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Saffron vegetative growth as affected by transplanting and direct corm planting under field conditions

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ABSTRACT

Purpose: One of the main challenges of saffron production under controlled environments (CE) is that when flowering ends, there is no specific plan for corm proliferation. It seems that transplanting can provide economic justification for saffron production in CE, by providing the possibility of replacement corms production. This study aimed to evaluate the possibility and effectiveness of transplanting of those corms that previously flowered in controlled condition. **Research method:** To compare the vegetative growth of saffron between two planting methods including direct planting (DP) and transplanting (TP) an experiment was conducted. In the TP method, corms that were flowered under CE were transplanted to four plots beside the plots of DP. At the end of the growing season, leaf and replacement corms (RC) criteria were measured in both planting methods. **Findings:** Leaf length and weight in DP were 19.5 and 85.1 % more than TP, respectively. Mean RC weight (4.01 *vs.* 2.35 g), the weight of main RC (14.22 *vs.* 9.56 g), and number of buds with flowering potential (1.87 *vs.* 1.28 No. per corm), in DP was more than TP. The number of RC (524 *vs.* 612 corms per m^2) was higher in TP, while RC yield (2093 *vs.* 1432 g m^2) was more in DP method. The percentage of large RC (> 9g) in DP and TP was 19.8 and 6.5 %, respectively. Also, 68 and 32 % of RC yields were belonged to large corms, in DP and TP methods, respectively. **Limitations:** This study was one of the first studies on saffron transplanting, and the methodologies should be improved in future studies to gain more favorable results. **Originality/Value:** It was concluded that transplanting of those corms which were flowered under CE is possible, and at least one-third of the RC yield was at the desired weight.

INTRODUCTION

Saffron (*Crocus sativus* L.), a member of Iridaceae, is an annual herbaceous medicinal and spice plant. In traditional medicine, it is used mainly as a tonic agent and antidepressant drug. Recently, it is used for the prevention of chronic diseases or cancer. In addition, due to its coloring, flavoring, and aroma capacity, saffron has many applications in the food industry (Cardone et al., 2020; Koocheki & Khajeh-Hosseini, 2020). Saffron global production is estimated at 418 t y^{-1} on 121,338 ha (Cardone et al., 2020). Of this amount, 404 tons are produced from an area equivalent to 112,000 hectares in Iran (IMA, 2019), which accounts for more than 95% of world production.

Saffron production under controlled environments (CE) is one of the recent advances in its production. In this method, both or one of the flowering phases (flower initiation and flower emergence) of saffron is passed outside the soil, under CE (Behdani & Fallahi, 2015; Koocheki & Khajeh-Hosseini, 2020). The real dormancy period of corms (around June, before flower initiation) is the best time for corm harvesting to be used in CE (Mollafilabi, 2014). However, in some studies, corms have been removed from the soil after the first stage of flowering, and therefore, only the second stage of flowering has passed under CE (Fallahi et al., 2017). For appropriate flower initiation, it is recommended to corms be incubated at a dark place with a temperature of about 25 °C and relative humidity of around 85% for 55-150 days. After that, for flower emergence, corms are transferred to another place with ~15 °C and periodicity of 8 hours light and 16 hours darkness (Molina et al., 2004; Alonso et al., 2012; Mollafilabi, 2014).

Saffron production under CE has many advantages such as reducing the adverse effect of climate change on flowering, eliminating the harmful impacts of improper soil structure on flower emergence, considerable savings in water consumption, providing appropriate microclimate for flowering, eliminating the effects of cold, rainfall and wind on the flowers, lower flower contamination, easer flower harvesting, and eventually higher stigma quality and quantity (Sadeghi, 2013; Mollafilabi, 2014; Behdani & Fallahi, 2015; Fallahi et al., 2018; Koocheki & Khajeh-Hosseini, 2020). The possibility and the usefulness of flower production under CE on the yield and quality of saffron have been proven in previous studies (Molina et al., 2004; Maggio et al., 2006; Poggi et al., 2010; Fallahi et al., 2017; Ali Ahmad et al., 2017). However, there is sever uncertainty about the economic justification of this method, because there is no specified program for corms proliferation after flowering.

In a study on vertical production of saffron with a mixture of perlite, soil, and manure as substrate, although flowering was significantly more than its outdoor production in soil media, corm production was not desirable (Ali Ahmad et al., 2017). Results of a hydroponically conducted study on saffron showed that low red to far-red photon flux density ratio during the development of the daughter corms stage accelerated the translocation of photoassimilates from the leaves to the corms to generate carbohydrate-enriched replacement corms (Kajakawa et al., 2018). In another study in a glasshouse, saffron corms were planted in pots filled with sterile quartz sand on a layer of sterilized expanded clay. Results revealed that 2.63 replacement corms were produced per each planted corm and there was 12.6 % weight variation between planted and replaced corms (Caser et al., 2019).

Some researchers have proposed to transfer saffron seedlings to the fields after flowering for the production of replacement corms to be used in a new cycle of flower production (Alonso et al., 2012; Sadeghi, 2013). The possibility and usefulness of transplanting only in a preliminary study has been evaluated by Molina et al. (2010), and recently by Fallahi et al. (2020) and Aghhavani-Shajari et al. (2021). Therefore, many of the requirements of this method have not been thoroughly investigated. Accordingly, this study aimed to evaluate the effect of transplanting on saffron vegetative growth and corm proliferation.

MATERIALS AND METHODS

In this experiment, the vegetative growth of saffron was compared between two planting methods, including direct planting (DP) and transplanting (TP) during the growing season of 2019-2020 (one cycle of saffron growth). For this purpose, a complete randomized block design with four replicates for each treatment was used. The experiment was carried out at the research field of Faculty of Agriculture, University of Birjand, Iran. Birjand (32° 52' N, 59° 12' E, and 1491 meters above sea level) has a semi-arid climate with average annual precipitation of 170 mm, mean potential evaporation of 2565 mm, mean annual relative humidity of 36 % and mean annual temperature of 16.5 °C. In this region, near to 90% of precipitation occurs during saffron growing season.

Before the experiment, a soil sample was prepared from the soil used in both planting methods. The results of soil analysis have presented in Table 1. In the DP method, four plots (each 1 m^2, but it is better to increase plot area in future studies) were considered for corm planting. In each plot, the corms were planted in a square arrangement (10×10 cm) at a depth of 10 cm, on 26 October 2019. In the TP method, the corms which were flowered under a controlled environment [in an incubator on a 30×30 cm container with a sponge on the bottom; temperature= 15 °C, Humidity= 80% and photoperiod= 8 hours of light and 16 hours of darkness based on Molina et al. (2004)], were transplanted to four plots beside the plots of the DP, on 3 December 2019. The planting arrangement and depth in TP were similar to DP. The weight of used corms in both planting methods was 8-12 g.

To achieve the main aim of the experiment, namely increasing the weight of replacement corms, in both planting methods, the inputs (such as water and fertilizers) were used in large quantities, compared to the conventional (traditional) saffron cultivation. Rotten cow manure was consumed uniformly in all plots at the rate of 40 tons ha^{-1} on 12 December 2019. Irrigation was done 10 times during the growing season from 5th December, 2019 up to 26th April, 2020 with intervals of about 12 days. Four irrigation rounds were not carried out due to sufficient rainfall. The amount of consumed water per round was about 550 m^3 ha^{-1}. Humic acid, as a very useful organic fertilizer in the vegetative growth of saffron (Aghhavani-Shajari et al., 2018), was applied four times along with irrigation (concentration of 0.1% or 10 L ha^{-1}) on 5 December, 25 January, 25 February, and 25 March, during vegetative growth (replacement corms initiation and then their filling up with photoassimilates). The main contents of humic acid are shown in Table 2. Tabak fertilizer© was also consumed three times on 10 January, 10 February, and 10 March as fertigation at the rate of 10 kg ha^{-1}. In addition, five times foliar application of Tabak fertilizer© (along with dishwashing liquid as a surfactant) were applied at the rate of 5 kg ha^{-1} (concentration of 0.3%) during the late growth stage (3 March, 11 March, 26 March, 11 April, and 26 April), when root uptake ability decreases. The main characteristics of used Tabak fertilizer are shown in Table 3. In addition, the main climatic factors in the research station are provided in Fig. 1.

Table 1. Soil properties used in the experiment

Saturation percentage	pH	EC ($dS.m^{-1}$)	Nitrogen (%)	P (ppm)	K_{ava} (ppm)
22	7.7	1.46	0.035	8	340
Bulk density ($g.cm^3$)	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)	Soil texture
1.57	0.7	64	28	8	Sandy loam

Table 2. The characteristics of humic acid (Humisoil brand, produced by AriaShimi Co.) used for fertilization

K_2O	Fulvic acid	Humic acid	K_2O	Fulvic acid	Humic acid
Weight percentage ($w.w^{-1}$)			By volume ($w.v^{-1}$)		
3	3	12	3.5	3.5	13.5

Table 3. The characteristics of ®Tabak fertilizer (produced by AriaShimi Co.) used for fertilization

N	P_2O_5	K_2O	Fe	Zn	Mn	Cu	B
%							
19	19	19	0.2	0.1	0.1	0.07	0.03

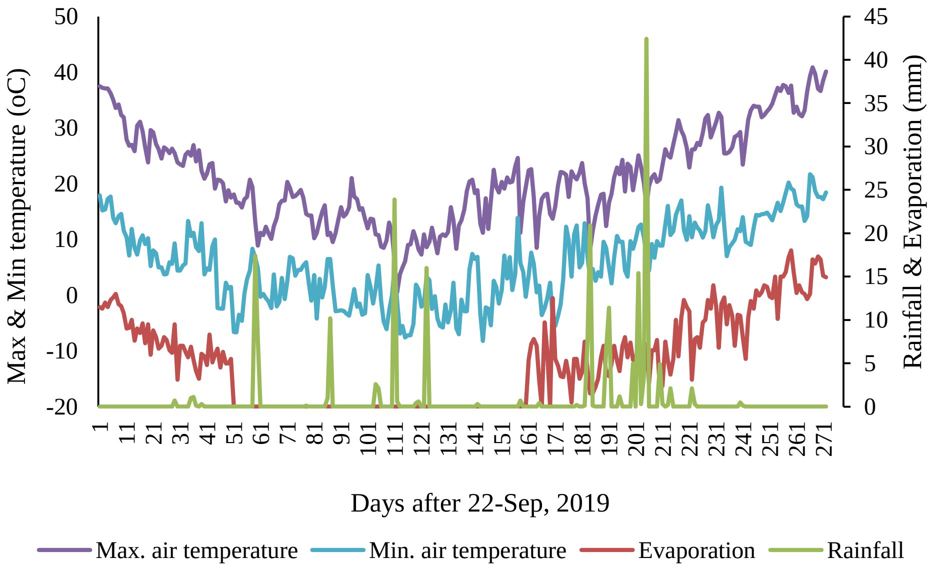

Fig. 1. The main climatic factors in the experimental site during saffron growing season.

To evaluate the aerial part growth of saffron, the leaves of 10 plants (grown from mother corms) were harvested on 4 May 2020. Then, length and dry weight of leaves were determined. Moreover, after leaf senescence the replacement corms of 10 plants were removed from the soil to evaluate their final growth status in relation to the planting method. Then, the number of replacement corms (RC), weight of RC (with and without tunics), mean weight of RC, main RC weight (the biggest RC in each plant), scale weight and number of buds with flowering potential (buds with a diameter of ~3mm) per RC were measured. In addition, the number and yield of RC in different weight groups (<3, 3-6, 6-9, 9-12, 12-15, 15-18 and 18-21 g) were determined.

Data were analyzed by SAS 9.2, and figures were drawn using Excel software. T-test was used to compare results between two planting methods.

RESULTS AND DISCUSSION

Leaf growth

There was a significant difference between two planting methods in terms of saffron leaf length and weight. The leaf length and weight in direct planting (DP) were 19.5 and 85.1 % more than transplanting (TP), respectively (Fig. 2 & Fig. 3). In a similar study on saffron, leaf length in transplanted plants was higher at the early growing season, but due to the emergence of new leaves in the DP method, even in the final stages of growth (up to early April), there was no significant difference between two planting methods at the leaf senescence stage (Aghhavani-Shajari et al., 2021). Another study revealed that saffron transplanting in a soilless system (perlite substrate) was not favorable in terms of leaf growth (Fallahi et al., 2020). Molina et al. (2010) also found that although plants in the TP method had favorable leaf growth, their leaf photosynthesis rate was lower than DP (Molina et al., 2010).

The decrease in leaf weight was about 4.36 times higher, compared with reduction in leaf length, when TP was used (Fig. 2 & Fig. 3). It seems that this has occurred due to more reliance of transplanted plants on leaf reserves through remobilization. In a previous study on saffron, it was concluded that leaves weight reduces rapidly in the last stage of plant growth due to the remobilization of photoassimilates (photosynthetic products) from leaves to replaced corms. It was also shown that saffron is a source- limited (insufficient production of photoassimilates) crop when small corms are used for plantation (Fallahi & Mahmoodi, 2018). Accordingly, it seems that source limitation has intensified in the TP method due to lower leaf length; thereby, more reallocation of photoassimilates has led to a significant reduction in leaf weight at the end of the growing season.

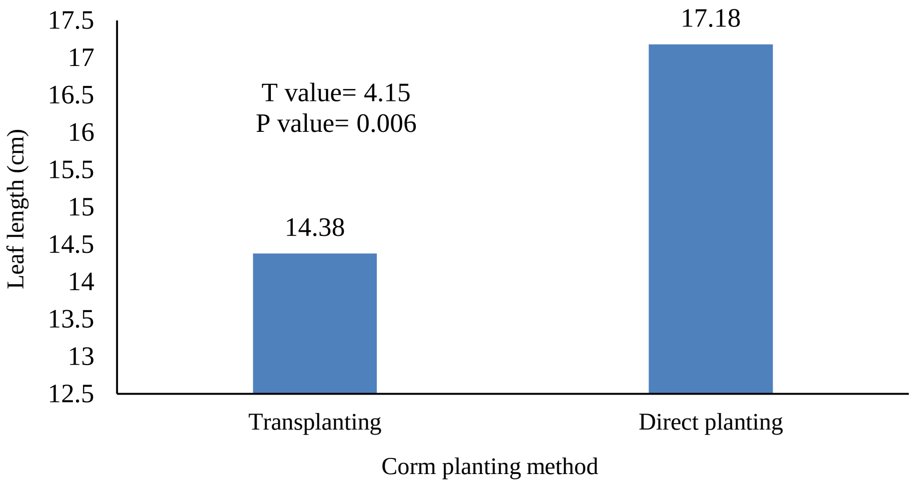

Fig. 2. Leaf length of saffron as affected by direct planting and transplanting methods. P_{value} less than 0.05 means that there is a significant difference between two treatments.

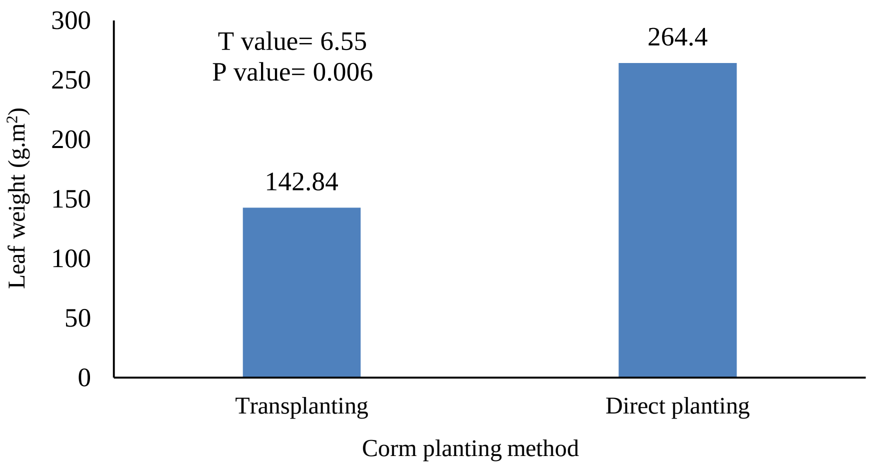

Fig. 3. Leaf weight of saffron as affected by direct planting and transplanting methods. P_{value} less than 0.05 means that there is a significant difference between the two treatments.

Replacement corms growth

The effect of planting method was significant on all criteria of saffron replacement corm (RC) growth. Direct planting (DP) caused an increase of 71 % in mean RC weight compared with the transplanting method (TP) (Fig. 4). Similarly, the weight of main (central) RC in DP was 48.7 % more than TP (Fig. 5). As a result, the number of buds with flowering potential per RC increased significantly by 46 %, when DP was used (Fig. 6). In a study on saffron transplanting, the lower stomatal conductivity and photosynthesis were considered as the main reasons for lower weight of produced RC (Molina et al., 2010). In another study, it was found that although the mean weight of RC in DP was more than TP at the end of the first growing season, but by increasing the age of the field to two years, the corm weight in TP increased to a level higher than DP (Aghhavani-Shajari et al., 2021).

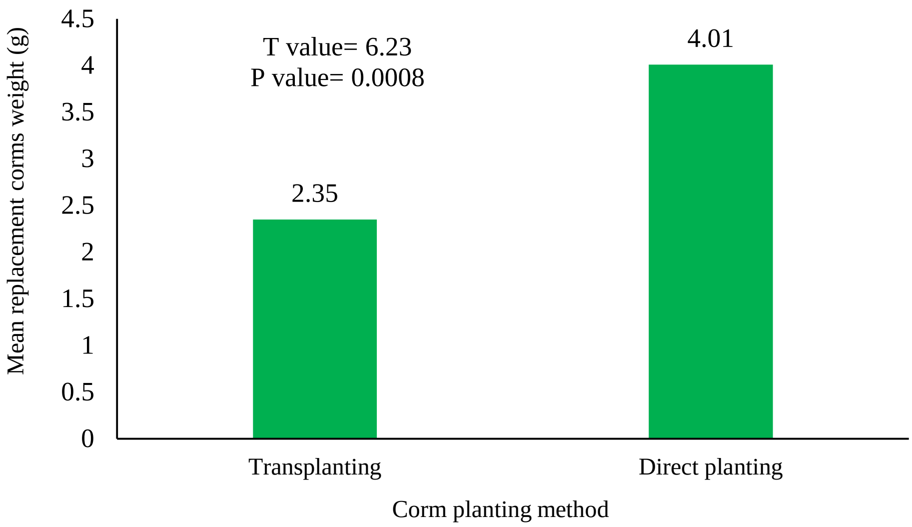

Fig. 4. Mean corm weight of saffron as affected by direct planting and transplanting methods. P_{value} less than 0.05 means that there is a significant difference between two treatments.

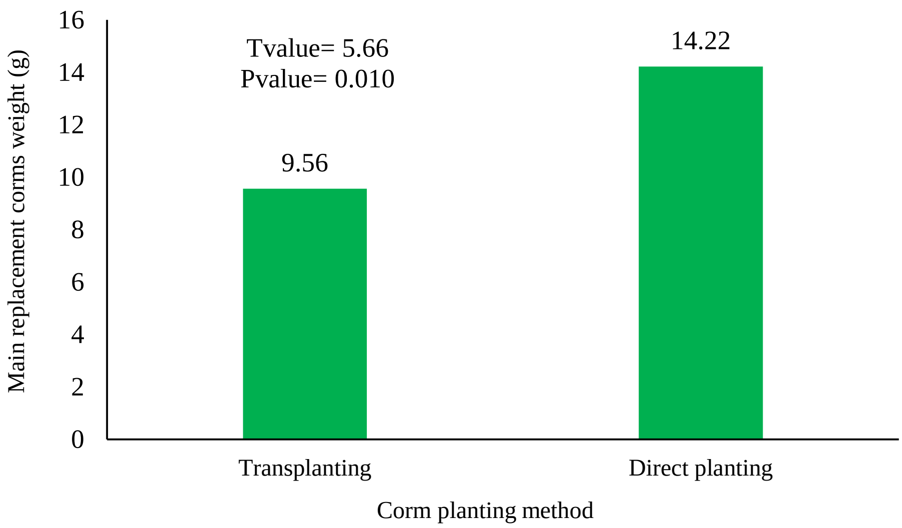

Fig. 5. The weight of main corm (biggest replacement corm in each plant) of saffron as affected by direct planting and transplanting methods.
P_{value} less than 0.05 means that there is a significant difference between two treatments.

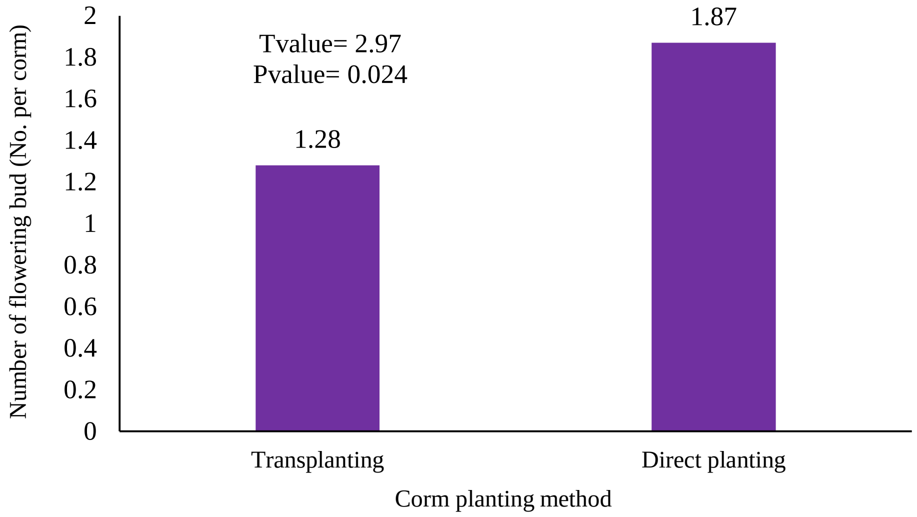

Fig. 6. Number of buds with flowering potential as affected by direct planting and transplanting methods. P_{value} less than 0.05 means that there is a significant difference between two treatments.

The planting method had a significant effect on the total number of RC and their number per each weight category. TP caused a 16.8 % increase in the total number of RC, but this enhancement was observed in the weight groups below 9 g. So that, number of RC in TP method, in weight categories of below 3, 3-6 and 6-9 g, were 25.5, 128.5 and 125 % more, but in weight categories of 9-12, 12-15, and 15-18 g were 28.5, 500 and 350 %, lower than DP, respectively. In addition, 1.52 % of RC were belong to the weight category of 18-21 g, when DP was used, while there was no corm in this category in TP method (Table 4). It has been reported that corm proliferation rate at the early growing season is lower in TP than DP, due to the stress imposition on the transplanted plants exactly after transplanting. This occurrence causes a reduction in the duration of active period of corm filling and thereby RC weight in TP (Aghhavani-Shajari et al., 2021). In the mentioned study, the number of RC per plant in TP and DP were 4.3 and 4.8 and the weight of main replacement corm was 6 and 11.7 g respectively, which were improved in the present study (Fig. 4 & Table 4) probably by transplantation in lighter soil with more organic matter content (Table 1).

Saffron planting method significantly affected the yield of RC. DP improved the total yield of RC by about 46 % in comparison with TP. Except in weight categories of 3-6 and 6-9 g, the yield of RC in other categories was higher when DP was used (Table 5). In saffron, corms with more than 9 g have an acceptable ability for flowering (Koocheki et al., 2019). It was concluded that 68.3 and 32.5 % of RC yield were belonged to this category in DP and TP methods, respectively. In DP method, about 7.5 % of RC yield was belonged to the weight category of 18-21 g, while there was no corm in this category in the TP method. However, TP method was more useful compared to the results of Ali Ahmad et al. (2017), on keeping flowered corms in the same flowering bed in a vertical system, without corm transplanting and the results of Fallahi et al. (2020) on corm transplanting in perlite substrate. The share of scales in corm yield, was 6.5 % for DP, while 4.85 % for TP (Table 5).

Table 4. Comparison of number of saffron replacement corms between transplanting and direct planting methods

Planting method	Total number of corms per m^2	Number of corm in each weight category (No m^{-2})						
		<3 g	3-6 g	6-9 g	9-12 g	12-15 g	15-18 g	18-21 g
Direct planting	524	376	28	16	36	24	36	8
Transplanting	612	472	64	36	28	4	8	0
T *value*	-3.04	-2.01	-8.05	-4.63	1.89	6.61	7.62	7.41
P value	0.0229	0.0917	0.0002	0.0036	0.1083	0.0050	0.0030	0.0051

P_{value} less than 0.05 means that there is a significant difference between two treatments.

Table 5. Comparison of saffron replacement corms yield between transplanting and direct planting methods

Planting method	Corm yield with scales (g m^{-2})	Corm yield without tunic (g m^{-2})	Tunic weight (g m^{-2})	Weight of corms in each weight category (g m^{-2})						
				0-3	3-6	6-9	9-12	12-15	15-18	18-21
Direct planting	2093.2	1964.4	128.8	460.52	93.04	110.33	393.74	311.65	566.80	157.11
Transplanting	1432.8	1363.2	69.6	373.31	315.21	278.76	289.76	50.29	125.47	0.0
T *value*	7.61	6.12	5.94	2.51	-24.45	-14.50	4.09	9.64	9.98	9.70
P value	0.0003	0.0009	0.0067	0.0457	<0.0001	<0.0001	0.0065	<0.0001	0.0015	0.0023

P_{value} less than 0.05 means that there is a significant difference between the two treatments.

CONCLUSION

In this preliminary research, it was concluded that corm proliferation was favorable in corms that previously flowered in a controlled environment and then were transferred to the field environment. However, only one-third of the produced corms had the desired weight (>9 g), which can be increased in future studies by innovating methodology. Probably items such as transplanting depth, soil organic matter content, soil texture, transplanting as basin or in-furrow, etc. may affect the success of saffron transplanting. Detailed results on the comparison of flowering between corm planting under field and controlled environments are not presented in this paper. However, dry stigma yield was 0.35 and 0.40 g per 100 planted corms, for field and controlled environments, respectively. Overall, it was concluded that saffron transplanting in the field is possible, but there is a need to improve methods to gain more favorable results.

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Conflict of interest

There is no conflict of interest to declare.

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