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Research Article

Investigating flower yield and corm behavior of saffron under different dense planting systems in Kermanshah, western Iran

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ABSTRACT- This study was conducted in Kermanshah, Iran (2016-2019), to investigate the effects of dense corm planting on the yield and yield components of saffron plants. The research was designed as a factorial experiment within a completely randomized design, with four repetitions. The experimental factors included harvest times (years) and dense corm planting at three levels: 100, 200, and 300 corms per square meter. The results showed that increasing dense corm planting over three years had a significant effect ($P < 0.01$) on several traits, including the number of flowers, fresh weight of petals, dry weight of stigmas, flowering duration (days), corm diameter, dry corm weight, and the number of daughter corms. The interaction effect of year and the planting density of corms was significant ($P < 0.01$) on all studied traits except for flowering duration. Using a high planting density of 300 corms per square meter over three years resulted in a decrease in the fresh weight of petals (65.6%) and the dry weight of stigmas (78.4%). Thus, a dense planting of 200 corms per square meter is recommended for achieving maximum yield and economic benefit in saffron cultivation under the climatic conditions of Kermanshah over three years.

INTRODUCTION

Saffron (*Crocus sativus* L.) is a medicinal plant native to the Iranian Plateau with a cultivation history spanning 3,000 years (Beiki et al., 2010). Currently, saffron is cultivated in various regions characterized by low rainfall, hot summers, and cold winters, including dry areas in southern Europe, North Africa, the Middle East, and Central Asia (Rezvani Moghaddam, 2020). The primary saffron-producing countries include Iran, India, Greece, Afghanistan, Morocco, Spain, Italy, China, and Azerbaijan (Shahnoushi et al., 2020), and the area under saffron cultivation is expanding in some countries, such as Turkey, Pakistan, France, and the United States (Rashed-Mohassel, 2020).

Saffron is one of the most expensive agricultural and medicinal products worldwide and holds a special place among Iran's export products, with more than 95% of global production attributed to Iran (Alizadeh et al., 2021). Despite its significant importance, saffron yield per hectare in Iran’s agricultural sector has declined considerably, from 6.15 kg/ha in 1971 to 3.42 kg/ha in 2017 (Ramezani et al., 2022). This decline can be attributed in part to factors such as drought and soil warming, but it is primarily due to the poor management and improper utilization of production resources (Khajeh-Hosseini and Fallahpour, 2020).

In addition to suitable climatic conditions and soil, saffron requires proper agricultural management to maximize its environmental potential. Many factors influence the quantitative and qualitative yield of saffron, encompassing various aspects such as climatic conditions, pests, diseases, weeds, irrigation, storage, the timing of sowing, the number of corms planted in the initial year, and the ideal depth for planting (Naderi Darbaghshahi et al., 2008). Saffron is considered a strategic plant that can significantly impact the economies of dry and semi-dry regions both quantitatively and qualitatively (Choopan et al., 2021). Due to the unique methods of plant breeding in saffron and its triploid nature, improving its production through agricultural practices can prompt outstanding benefits. Since saffron is propagated through corms, the number of corms planted in the first year is closely related to achieving high yields (Koocheki et al., 2019). Planting density in the initial and subsequent years can enhance yield, shorten the planting cycle, and ultimately boost the economic viability of saffron cultivation (Esmaeilian et al., 2022). Behnia and Mokhtari (2010) examined the effect of three different planting densities (5, 10, and 15 corms per 30 cm row) on saffron yield over four years. They found that planting 10 and 15 corms per 30 cm row resulted in maximum yield in the fourth year of cultivation. Low-density cultivation of saffron may not be economically justifiable in the initial years of growth (Behnia and Mokhtari, 2009). Therefore, high-density saffron planting can practically compensate for initial yield loss (Koocheki et al., 2012). Despite relevant

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research in the past, the available literature on the density of planted corms is scanty. Thus, the present study aimed to examine how varying corm densities would impact the production of saffron flowers and corms over three years in a field experiment. This approach aimed to take effective steps toward the sustainable production of this important medicinal plant by selecting an appropriate planting density.

MATERIALS AND METHODS

Site description

This study was conducted over three years (2016-2019) at the Agricultural and Natural Resources Research Farm of Razi University in Kermanshah, Iran (34° 21' N, 47° 9' E). The research site is characterized by a clay loam soil structure and a typical continental climate with cold and mild temperatures, receiving an average annual rainfall of 450 mm. Soil samples were randomly collected from a depth of 0 to 30 cm and subjected to detailed analysis (Table 1).

Experimental design

A field experiment was implemented using a factorial completely randomized design with four replications. The experimental treatments comprised two factors: harvest times (years) and planting density, with three levels of planting density set at 100, 200, and 300 corms per square meter.

Agronomic practices

Each experimental plot measured 70 × 140 cm^2 and consisted of seven rows, with each row containing five ridges spaced 20 cm apart. The corms were of the Zaveh ecotype from Kashmar, Iran. They were weighed before planting, and those weighing 2-4 g were selected for use. Four irrigation rounds were conducted throughout the study. The first irrigation was applied immediately after planting on October 20th. The second irrigation occurred on November 20th, following flower harvest and leaf emergence. The third irrigation was administered on March 16th, and the fourth, which served as supplementary irrigation for daughter corm growth, was carried out on April 4th in each of the three years of the experiment. Manual weeding and weed control were performed throughout the growing season.

Flower and corm measurements

Due to the low yield of the corms in the first year and the uncertainty of treatment effects during that period, flower and corm yield assessments were initiated in the second year. Daily sampling was conducted to collect and count flowers, measure the dry weight of the corms, and record the fresh weight of the petals. These samples were then transferred to the laboratory for further analysis. Additionally, destructive sampling of saffron corms was performed at the end of the growing season in an area equivalent to one-fourth of a square meter (0.5 meters by 0.5 meters). Various parameters, including the number of daughter corms, corm diameter, and dry weight, were measured. As in the first year, yield-related traits of the flowers and saffron corms were measured in the second and third years from the remaining area of each plot after the daughter corms were harvested in June.

Statistical analysis

Following data collection, the data were assessed for normality before being subjected to analysis of variance (ANOVA) using the SAS statistical analysis software (v9.3, SAS Institute, Cary, USA). Mean values were compared using Duncan's multiple range test ($P < 0.05$).

RESULTS AND DISCUSSION

Saffron flower indices

The analysis of variance indicated that increasing corm density significantly influenced the number of flowers, fresh petal weight, stigma dry weight, and flowering duration ($P < 0.01$) over the three-year period. Additionally, the interaction effect of year × density was found to be significant ($P < 0.01$) for the number of flowers, fresh petal weight, and stigma dry weight, but it did not have a significant impact on flowering duration (Table 2).

A comparison of the means revealed that an increase in corm density significantly raised the number of flowers per square meter. The highest number of flowers, with a mean of 118.5, was observed at a density of 300 corms m^{-2} in the first year. Conversely, the lowest value for this trait was recorded at a planting density of 100 corms m^{-2} in the third year (Fig. 1). Similarly, the comparison of the mean values indicated that increasing corm density significantly enhanced the fresh weight of petals per square meter.

The maximum fresh petal weight, with a mean value of 21.09 g m^{-2}, was achieved at a planting density of 300 corms m^{-2} in the first year. In contrast, the lowest fresh petal weight was recorded at a planting density of 100 corms m^{-2} in the third year (Fig. 2). The comparison of mean values regarding stigma dry weight followed a pattern similar to that observed in the number of flowers, with increased corm density leading to a significant rise in stigma dry weight in the first year.

The highest dry weights of stigmas, 0.44 and 0.43 g m^{-2}, were obtained at planting densities of 300 and 200 corms m^{-2} in the first and second years, respectively. Conversely, the lowest stigma dry weights were observed at a planting density of 100 corms m^{-2} in the first and third years, with values of 0.03 and 0.04 g m^{-2}, respectively (Fig. 3). The results demonstrated that increasing planting density prolonged the flowering duration, with the longest duration associated with a dense corm planting of 300 corms m^{-2} (Table 3).

Furthermore, the comparison of the average effects of the year revealed that the third year exhibited the shortest flowering duration (Table 3). Saffron plants cultivated at high densities produced more flowers per unit area compared to those grown at low and medium densities. Similar findings were reported by De Juan et al. (2009) and Gresta et al. (2009b), who observed a significant increase in the number of flowers with higher planting densities. High planting densities result in a greater number of nodes per unit area, which likely leads to an increase in the number of flowers and, subsequently, an increase in petal weight (Sadeghi et al., 2014).

A study by Kothari et al. (2021) demonstrated the impact of planting density on the fresh and dry petal weights, showing that the highest petal weight was obtained at the highest corm density (12 t corms ha^{-1}) compared to lower densities (4 t corms ha^{-1} and 8 t corms ha^{-1}). Research by Esmaeilian et al. (2022) also found that higher planting densities resulted in greater petal weight, with a density of 300 corms m^{-2} being the most effective treatment, consistent with our findings of improved flower yield due to the increased planting density. According to Shajari et al. (2020), the longevity of the saffron field significantly impacts its yield. Other studies on dense corm planting have shown that the highest stigma dry weight was obtained in treatments with medium corm densities at two levels (111 and 119 corms m^{-2}) and high corm densities at three levels (139, 143, and 179 corms m^{-2}) (Shajari et al., 2020). The lowest stigma dry weight was observed at a density of 93 corms m^{-2} (Colla and Rouphael, 2009). However, since stigma yield is more influenced by the number of flowers per unit area than by the weight of individual petals, increasing corm density ultimately leads to an increase in stigma yield per unit area, with a negligible effect on the weight of each petal.

Previous studies demonstrated that high-density cultivation of saffron can lead to earlier economic returns from saffron fields. However, most farmers prefer to plant at medium densities to mitigate initial production costs. The optimal planting density is contingent on the production method and the intended duration of field cultivation. In controlled cultivation systems, planting at densities exceeding 450 corms m^{-2} is feasible (Molina et al., 2005). While high-density saffron cultivation allows for an earlier harvest, it is advisable only when the crop is intended for a single year. Excessive corm proliferation in the second year can adversely affect yield. Although high-density planting is expected to increase flower yield per unit area, it may reduce yield per biological unit, such as the mother corm, due to intensified competition for nutrients (El Hajj et al., 2019).

In the first year of this experiment, an increase in plant density from 100 to 300 corms m^{-2} resulted in a rise in the number of flowers, fresh stigma weight, and dry stigma yield. Cardone et al. (2020) similarly found that dense planting significantly increased both the number of flowers and dry stigma yield. Dense planting can also shorten the production cycle of saffron, as yield typically declines after six or seven years (Koocheki et al., 2012). Mollafilabi et al. (2016) reported that the highest yield was achieved at the highest density of 150 corms m^{-2}, with a yield of 7.36 kg ha^{-1} in the first year.

Corm characteristics

The characteristics of saffron corms, including the number of daughter corms, corm dry weight, and corm diameter were significantly affected ($P < 0.01$) by the year, planting density of corms, and the interaction between year and density (Table 4). The highest number of daughter corms, with a mean of 57.5 corms m^{-2}, was observed at a planting density of 300 corms m^{-2} in the second year. Conversely, the lowest value (10.75 corms m^{-2}) was recorded at a density of 100 corms m^{-2} in the first year (Fig. 4). A comparison of the mean data revealed that the highest dry weight of corms, with an average of 4.25 g m^{-2}, was achieved at a density of 300 corms m^{-2} in the second year. The lowest value (0.86 g m^{-2}) was recorded at a density of 100 corms m^{-2} in the first year (Fig. 5). The increase in corm density significantly impacted corm diameter. The largest corm diameter, averaging 11.65 cm, was obtained at a planting density of 200 corms m^{-2} in the first year, with no significant differences observed among densities of 100, 200, and 300 corms m^{-2} (Fig. 6). The smallest corm diameter (2.26 cm) was recorded at a density of 100 corms m^{-2} in the third year, with no significant differences among the densities tested (Fig. 6). Low-density saffron cultivation may not be economically viable, especially in the first year, while high-density planting can diminish the potential of the mother corm to sustain high yields over several years. In contrast, moderate planting densities appear to offer a balance, effectively enhancing the number of flowers and other yield parameters. From 2016 to 2019, the dry weight of stigmas at a density of 100 corms m^{-2} remained largely unchanged (Fig. 3).

In the second year, our results showed that increasing planting density to 200 corms m^{-2} improved the number of flowers, fresh petal weight, and stigma dry weight. However, further increases in density to 300 corms m^{-2} led to significant declines in these traits. The marked reduction in flower quantity and petal production at a high density (300 corms m^{-2}) during the second year is likely attributable to increased competition among daughter corms following the initial growing season. This outcome aligns with the findings of Koocheki et al. (2012). The highest number of flowers and associated components were recorded at a planting density of 200 corms m^{-2}. Therefore, careful management of corm density is crucial during saffron cultivation. Moderate planting densities may be optimal, depending on soil conditions, nutrient availability, weather conditions, and saffron genotype. Additionally, proper management of the cultivation period is necessary to achieve high saffron yields. High planting densities may reduce the number of daughter corms due to the increased competition for nutrients (El Hajj et al., 2019).

Our findings are consistent with the results observed at a density of 300 corms m^{-2}, where a higher planting density resulted in greater fresh flower yield during the initial years. However, increased competition may negatively impact daughter corms. Thus, moderate densities are likely to produce more desirable daughter corms for future planting (Seyyedi et al., 2018). Corm size has a positive correlation with fresh flower yield, with larger corms producing higher yields compared to smaller ones (Gresta et al., 2009a). The decline in fresh flower yield in the second and third years at a planting density of 300 corms m^{-2} (Fig. 1) may be due to a reduction in the production of larger daughter corms. Increasing corm diameter has been associated with a threefold increase in saffron production (Molina et al., 2010).

Larger corms not only boost farm yield in the first year but also enhance the capacity for flower harvest and farm yield in subsequent years by producing more and larger corms (Koocheki et al., 2019). As corm weight increases, the economic yield of saffron generally rises, reflected in the number of harvested flowers per unit area or the dry weight of stigmas produced per unit area. Although increasing planting density to 200 corms m^{-2} enhanced daughter corm yield, further increases to 300 corms m^{-2} led to a significant reduction in the number of large corms in the third year (Fig. 5). The formation of daughter corms is influenced by environmental conditions, with higher planting densities potentially reducing the formation of large daughter corms due to the competition among small corms during the growing season (Koocheki et al., 2012). A positive correlation between corm size and flower yield has been reported (Gresta et al., 2009a). Consequently, the reduction in flower yield at a density of 300 corms m^{-2} in the second year may be due to the decreased formation of large daughter corms in the first year. During the saffron growth season, new corms are produced after the flowering stage, and their number increases annually (Kumar et al., 2009). Therefore, the increase in the number of corms and yield in subsequent years is primarily driven by the seasonal growth cycle of saffron.

Table 1. Physical and chemical properties of soil used in this experiment

Organic carbon (%)	P (mg.kg^{-1})	K (mg.kg^{-1})	Mn (mg.kg^{-1})	Fe (mg.kg^{-1})	Zn (mg.kg^{-1})	Cu (mg.kg^{-1})	Soil texture
1.25	5.8	520	4.6	3.9	1.4	1.34	Loamy clay

Table 2. Analysis of variance for saffron flower indices

S.O.V	df	Mean Squares			
		Number of flowers (m^{-2})	Fresh weight of petals (g/m^{-2})	Dry weight of stigmas (g/m^{-2})	Flowering duration (day)
Harvest times (H)	2	2477.52**	58.06**	0.04**	25.08**
Density (D)	2	7533.52**	417.14**	0.17**	46.08**
H × D	4	5113.48**	94.23**	0.08**	2.91 ^{ns}
Error	27	10.20	2.40	0.002	1.87
Coefficient of variation (%)		6.78	14.55	22.85	14.82

ns: Not significant; * and **: Significant at the 5% and 1% probability levels, respectively.

Table 3. Mean comparison of main effects of saffron flowering duration

Harvest times (Year)	First	10a
	Second	10.16a
	Third	7.58b
Density	100	7.91b
	200	8.33b
	300	11.50a

Table 4. Analysis of variance for corm characteristics of saffron

S.O.V	df	Mean Squares		
		Number of daughter corms (m^2)	Dry weight of corms (g/m^2)	Corms diameter (cm)
Harvest times (H)	2	404.36**	7.48**	251.38**
Density (D)	2	1956.86**	9.93**	4.28**
H × D	4	758.44**	1.69**	2.84**
Error	27	6.10	0.09	0.64
Coefficient of variation (%)		7.60	14.23	12.81

ns: Not significant; * and **: Significant at the 5% and 1% probability levels, respectively.

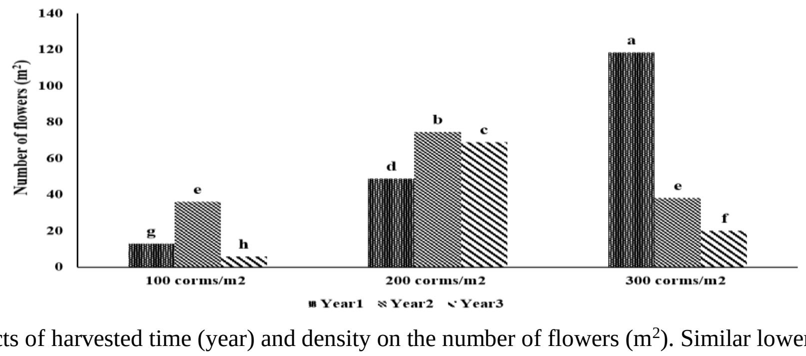

Fig. 1. Interaction effects of harvested time (year) and density on the number of flowers (m^2). Similar lowercase letters over the bars indicate no significant difference at $P < 0.05$ among mean values.

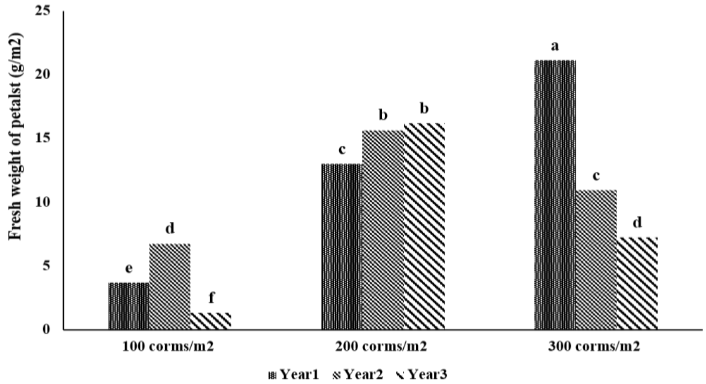

Fig. 2. Interaction effects of harvested time (year) and density on the fresh weight of petals (g m^{-2}). Similar lowercase letters over the bars indicate no significant difference at P < 0.05 among mean values.

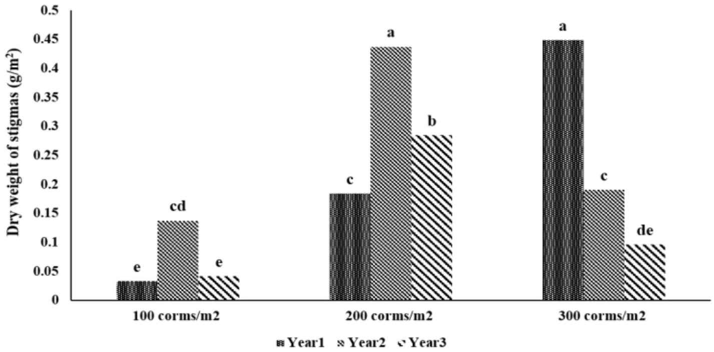

Fig. 3. Interaction effects of harvested time (year) and density on the dry weight of stigmas (g m^{-2}). Similar lowercase letters over the bars indicate no significant difference at P < 0.05 among mean values.

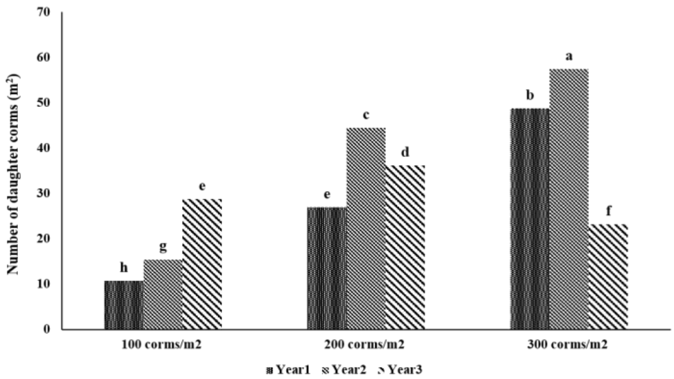

Fig. 4. Interaction effects of harvested time (year) and density on the number of daughter corms. Similar lowercase letters over the bars indicate no significant difference at P < 0.05 among mean values.

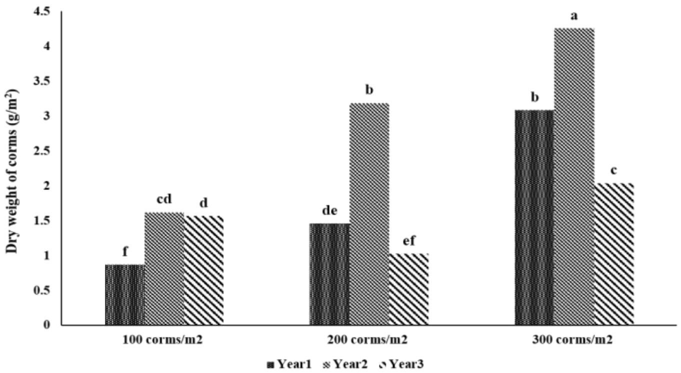

Fig. 5. Interaction effects of harvested time (year) and density on the dry weight of the corms. Similar lowercase letters over the bars indicate no significant difference at P < 0.05 among mean values

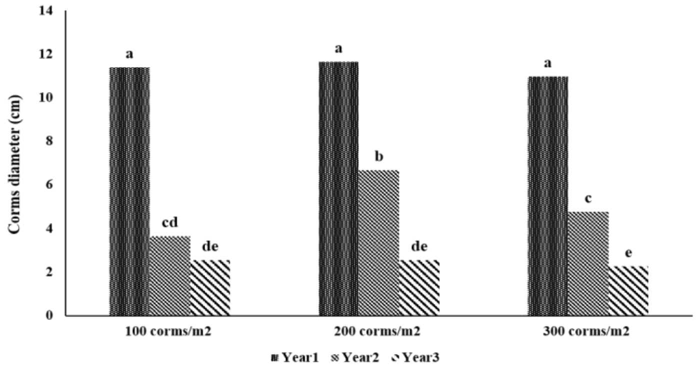

Fig. 6. Interaction effects of harvested time (year) and density on corm diameter. Similar lowercase letters over the bars indicate no significant difference at $P < 0.05$ among mean values.

CONCLUSION

The findings indicated that planting corm density resulted in higher yields of flowers and corms. The highest number of flowers was obtained at a density of 200 corms m^{-2}. Based on the decreasing trend observed over three years with high planting density (300 corms m^{-2}) in terms of fresh weight of petals and dry weight of stigmas, it is recommended to use a planting density of 200 corms m^{-2} for saffron cultivation. However, depending on the size of the mother corm, dense corm planting may be lower or greater than 200 corms m^{-2}. Therefore, based on the results of this study, it can be generally stated that the highest dry stigma yield and yield of daughter corms were obtained after two years of cultivation and at a moderate planting density (200 corms m^{-2}). The desired planting density and annual production of saffron corms should be determined based on a combination of factors that can affect the number and size of corms produced in the soil.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization, Hooman Salari and Elnaz Zamani; methodology, Elanz Zamani; software, Elnaz Zamani.; formal analysis, Elnaz Zamani; investigation, Elnaz Zamani; data curation, Mahtab Mehrkish and Elnaz Zamani; writing—original draft preparation, Elnaz Zamani; writing—review and editing, Hooman Salari; visualization, Hooman Salari; supervision, Hooman Salari; project administration, Hooman Salari; funding acquisition, Hooman Salari.

DECLARATION OF COMPETING INTEREST

The authors declare no conflict of interest.

ETHICAL STATEMENT

All authors are aware on content of the manuscript and consented to submit it to Iran Agricultural Research. An ethics statement is not applicable since this study is based exclusively on published literature.

DATA AVAILABILITY

The raw data of this research are available at the request of the reviewers and editors.

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