in medium-sized compared with small-sized corms. Eventually, increasing nutrient availability causes corms to perform better than solely depending on food storage, because it helps roots to grow faster and thus encourages a faster vegetative development (Heydari et al., 2014). Besides, concerning small-sized corms, leaf emergence date was hastened in corms by fertilizers with SAP than in those treated by fertilizers alone; by 10.8, 4.3, and 7.7 days in SS/Seaumic/SAP, SS/ZFM++/SAP, and SS/LIForte/SAP compared to SS/Seaumic, SS/ZFM++ and SS/ LIForte, respectively. The use of SAP accelerates cell division in corm by providing more moisture. These materials can enhance leaf growth and consequently more photo-assimilates partitioning to corms (Khorramdel et al., 2013; Fallahi et al., 2014). Further, leaf emergence occurred earlier by 5.2 and 4.2 days in the treatment MS/Seaumic compared to MS/ZFM++, and MS/LIForte, respectively. The earliest leaf emergence occurred in the treatments MS/Seaumic and MS/Seaumic/SAP (around 20 DAP), with no significant difference between both treatments. Heydari et al. (2014) had earlier reported on the positive effect of organic fertilizer containing humic acid on saffron vegetative growth.

The date of flowering (Table 1) was earlier by 5.0 days in control MS compared with control SS, and by 5.7 days in MS/SAP compared with SS/SAP. Saffron is a subhysteranthous plant, meaning that flowers can appear after leaf appearance (Mathew, 1977). Early studies of Mashayekhi

Table 1. Effects of fertilizers (nano-chelate Super Plus ZFM, Lithovit®-Forte, and Seaumic) and super absorbent polymers (SAP) on phenological dates and leaf development of small- and medium-sized saffron corms

Treatments	DLA (DAP)	DF (DAP)	DH (DAP)	LN	LL
SS (control)	42.2 ± 2.6 a	47.3 ± 2.3a	45.0 ± 2a	10 ± 1.9 d	40 ± 1.1 f
SS/SAP	40.0 ± 2.3 ab	42.0 ± 1.4b	44.5 ± 2.6a	10 ± 3.4 d	41.2 ± 3.6 f
SS/Seaumic	36.3 ± 1.0cd	38.7 ± 1.9bc	38.2 ± 1.8cd	12 ± 3.8 bcd	56.7 ± 2.3 cd
SS/ZFM++	38.3 ± 1.7 bc	38.8 ± 2.8bc	38.0 ± 3.2cd	9.8 ± 1.5 d	40 ± 2.9 f
SS/LIForte	37.7 ± 2.2bc	40.3 ± 1.6b	40.5 ± 2bc	13.8 ± 1.7 abc	55.8 ± 3.3 cd
SS/Seaumic/SAP	25.5 ± 1.4g	26.7 ± 3.6ef	27.7 ± 3.2e	12.2 ± 2.8 bcd	56 ± 5.8 cd
SS/ZFM++/SAP	34 .0± 1.4 e	35.5 ± 1.4cd	36.8 ± 3cd	11.3 ± 1.9 bcd	43.2 ± 3.3 ef
SS/LIForte/SAP	30.0 ± 2.3 f	34.3 ± 4.2d	36.7 ± 3.6d	13.3 ± 2.3 abcd	57.2 ± 3.7 cd
MS (control)	40.0 ± 2.1 ab	42.0 ± 2.4 b	42.3 ± 2ab	10.5 ± 1 cd	41.3 ± 3.1 f
MS/SAP	35.3 ± 0.8 de	36.3 ± 2.5cd	37.5 ± 3.8cd	12.3 ± 3.4 abcd	53.8 ± 4.8 d
MS/Seaumic	20.5 ± 3.0 i	20.2 ± 3.7g	20.8 ± 3f	13 ± 1.7 abcd	59 ± 2.5 bc
MS/ZFM++	25.7 ± 1.6 g	27.7 ± 3.5e	27.3 ± 1.9e	10.3 ± 3.7 cd	43.5 ± 4.4 ef
MS/LIForte	24.7 ± 1.2 g	26.5 ± 2.9ef	26.5 ± 5.2e	14.3 ± 1.8 ab	58.2 ± 3 cd
MS/Seaumic/SAP	20.3 ± 1.7 i	19.2 ± 2.5g	20.0 ± 1.8f	14 ± 4.4 abc	64.3 ± 4.6 a
MS/ZFM++/SAP	23.5 ± 1.8 gh	24.0 ± 2.8f	25.5 ± 1.6e	11 ± 2.6 bcd	46.5 ± 3.2 e
MS/LIForte/SAP	22.0 ± 1.8 hi	25.7 ± 1.4ef	26.5 ± 2.4e	15.8 ± 2.9 a	62.5 ± 2.7 ab

SS: small-sized corms (4–6 g), MS: medium-sized corms (6–8 g), DLA: date of leaf appearance, DF: date of flowering, DH: date of harvest, DAP: days after planting, LN: leaf number, LL: Leaf length. Means (n = 125) followed by the same letter within each column are not significantly different according to Duncan's multiple range tests. ± Standard Deviation

et al. (2006) and Nassiri Mahallati et al. (2007) denoted a crucial effect of corm size on saffron flowering. Experiments of Çavuşoğlu et al. (2009), and Ghobadi et al. (2015) showed that flowering dates were affected by corm size where bigger corms began to flower earlier than smaller ones. Compared with control cases, earlier flowering dates were recorded in treatments where fertilizers were used with SAP (earliness range of 11.8–20.6 days and 16.3–22.8 days in SS and MS corms, respectively), and in treatments where SAP was applied alone (earliness range of 6.5–15.3 days and 10.6–17.1 days in SS and MS corms, respectively).

Concerning both corm sizes, Seaumic used with SAP caused earlier flowering dates than nano-chelate Super Plus ZFM (ZFM++) or Lithovit®-Forte (LIForte) used with SAP. According to Sepaskhah & Yarami (2009), saffron flower growth and yield is most sensitive to soil water depletion. SAP accelerates flowering of saffron by maintaining adequate soil moisture throughout the growing season of saffron (Khorramdel et al., 2013). The earliest flowering and harvest dates (Table 1) were noted in the treatments MS/Seaumic and MS/Seaumic/SAP (20.2 and 20.8 DAP, and 19.2 and 20.0 DAP, respectively), with no significant difference between both treatments. Seaumic and Lithovit®-Forte applied with SAP on small-sized corms hastened the harvest date by 10.5 and 3.8 days compared to their application without SAP. On medium-sized corms, the use of fertilizers without SAP caused almost similar harvest dates compared with their use with SAP. Overall, treated corms of both weight categories recorded significantly earlier harvest dates compared to non-treated corms, and all treated corms of 6–8 g had earlier harvest dates compared with those of 4–6 g.

According to Tavakkoli et al. (2014), planting large corms will cause an increase in the number and length of saffron leaves. However, current results (Table 1) showed no significant difference in terms of both indicators among untreated corms of small- and medium size. Compared to control cases, average leaf number (Table 1) increased by 3.8 following the application of Lithovit®-Forte without SAP on small- and medium-sized corms, and by 5.3 following the use of the same product with SAP on medium-sized corms.

Compared with the nano-chelate Super Plus ZFM, Lithovit®-Forte showed superior effect on the leaf number of both corm weights when products were used without SAP, as well as on the leaf number of medium-sized corms when the three products were used with SAP. On the contrary, Gresta et al. (2017) had earlier reported a significant increase in the leaf number per corm as a result of subjecting bigger corms to nitrogen fertilization.

The use of Seaumic and Lithovit®-Forte on small-and medium-sized corms caused significantly higher averages of leaf length (Table 1) compared with nano-chelate Super Plus ZFM, whether the products were used with or without SAP. Also, same products used with SAP induced a significant increase in leaf length compared to their use without SAP on medium-sized corms (by 5.3 and 4.3 cm, respectively); with the highest values of leaf length recorded in MS/Seaumic/SAP and MS/LIForte/SAP, with no significant difference between both treatments.

The number and length of saffron leaves have a great effect on determining the photosynthetic capacity of the plant; improving leaf traits means increasing the photosynthesis in the plant (Kafi et al., 2006). Lithovit®-Forte could increase leaf number and length even when applied without SAP. Eventually, the product can significantly boost the rate of photosynthesis, and with its highly energized particles, plants are able to keep the stomata closed longer in case of water stress, leading to a lower water requirement. The product contains also trace elements and micronutrients including manganese, copper, and zinc, earlier studies of Baghai & Maleki Farahani (2013) and Rostami et al. (2019) have proved the positive role of which on saffron leaf length. Seaumic contains humic acid, seaweed extracts, and is rich in all kinds of nutritive elements and plant growth regulators, thus it causes a greater root development and a greater microbial activity in the soil, which in turn may have led to increased nutrient availability and better growth of saffron leaves. According to Golzari Jahan Abadi et al. (2017), the use of biofertilizers based on humic acid had a significant effect on leaf number. Increased leaf length was also reported by Kamel (2018) as a result of using micronutrient fertilizer containing seaweed extract.

The number of flowers is one of the most economically important attributes of saffron (Agayev et al., 2009). According to Temperini et al. (2009), about 16 to 80% of flower yield changes depend on soil variables. The use of SAP alone caused a significant improvement (by 14%) in flowers number per m^2 of medium-sized corms compared with control (Table 2), matching the percent increase of this indicator obtained by Fallahi et al. (2017). However, same authors obtained higher number of flowers per m^2 following the application a similar rate of SAP (40 kg/ha). Further, Azizi et al. (2020) noted a 32.0% increase in flowers number following the application of micronutrients. In the current experiment, products rich with micronutrients, such as nano-chelate Super Plus ZFM and Lithovit®-Forte, tested without SAP, had significantly improved this indicator compared with non-treated corms (by 15.4 and 10.9%, respectively for lighter corms and by 17.8 and 10.1%, respectively for heavier corms). Nano-chelate Super Plus ZFM tested without SAP on both corm sizes had superior effect on flower number per m^2 compared with Seaumic, which may be attributed to the higher iron and zinc content in the first product compared to the second. Iron and zinc application could affect saffron flowering (Koocheki & Seyyedi, 2016). Azarpour et al. (2013) obtained the highest amount of fresh flower yield after foliar spraying of nano-iron fertilizers. On the other hand, combining fertilizers with SAP improved flower number per m^2 compared with the use of fertilizers alone, except in SS/LIForte/SAP. In all treatments where fertilizers were tested in combination with SAP, this indicator recorded the highest value with Seaumic, with a 65.1% improvement in MS/Seaumic/SAP compared with control MS. According to Osmani Roudi et al. (2015) and Mollafilabi & Khorramdel (2016), humic acid application was found to have a good influence on the quantity of saffron flowers and to improve saffron yield. Also, a combined use of organic fertilizer with SAP caused the highest number of saffron flower in the study of Ramezani et al. (2020).

One other important yield components on which the economic value of the saffron product depends is the stigma yield (Baghai & Maleki Farahani, 2013). Enhancement in the mother corm weight had caused significant increases in stigma yield (de Juan et al., 2009; Aghhavani-Shajari et al., 2015). However, results of the current experiment came in contradiction; dry stigma yield (g/m^2) obtained of non-treated SS corms was of 0.137 g/m^2, and that of non-treated MS corms was of 0.1058 g/m^2. Koocheki & Teimouri (2014) reported higher flower and stigma yields resulting of an increase of corm weight from 4 g to 8–12 grams.

Furthermore, saffron yield can considerably be affected by changes of nutrient uptake and fertilizer applications (Rostami et al., 2019). Both the vegetative and reproductive growth phases (Amiri, 2008) as well as biomass partitioning (Gholami et al., 2017) in saffron have a near relation with good water and nutrient availability. Compared with control, Seaumic and Nano-chelate Super Plus ZFM applied without SAP increased the dry stigma yield (DSY) by around 43.9 and 33.7% in SS-corms and by 60 and 50.7% in MS-corms respectively, and Lithovit®-Forte increased DSY by 60.1% in MS-corms. Further, DSY were significantly higher in SS/Seaumic and SS/ZFM++ than in SS-LIForte (by 0.13 and 0.09 g/m^2, respectively).

Richness of Seaumic and Nano-chelate Super Plus ZFM with micronutrients could have played an important role on the saffron yield. Maleki Farahani & Aghighi Shahverdi (2015) reported significant enhancement in saffron yield because of nano-iron application. In the study of Seghatoleslami & Sabzekar (2016), the application of nano-zinc and ordinary zinc increased stigma dry weight by 9 and 6% respectively compared to control.

Both FSY and DSY were significantly higher in MS/SAP compared with SS/SAP. The use of SAP alone increased

Table 2. Effects of fertilizers (nano-chelate Super Plus ZFM, Lithovit®-Forte, and Seaumic) and super absorbent polymers (SAP) on productive traits of small- and medium-sized saffron corms

Treatments	FN	FSY (g/m^2)	DSY (g/m^2)	YDC (g/m^2)	NDC
SS (control)	34 ± 2 k	.2033 ± .014 h	.13717 ± .017fg	560 ± 2.4n	59 ± 3.2h
SS/SAP	34.2 ± 1.7 k	.1967 ± .017h	.097 ± .003g	571.5 ± 4.1l	58.7 ± 2.8h
SS/Seaumic	36 ± 2.5 ijk	.4283 ± .017def	.2443 ± .027cd	647.8 ±4.4h	62.3 ± 2.9gh
SS/ZFM++	40.2 ± 2.5 fgh	.4 ± .017ef	.2067 ± .023de	566.2 ± 2.8m	65 ± 2.1defg
SS/LIForte	38.2 ± 3.6 ghij	.2950 ± .029g	.115 ± .011fg	656.8 ± 2.5g	68.7 ± 4.2bcde
SS/Seaumic/SAP	60.7 ± 3.6 c	.8367 ± .034b	.48 ± .023b	675.7 ± 3.1e	69 ± 4.2bcd
SS/ZFM++/SAP	55.3 ± 2.3 d	.6583 ± .016c	.495 ± .027b	588 ± 3.8 k	65.2 ± 3.5defg
SS/LIForte/SAP	37.2 ± 2.6 hijk	.2983 ± .023g	.1118 ± .013fg	662.2 ± 1.7f	64.5 ± 3.4fg
MS (control)	35.5 ± 2.4 jk	.2067 ± .016h	.1058 ± .01g	617.5 ± 2.9j	62.5 ± 2.4gh
MS/SAP	41.3 ± 4 efg	.2867 ± .01g	.16500 ± .015ef	632 ± 1.3i	64.7 ± 3efg
MS/Seaumic	38 ± 3.8 ghij	.4617 ± .026d	.2666 ± .012c	697.8 ± 2.1d	70.5 ± 3.3abc
MS/ZFM++	43.2 ± 1.2 ef	.4683 ± .047d	.215 ± .024cde	658.8 ± 1.7fg	68.2 ± 2.9cdef
MS/LIForte	39.5 ± 3.2 fghi	.39 ± .025f	.235 ± .021cd	759.3 ± 3.6c	72.2 ± 2.8ab
MS/Seaumic/SAP	101.7 ± 3.5 a	2.0150 ± .12a	1.1116 ± .164a	850 ± 4.7a	73.5 ± 3.2a
MS/ZFM++/SAP	65.5 ± 4.2 b	.8467 ± .023b	.52 ± .026b	675.2 ± 1.9e	67 ± 2.5cdef
MS/LIForte/SAP	44.2 ± 1.7 e	.4417 ± .025de	.22 ± .014cde	774.8 ± 3.5b	74 ± 2.8a

SS: small-sized corms (4-6 g), MS: medium-sized corms (6-8 g), FN: flower number, FSY: fresh stigma yield (g/m^2), DSY: dry stigma yield (g/m^2), YDC: yield of daughter corms, NDC: number of daughter corms. Means (n = 125) followed by the same letter within each column are not significantly different according to Duncan's multiple range tests

FSY and DSY of MS corms by 27.9% and 35.8%, respectively compared with control MS. A 24% increase in both indicators was found by Fallahi et al. (2017) using a similar rate of SAP.

The use of fertilizers with SAP increased FSY compared to control cases. Also, Seaumic and Nano-chelate Super Plus ZFM used with SAP improved DSY by around 71.4 and 72.3% in SS-corms and 90.4 and 79.6% in MS-corms, respectively. The highest FSY and DSY recorded in MS/Seaumic/SAP (2.01 and 1.11 g/m^2). Humic acid and seaweed extracts contained in Seaumic may have contributed to superior yields obtained in the latter treatment. Early studies of Ahmadi et al. (2018), Gerdakaneh et al. (2020) and Khorramdel et al. (2022) found that humic acid application has improved saffron yield. Armak et al. (2021) stigma dry weight was improved by 86.49% relative to control following the application of Super Humic treatment. According to MacDonald et al. (2012), seaweed extract improves soil ventilation, growth, and production in many plants, which is related to the content of amino acids that stimulate different growth attributes.

Further, Seaumic or the Nano-chelate Super Plus ZFM applied with SAP caused significantly higher FSYM and DSYM compared with the use of both fertilizers without SAP. The availability of adequate moisture will lead to a better growth and flowering of saffron (Khorramdel et al., 2013; Fallahi et al., 2014). An advantage of using SAP is that it may decrease water need and increase WUE (water-use efficiency) of saffron by reducing the amount of water consumption during its life cycle. Therefore, consuming SAP is a viable alternative for enhancing saffron flowering in regions under drought stress (Fallahi et al., 2016). In a close context, Khoshpeyk et al. (2022) reported that the use of nanosilicon together with SAP in saline conditions caused improvement in flower and stigma yield of saffron over three consecutive years.

Saffron can grow like a perennial plant on the field for several years and multiplies by increasing the number of daughter corms (Koocheki et al., 2015). According to Arslan et al. (2007), corm weight has a positive effect on the production and growth of daughter corms. In the current study, Yield of daughter corms (YDC) obtained from medium-sized corms was higher than that of small-sized corms (respective ranges of 617.5–850.0 g/m^2 and 560.0–675.7 g/m^2). Compared with control cases, YDC increased in all treatments, and mostly in treatments where fertilizers were used with SAP; it improved by 17.1, 15.4, and 4.76% in SS/Seaumic/SAP, SS/LIForte/SAP, and SS/ZFM++/SAP and by 27.3, 20.3, and 8.54% in MS/Seaumic/SAP, MS/LIForte/SAP, and MS/ZFM++/SAP, respectively. The highest number of daughter corms (NDC) was in the treatments MS/LIForte/SAP and MS/Seaumic/SAP, with around 15% improvement compared with MS (control), and around 20% improvement compared with SS (control).

According to Islam et al. (2011), the formation of daughter corms is significantly affected by both the availability of water and soil nutrients. The use of SAP provides suitable conditions for the production of daughter corms, by increasing the water retention capacity soil, improving porosity, increasing ventilation, and providing essential nutrients required by the plant in the rhizosphere environment (Wu et al., 2008; Ramezani et al., 2020). Also, humic acid stimulates corm growth by improving the nutrient conditions of the planted corms, which ultimately determines the potential yield of saffron. Golzari Jahan Abadi et al. (2017) found 56.7 and 61.6% increase in the number of daughter corms and fresh weight of mother corms respectively compared to control following humic acid treatment.

The value of saffron (dry stigma) is due to its qualitative properties and the presence of three main secondary metabolites: crocin, picrogrosin, safranal, and their derivatives (Moraga et al., 2009). The main carotenoid of saffron is crocin and is responsible for the spice colour, whereas, picrocrocin is the molecule responsible for its bitter taste and safranal is one of the many molecules imparting the characteristic spice aroma (José Bagur et al., 2017). Picrocrocin content (Table 3) increased significantly compared to control cases in all treatments except, SS/SAP, MS/SAP, SS/LIForte/SAP and MS/LIForte/SAP. Treatments with Seaumic and Nano-chelate Super Plus ZFM, applied with or without SAP, resulted in significantly higher picrocrocin content compared to treatments with LIForte. The first two products had superior effect on picrocrocin content when used with SAP than without it; improvement by 6.3 and 7.5% in SS/Seaumic/SAP and SS/ZFM++/SAP compared to SS/SAP, and by 6.9 and 8.3% in MS/Seaumic/SAP and MS/ZFM++/SAP compared to MS/SAP. Results also showed that crocin content was significantly higher than control cases in all treatments, except in SS/SAP, MS/SAP, and MS/LIForte/SAP, with the highest crocin content obtained in MS/ZFM++ (180.7%) and SS/ZFM++ (178.5%), with no significant difference between both treatments. Seaumic and Nano-chelate Super Plus ZFM applied alone improved crocin content of smaller corms by 9.8 and 12.6%, respectively, and that of bigger corms by 8.3 and 12.4%, respectively. On the contrary, LIForte applied alone improved crocin content of smaller corms by 6%. Besides, crocin content decreased significantly when Nano-chelate Super Plus ZFM was combined with SAP; by 5.2% in SS-corms and by 5.5% in MS-corms. Akbarian et al. (2012) reported that increasing concentrations of K, Fe, and Zn elements could increase picocrocin content, but decrease the crocin content.

Humic acid can chelate elements such as nitrogen, phosphorus, potassium, and iron, increase their absorption, and ameliorate the activity of enzymes involved in the center attributed organic compounds in plants (de Santiago et al., 2008). Furthermore, Seaumic and ZFM++ applied alone had a superior effect on qualitative indicators (higher picrocrocin and crocine contents) compared to their use in combina-

Table 3. Effects of fertilizers (nano-chelate Super Plus ZFM, Lithovit®-Forte, and Seaumic) and super absorbent polymers (SAP) on saffron quality

	Picrocrocin	Safranal	Crocin
SS (control)	73.3 ± 4.9 j	24.1 ± 1.9b	165.9 ± 1.5i
SS/SAP	74 ± 2.9 ij	24.3 ± 2ab	168 ± 2.2hi
SS/Seaumic	85.3 ± 4.7abcd	26.9 ± 3.3ab	175.7 ± 2.4bcd
SS/ZFM++	87.1 ± 2.9 ab	27.9 ± 3ab	178.5 ± 3ab
SS/LIForte	78 ±1.3fghi	25 ± 4.7ab	171.9 ± 2.2defg
SS/Seaumic/SAP	80.3 ± 5.8efg	25.6 ± 1.1ab	172.6 ± 6def
SS/ZFM++/SAP	81.5 ± 1.8def	25.9 ± 1.6ab	173.3 ± 3.8cdef
SS/LIForte/SAP	76.1 ± 2.3hij	24.7 ± 3.8ab	170.9 ± 2.2fgh
MS (control)	75.4 ± 4hij	24.6 ± 2.3ab	168.3 ± 2.8ghi
MS/SAP	75.3 ± 2.2hij	24.5 ± 1.8ab	169.7 ± 2.2fgh
MS/Seaumic	85.5 ± 1.8abc	27.3 ± 3.7 ab	176.6 ± 2.4bc
MS/ZFM++	88.1 ± 2a	28.2 ± 1.8a	180.7 ± 2a
MS/LIForte	78.3 ± 2.4fgh	25 ± 3.1ab	172.2 ± 4.1defg
MS/Seaumic/SAP	82.8 ± 3.6cde	26 ± 2ab	174.9 ± 2.1bcde
MS/ZFM++/SAP	83.6 ± 1.3bcde	26.2 ± 3ab	175.2 ± 2.9bcd
MS/LIForte/SAP	76.5 ± 2ghij	24.81 ± 2.8ab	171.2 ± 3efgh

SS: small-sized corms (4–6 g), MS: medium-sized corms (6–8 g); Means followed by the same letter within each column are not significantly different according to Duncan's multiple range tests tion with SAP, while they had superior effect on dry stigma yield when combined with SAP compared to their use alone. According to Heydari et al. (2014), in heavier stigmas, we should expect a lower percentage of safranal, crocin and picrocrocin and therefore a reduction in the aroma and taste of the stigma. Therefore, it is possible that the plant growth speed is higher than the speed and amount of essential oil production by the plant and it causes its concentration to decrease in the stigma. On the contrary, Khoshpeyk et al. (2022) concluded that if a product leads to the improvement of the quantitative performance of one or more traits, it might be effective in increasing the qualitative performance of other substances such as secondary metabolites.

Safranal content did not significantly differ between treated and non-treated corms of both sizes, except a significant improvement in the treatment MS/ZFM++ compared with control SS-corms.

According to Ahmadi et al. (2017), because the biosynthesis of safranal start from cleavage of zeaxanthin to produce cyclic carotenoid (safranal and picrocrocin), it seems that decrease in safranal with increase in picrocrocin are due to competition.

Conclusion

Obtained results suggests that the use of the products Seaumic and Nano-chelate Super Plus ZFM without SAP may compensate the low weight of planted corms; improvements of 30% of smaller corms' dry stigma yield is of a great economic importance. The positive effects of both products on saffron yield may be optimized, reaching more than 70% improvement, when combined with the application of SAP in the rate proposed by the current study. Such a combination may be recommended in regions with drought stress or saline conditions. Furthermore, these products are more recommended than Lithovit®-Forte when targeting a higher saffron quality. The latter product might be more efficient on corms of > 6 g weight.

Funding details

This work did not receive any fund

Disclosure statement

The authors report there are no competing interests to declare

References

Agayev, Y. M. O., Fernandez, J. A. & Zarifi, E. (2009). Clonal selection of saffron (*Crocus sativus* L.): the first optimistic experimental results. *Euphytica, 169*(1), 81–99.

Aghhavani-Shajari, M., Rezvani Moghaddam, P., Koocheki, A., Fallahi, H. R. & Taherpour- Kalantar, R. (2015). Evaluation of the effects of soil texture on yield and growth of saffron (*Crocus sativus* L.). *Saffron Agronomy and Technology, 2*(4), 311–322.

Ahmadi, F., Aminifard, M. H., Khayat, M. & Samadzadeh, A. R. (2017). Effects of different humic acid levels and planting density on antioxidant activities and active ingredients of saffron (*Crocus sativus* L.). *Saffron Agronomy and Technology, 5*(1), 61-71.

Ahmadi, F., Aminifard, M. H., Khayyat, M. & Samadzade, A. R. (2018). Effects of humic acid and corm density on saffron yield and yield components in the second year. *Saffron Agronomy and Technology, 6*(2), 197–207.

Akbarian, M. M., Sharifabad, H. H., Noormohammadi, G. H. & Kojouri, F. D. (2012). The effect of potassium, zinc and iron foliar application on the production of saffron (*Crocus sativa*). *Annals of Biological Research, 3*(12), 5651–5658.

Alipoor -Miandehi, Z., Mahmoodi, S., Behdani, M. A. & Sayyari, M. H. (2015). Effect of bio manure and chemical fertilizers and corm weight on the corm characteristics of saffron (*Crocus sativus*). *Plant Products Technology (Agricultural Research), 15*(2), 13–24.

Amiri, M. E. (2008). Impact of animal manures and chemical fertilizers on yield components of saffron (*Crocus sativus* L.). *American-Eurasian Journal of Agriculture and Environmental Science, 4*(3), 274–279.

Amirnia, R., Bayat, M. & Tajbakhsh, M. (2014). Effects of nano fertilizer application and maternal corm weight on flowering at some saffron (*Crocus sativus* L.) ecotypes. *Turkish Journal of Field Crops, 19*(2), 158.

Armak, A. A., Feizi, H. & Alipanah, M. (2021). Influence of nitrogen, acid humic and nitrogen, phosphorus-soluble bacteria on saffron (*Crocus sativus* L.) corm reproduction and flower production of Torbat Heydarieh landrace. *Iranian Journal of Seed Science and Technology, 10*(2), 73-84.

Arslan, N., Gürbüz, B., Ipek, A., Özcan, S., Sarihan, E., Daeshian, A.M. & Moghadassi, M.S. (2007). The effect of corm size and different harvesting times on Saffron (*Crocus sativus* L.) regeneration. *Acta Horticulturae*, *739*, 113-117.

Azarpour, E., Asghari, J., Bozorgi, H. R. & Kamalpour, G. (2013). Foliar spraying of Ascophyllum nodosum extract, methanol and iron fertilizers on fresh flower cover yield of saffron plant (*Crocus sativus* L.). *International Journal of Agriculture and Crop Sciences (IJACS), 5*(17), 1854-1862.

Azizi, G., Musavi, S. G., Seghatoleslami, M. J. & Fazeli Rostampour, M. (2020). The effect of foliar application of seaweed extract, urea and micronutrient fertilizers on performance and its components of saffron (*Crocus sativus* L.). *Journal of Saffron Research, 8*(1), 141-159.

Baghai, N. & Maleki Farahani, S. (2013). Comparison of Nano and micro Chelated iron fertilizers on quantitative yield and assimilates allocation of saffron (*Crocus sativus* L.). *Journal of Saffron Research, 1*(2), 156-169.

Çavuşoğlu, A., Erkel, E. İ. **&** Sülüşoğlu, M. (2009). Saffron (*Crocus sativus* L.) studies with two mother corm dimensions on yield and harvest period under greenhouse condition. *American-Eurasian Journal of Sustainable Agriculture, 3*(2), 126-129.

Chen, Y., Camps-Arbestain, M., Shen, Q., Singh, B. & Cayuela, M. L. (2018). The long-term role of organic amendments in building soil nutrient fertility: a meta-analysis and review. *Nutrient Cycling in Agroecosystems, 111*(2), 103-125.

Chhipa, H. (2017). Nanofertilizers and nanopesticides for agriculture. *Environmental Chemistry Letters, 15*, 15-22.

Cid-Pérez, T. S., Nevárez-Moorillón, G. V., Ochoa-Velasco, C. E., Navarro-Cruz, A. R., Hernández-Carranza, P. & Avila-Sosa, R. (2021). The relation between drying conditions and the development of volatile compounds in saffron (*Crocus sativus*). *Molecules, 26*(22), 6954.

de Juan, J. A., Córcoles, H. L., Muñoz, R. M. & Picornell, M. R. (2009). Yield and yield components of saffron under different cropping systems. *Industrial Crops and Products, 30*(2), 212-219.

de Santiago, A., Quintero, J.M., Carmona, E. & Delgado, A. (2008). Humic substances increase the effectiveness of iron sulfate and vivianite preventing iron chlorosis in white lupin. *Biology and Fertility of Soils, 44*(6), 875-883.

Dourandish, A., Ramezani, M. & Aminizadeh, M. (2019). Investigation of the effective factors on use of chemical fertilizers in saffron farms (Case study: Gonabad country). *Saffron Agronomy and Technology, 7*(3), 359-376.

Ebrahimi, M., Pouyan, M. Shahi, T., Fallahi, H. R., Hoseini, S., Ragh Ara, H. & Branca, F. (2022). Effects of organic fertilizers and mother corm weight on yield, apocarotenoid concentration and accumulation of metal contaminants in saffron (*Crocus sativus* L.). *Biological Agriculture and Horticulture, 38*(2), 73-93.

Fallahi, H. R., Feli, A. & Salari-Nasab, S. (2014). Study the effects of super absorbent on growth of saffron. In: *Proceeding of the 3rd National Conference on the Scientific Achievements of saffron.* November, Torbat Heydariyeh University, Iran.

Fallahi, H. R., Paravar, A., Behdani, M. A., Aghhavani-Shajari, M. & Fallahi, M. J. (2014). Effects of saffron corm and leaf extracts on early growth of some plants to investigate the possibility of using them as associated crop. *Notulae Scientia Biologicae, 6*(3), 282-287.

Fallahi, H. R., Kalantari, R. T., Shajarim, A. & Soltanzadeh, M. G. (2015). Effect of super absorbent polymer and irrigation deficit on water use efficiency, growth and yield of cotton. *Not. Sci. Biol., 7*(3), 338-344.

Fallahi, H. R., Zamani, G., Mehrabani, M., Aghhavani-Shajari, M. & Samadzadeh, A. (2016). Influence of superabsorbent polymer rates on growth of saffron replacement corms. *Journal of Crop Science and Biotechnology, 19*(1), 77-84.

Fallahi, H. R., Zamani, G., Aghhavani-Shajari, M., Samadzadeh, A., Branca, F. & Mehrabani, M. (2017). Saffron flower and stigma yield changes in response to application of different levels of super absorbent polymer. *Journal of Medicinal plants and By-product, 6*(2), 145-151.

Fallahi, H. R. & Mahmoodi, S. (2018). Influence of organic and chemical fertilization on growth and flowering of saffron under two irrigation regimes. *Saffron Agronomy and Technology, 6*(2), 147-166.

Gerdakaneh, M., Amini, E. & Khan Ahmadi, M. (2020). Effects of soil and foliar spraying application of humic acid on qualitative and quantitative properties of saffron. *Journal of Saffron Research, 8*(1), 71-84.

Ghobadi, F., Ghorbani Javid, M. & Sorooshzadeh, A. (2015). Effects of planting date and corm size on flower yield and physiological traits of saffron (*Crocus sativus* L.) under Varamin plain climatic conditions. *Saffron Agronomy and Technology, 2*(4), 265-276.

Gholami, M., Kafi, M. & Khazaei, H. R. (2017). Study of the relations of sink and source in saffron by means of correlation coefficients under different irrigation and fertilization levels. *Saffron Agronomy and Technology, 5*(3), 195-210.

Golzari Jahan Abadi, M., Behdani, M. A., Sayyari Zahan, M. H. & Khorramdel, S. (2017). Effect of some fertilizer sources and mother corm weight on growth criteria and qualitative traits of saffron (*Crocus sativus* L.). *Journal of Saffron Research, 4*(2), 172-186.

Gresta, F., Napoli, E., Ceravolo, G., Santonoceto, C., Strano, T. & Ruberto, G. (2017). Stigmas yield and volatile compounds of saffron (*Crocus sativus*) in a late sowing under greenhouse with two nitrogen rates. *Acta Horticulturae, 1184*, 293-299.

Heydari, Z., Besharati, H. & Maleki Farahani, S. (2014). Effect of some chemical fertilizer and biofertilizer on quantitative and qualitative characteristics of Saffron. *Saffron Agronomy and Technology, 2*(3), 177-189.

International Standard, "Saffron-Specification" ISO 3632-1:1993(E), International Organization for Standardization, Switzerland. (1993).

Islam, M. R., Xue, X., Mao, S., Ren, C., Eneji, A. E. & Hu, Y. (2011). Effects of water-saving superabsorbent polymer on antioxidant enzyme activities and lipid peroxidation in oat (*Avena sativa* L.) under drought stress. *Journal of the Science of Food and Agriculture, 91*(4), 680-686.

José Bagur, M., Alonso Salinas, G. L., Jiménez-Monreal, A. M., Chaouqi, S., Llorens, S., Martínez-Tomé, M. & Alonso, G. L. (2017). Saffron: An old medicinal plant and a potential novel functional food. *Molecules, 23*(1), 30.

Kafi, M., Rashed-Mohassel, M. H., Koocheki, A. & Mollafilabi, A. (2006). Saffron, Production and Processing. Ferdowsi University of Mashhad press, Iran. Persian with English Summary.

Kamel, P. (2018). Effect of time and amount of total fertilizer containing seaweed extract on growth characteristics of aerial parts and saffron. University of Sabzvar, Iran.

Khorramdel, S., Gheshm, R., Amin-Ghafori, A. & Esmaielpour, B. (2013). Evaluation of soil texture and superabsorbent polymer impacts on agronomical characteristics and yield of saffron. *Journal of Saffron Research, 1*(2), 120-135.

Khorramdel, S., Mokhtari, M. & Latifi, H. (2022). The impact of various soil fertilizers on yield and growth criteria of saffron: A meta-analysis of field studies. *Saffron Agronomy and Technology, 10*(2), 129-147.

Khoshpeyk, S., Sadrabadi Haghghi, R. & Ahmadian, A. (2022). The effect of irrigation water quality and application of silicon, nanosilicon and superabsorbent polymer on the yield and active ingredient of saffron (*Crocus sativus* L.). *Journal of Saffron Research, 10*(1), 64-83.

Kirmani, N. A., Sofi, J. A., Bhat, M. A. & Ansar-Ul-Haq, S. (2014). Sustainable saffron production as influenced by integrated nitrogen management in Typic Hapludalfs of NW Himalayas. *Communications in Soil Science and Plant Analysis, 45*(5), 653–668.

Koocheki, A. & Teimouri, S. (2014). Effect of age of farm, corm size and manure fertilizer treatments on morphological criteria of Saffron (*Crocus sativus* L.) under Mashhad conditions. *Applied Field Crops Research, 27*(105), 148-157.

Koocheki, A., Fallahi, H. R., Amiri, M. B. & Ehyaei, H. R. (2015). Effects of humic acid application and mother corm weight on yield and growth of saffron (*Crocus sativus* L.). *Agricultural Ecology, 7*(4), 425-442.

Koocheki, A. & Seyyedi, S. M. (2016). Effects of corm size, organic fertilizers, Fe-EDTA and Zn-EDTA foliar application on nitrogen and phosphorus uptake of saffron (*Crocus sativus* L.) in a calcareous soil under greenhouse conditions. *Notulae Scientia Biologicae, 8*(4), 461-467.

Kothari, D., Thakur, R. & Kumar, R. (2021). Saffron (*Crocus sativus* L.): Gold of the spices – a comprehensive review. *Horticulture, Environment, and Biotechnology, 62*(5), 661-677.

Kumar, R., Singh, V., Devi, K., Sharma, M., Singh, M. K. & Ahuja, P. S. (2008). State of art of saffron (*Crocus sativus* L.) agronomy: A comprehensive review. *Food Reviews International, 25*(1), 44-85.

Lopez-Corcoles, H., Brasa-Ramos, A., Montero-Garcia, F., Romero-Valverde, M. & Montero-Riquelme, F. (2015). Short communication. Phenological growth stages of saffron plant (*Crocus sativus* L.) according to the BBCH Scale. *Revista de Investigacion Agraria, Spanish Journal of Agricultural Research, 13*(3), e09SC01.

MacDonald, J. E., Hacking, J., Weng, Y. & Norrie, J. (2012). Root growth of containerized lodgepole pine seedlings in response to *Ascophyllum nodosum* extract application during nursery culture. *Canadian Journal of Plant Science, 92*(6), 1207-1212.

Mahmoodi, F., Mahdinezhad, N., Fakheri, B. A. & Ahmadian, A. (2021). Effect of silver nanoparticles and corm weight on physiological and morphological traits of saffron (*Crocus sativus*) under Sistan climatic conditions. *Journal of Iranian Plant Ecophysiological Research, 16*(61), 45-63.

Maleki Farahani, S. & Aghighi Shahverdi, M. (2015). Evaluation the effect of nano-iron fertilizer in compare to iron chelate fertilizer on qualitative and quantitative yield of saffron. *Journal of Crops Improvement, 17*(1), 155-168.

Mashayekhi, K., Kamkar, B. & Soltani, A. (2006). The Effect of corm weight and environmental temperature on flowering behavior of saffron (*Crocus sativus*). In: *Proceedings of 2nd International Symposium on Saffron Biology and Technology, October, 28–30.*

Mathew, B. (1977). Crocus sativus and its allies (Iridaceae). *Plant Systematics and Evolution, 128*(1), 89-103.

McGimpsey, J. A., Douglas, M. H. & Wallace, A. R. (1997). Evaluation of saffron (*Crocus sativus* L.) production in New Zealand. *New Zeal. J. Hort. Sci., 25*(2), 159-168.

Menia, M., Iqbal, S., Zahida, R., Tahir, S., Rh, K., Aa, S. & Hussain, A. (2018). Production technology of safron for enhancing productivity. *J. Pharmacogn. Phytochem., 7*(1), 1033-1039.

Mollafilabi, A. & Khorramdel, S. (2016). Effects of cow manure and foliar spraying on agronomic criteria and yield of saffron (*Crocus sativus* L.) in a six-year-old farm. *Saffron Agronomy and Technology, 3*(4), 237-249.

Moraga, Á. R., Rambla, J. L., Ahrazem, O., Granell, A. & Gómez-Gómez, L. (2009). Metabolite and target transcript analyses during *Crocus sativus* stigma development. *Phytochemistry, 70*(8), 1009-1016.

Nassiri Mahallati, M., Koocheki, A., Boroumand Rezazadeh, Z. & Tabrizi, L. (2007). Effects of corm size and storage period on allocation of assimilates in different parts of saffron plant (*Crocus sativus* L.). *Iranian Journal of Field Crops Research, 5*(1), 155-165.

Nehvi, F. A., Lone, A. A., Khan, M. A. & Maqhdoomi, M. I. (2010). Comparative study on effect of nutrient management on growth and yield of saffron under temperate conditions of Kashmir. *Acta Horticulturae, 850*, 165-170.

Osmani Roudi, H. R., Masoumi, A., Hamidi, H. & Razavi, S. A. (2015). Effects of first irrigation date and organic fertilizer treatments on Saffron (*Crocus sativus* L.) yield under Khaf climatic conditions. *Saffron Agronomy and Technology, 3*(1), 33-25.

Ramezani, A., Aroiee, H., Azizi, M. & Ahmadian, A. (2020). Assessing the effect of irrigation management on economic yield and production of active ingredients of saffron medicinal plant (*Crocus sativus* L.) by application of organic fertilizer and nanocomposite superabsorbent polymers. *Saffron Agronomy and Technology, 8*(1), 3-18.

Rezaie, A., Feizi, H. & Moradi, R. (2019). Response of quantitative and qualitative characteristics of Saffron flower to the last irrigation cut-off time and various fertilizer resources. *Saffron Agronomy and Technology, 7*(1), 3-25.

Rostami, M., Talarposhti, R. M., Mohammadi, H. & Demyan, M. S. (2019). Morpho-physiological response of Saffron (*Crocus sativus* L.) to particle size and rates of zinc fertilizer. *Communications in Soil Science and Plant Analysis, 50*(10), 1250-1257.

Seghatoleslami, M. & Sabzekar, E. (2016). Saffron responses to summer irrigation and nano zinc oxide. In: *V International Symposium on Saffron Biology and Technology: Advances in Biology, Technologies, Uses and Market 1184, November*, 115-118.

Sepaskhah, A. R. & Yarami, N. (2009). Interaction effects of irrigation regime and salinity on flower yield and growth of saffron. *The Journal of Horticultural Science and Biotechnology, 84*(2), 216-222.

Shariatmadari, Z., Shoor, M., Rezvani Moghaddam, P., Tehranifar, A. & Ahmadian, A. (2018). Study the effects of organic and chemical fertilizers on replacement corms and flower characteristics of Saffron (*Crocus sativus* L.). *Saffron Agronomy and Technology, 6*(3), 291-308.

Shokrpour, M. (2019). Saffron (*Crocus sativus* L.) breeding: opportunities and challenges. Advances in plant breeding strategies. *Industrial and Food Crops*, *6*, 675-706.

Tavakkoli, A., Sorooshzade, A. & Ghorbani Javid, M. (2014).

Effect of buds removing and corm size on growth characteristics and yield of saffron (*Crocus sativus* L.). *Saffron Agronomy and Technology, 1*(2), 69-84.

Temperini, O., Rea, R., Temperini, A., Colla, G. & Rouphael, Y. (2009). Evaluation of saffron (*Crocus sativus* L.) production in Italy: Effects of the age of saffron fields and plant density. *Journal of Food, Agriculture & Environment, 7*(1), 19-23.

Vida, M., Akhtar, K. & Ebrahim, A. (2012). Effect of different drying methods on saffron (*Crocus sativus* L.) quality. *Iran. J. Chem. Chem. Eng., 13*(2), 85-89.

Wu, L., Liu, M. & Liang, R. (2008). Preparation and properties of a double-coated slow-release NPK compound fertilizer with superabsorbent and water-retention. *Bioresource Technology, 99*(3), 547-554.

Zarch, M. S., Khajoeinezad, G. R. Maghsoudi, A. A. & Mohammadinejad, G. (2020). Effects of applied water and superabsorbent polymer on the growth index and yield in saffron. *Environmental Stresses in Crop Sciences, 13*(3), 903-914.

Zhang, A., Shen, Y., Cen, M., Hong, X., Shao, Q., Chen, Y. & Zheng, B. (2019). Polysaccharide and crocin contents, and antioxidant activity of saffron from different origins. *Ind. Crops Prod., 133*, 111–117.

Received: **November, 14, 2022**; *Approved*: **February, 20, 2023;** *Published:* **February, 2025**