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Effect of planting density and harvest time on flower production from pot marigold (*Calendula officinalis L.)*

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Abstract: Pot marigold (*Calendula officinalis* L.) is a medical and aromatic plant used in several pharmacological products due to the bioactive compounds it contains. This study was conducted in Tekirdağ during 2023 to determine the effects of different planting densities and harvest times on the flower production of pot marigold under the ecological conditions of Thrace. The trial was conducted with three replicates in a split-split plot design, with three inter-row (30, 40, 50 cm) and three intra-row distances (10, 20, 30 cm). Flower harvesting was performed weekly over 14 periods. According to the results, planting density had a statistically significant effect on flower yield. The highest number of flowers per plant (4.64-9.22 flowers plant^{-1}), fresh weight of flowers per plant (2.37-5.61 g plant^{-1}), and dry weight of flowers per plant (0.50-1.17 g plant^{-1}) were obtained with 50 × 30 cm planting density in the 12th harvest period. The lowest values were obtained at a planting density of 30 × 10 cm during the 1st harvest period. In the trial, the best fresh (374.3-790.0 kg ha^{-1}) and dry flower (78.7-167.3 kg ha^{-1}) yield values per hectare were obtained from 30 × 10 cm planting density in the 12th and 14th harvest periods. Considering the total flower yields obtained in this one-year study, a planting density of 30 × 10 cm showed promising results for fresh and dry flower yields under Thrace conditions.

Keywords: Cultivation, Harvest period, Medicinal and aromatic plants, Plant spacing, Yield components.

Dikim sıklığı ve hasat zamanının aynısefa (*Calendula officinalis* L.) çiçek üretimi üzerine etkisi

Öz: Aynısefa, içerdiği biyoaktif bileşenler sayesinde birçok farmakolojik üründe kullanılan tıbbi ve aromatik bir bitkidir. Bu çalışma, Trakya ekolojik koşullarında farklı dikim sıklıklarının ve hasat zamanlarının aynısefada çiçek üretimi üzerine etkilerini belirlemek amacıyla 2023 yılında Tekirdağ'da yürütülmüştür. Deneme, üç sıra arası (30, 40, 50 cm) ve üç sıra üzeri (10, 20, 30 cm) mesafede, tesadüf bloklarında bölünmüş parseller deneme desenine göre üç tekerrürlü olarak yürütülmüştür. Çiçek hasatları 14 dönem boyunca haftalık aralıklarla yapılmıştır. Sonuçlara göre dikim sıklığının çiçek verimi üzerinde istatistiksel olarak anlamlı etkiler oluşturduğu belirlenmiştir. En yüksek çiçek sayısı (4,64-9,22 adet/bitki), taze çiçek ağırlığı (2,37-5,61 g/bitki) ve kuru çiçek ağırlığı (0,50-1,17 g/bitki) 50 × 30 cm dikim sıklığı uygulamasından ve 12. hasat zamanından elde edilmiş, en düşük değerler ise 30 × 10 cm dikim sıklığında 1. hasat zamanında elde edilmiştir. Denemede dekara taze (374,3-790,0 kg/ha) ve kuru çiçek (78,7-167,3 kg/ha) verimleri ise 30 × 10 cm dikim sıklığı uygulamasından ve 12. ve 14. hasat zamanlarında elde edilmiştir. Bir yıllık çalışmada elde edilen toplam çiçek verimi göz önüne alındığında, 30 × 10 cm'lik bir dikim sıklığının Trakya koşullarında taze ve kuru çiçek verimi açısından umut verici sonuçlar gösterdiği görülmüştür.

Anahtar kelimeler: Yetiştirme, Hasat dönemi, Tıbbi ve aromatik bitkiler, Bitki sıklığı, Verim bileşenleri,

1. Introduction

Pot marigold (*Calendula officinalis* L.) is an important medicinal and ornamental plant in the family Asteraceae, endemic to the Middle East and southern Europe (Bisset, 1994; Căpraru et al., 2004). Generally, an annual plant, pot marigold has bright yellow-orange flowers and a unique aromatic odor. In traditional medicine, it has been used for many years for the treatment of wounds, burns, skin infections, and digestive system disorders and infections (Scheffer, 1979; Gruenwald et al., 2004; Çolak, 2018). Pot marigold's fresh flower yield can range from 800 to 1900 kg ha^{-1} (Król, 2012; Kranthi Kishore et al., 2024), while its dried (drug) flower yield can vary between 141 and 223 kg ha^{-1} (Ayran & Kan, 2022). Pot marigold

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flowers contain several bioactive compounds like triterpenoids, flavonoids, carotenoids, coumarin, and essential oils, and these compounds are responsible for the plant's anti-inflammatory, antioxidant, antitumor, and wound-healing properties (Hamburger et al., 2003; Fronza et al., 2009; Balıkçı, 2019). The essential oil contents obtained from pot marigold flowers generally vary from 0.02-0.08%, with the main components identified as α-cadinol (35–40%), β-cadinene (12–13%), and T-muurolol (8–9%) (Ayran & Kan, 2023). Due to these features, the plant is commonly used in the pharmaceutical products, cosmetic, perfume, and functional food industries (Bruneton et al., 1995; Neukirch et al., 2004; Re et al., 2009).

The maximum flower yield obtainable from cultured plants per unit area varies with several factors, including genotype, environmental conditions, and agricultural practices. Agronomic practices in the cultivation of medicinal and aromatic plants under controlled conditions play a decisive role in yield and quality. Among these applications is planting density, which is one of the most effective factors on plant growth, flower yield, and secondary metabolite synthesis. Appropriate planting density ensures that plants benefit from optimal levels of sunlight, water, and nutrients and reduces competition among plants (Arslan, 1994). Overly dense planting may lower biomass production by increasing competition for light, water, and nutrients, while very sparse planting may reduce the total yield per unit area (Marisol et al., 2003).

Similarly, harvest time is an important factor directly affecting the amount and composition of secondary metabolites. The plant's physiological maturation period, environmental conditions, and developmental stage play determinative roles in the synthesis of these compounds. Early or late harvests may cause significant differences in both yield and chemical composition. Especially for species in which flower organs are used (e.g., *Calendula officinalis* L.), accurately timed harvesting during the flowering period ensures that the compounds with the highest biological activity are obtained. As a result, the evaluation of planting density and harvest time together is of great importance for both yield optimization and the quality of secondary metabolites (Parađiković et al., 2013; Yetiş, 2019).

This study was performed with the aim of determining the effect of different planting densities and harvest times in conditions in Thrace on the flower yield and yield criteria of pot marigold.

2. Materials and Methods

The seeds of the pot marigold population were obtained from Çukurova University Faculty of Agriculture Field Crops Department. Seeds were sown on May 2, 2023, at Artemisia (a seedling cultivation company), and the resulting seedlings were transplanted to the experimental field on June 5, 2023. The research was conducted at the Tekirdağ Namık Kemal University Faculty of Agriculture, Field Crops Department research fields. The trial area has clay-loam soil texture, non-hazardous salinity, low organic matter, low lime, and a neutral soil structure. The physical properties of the soil are as follows: soil pH 6.8; soil EC 0.02%; organic matter 1.77%; total Na 0.09%; P 22.48 ppm; K 228.88ppm; Ca 3765.76 ppm; Mg 600.67 ppm; Fe 17.7 ppm; Cu 1.69 ppm; Zn 0.36 ppm; and Mn 37 ppm.

When the climate data for 2023, the year of the research, and the long term are investigated, the June-January period of 2023 had mean temperatures that were above the long-term averages. Total rainfall amounts were clearly below the average over the last 50 years in all months except November (Figure 1).

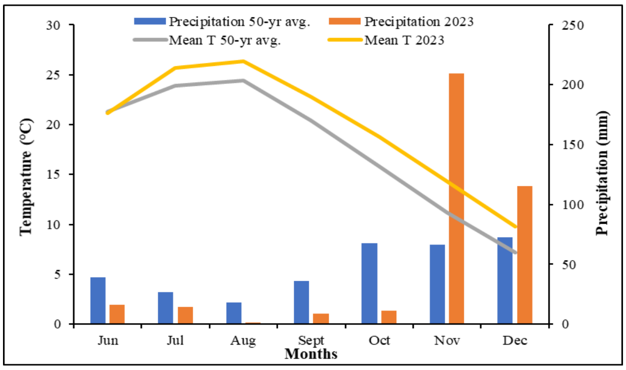

Figure 1. Basic weather parameters during the experiments in the 2023 growing seasons and the 50-year average.

The research was completed with 3 repeats according to the split-split plot design. The experimental plan was created with a main plot inter rows and subplots intra rows. Before planting, the trial area received a 20-20-0 composite fertilizer, calculated to provide 50 kg ha^{-1} of pure nitrogen. Seedlings were planted in 9 combinations at 3 inter rows (30 – 40 – 50 cm) and 3 intra rows (10 – 20 – 30 cm). Densities were organized as 30 × 10 (33.3 plants m^2), 30 × 20 (16.6 plants m^2), 30 × 30 (11.1 plants m^2), 40 × 10 (25 plants m^2), 40 ×

20 (12.5 plants m^2), 40 × 30 (8.33 plants m^2), 50 × 20 (10 plants m^2), and 50 × 30 (6.6 plants m^2). Each plot had a 3-meter row length comprising 4 rows, with 70 cm gaps left between plots. Before planting, mechanical weed control was performed. Apart from the water given to the seedlings during planting, surficial irrigation was performed 9 times during the growing period to meet the plants' vital requirements under summer temperatures.

Pot marigolds were harvested when the flower heads were fully open. Flowers were collected over a 14-week harvest duration at weekly intervals. The harvesting dates were as follows: 1st harvest: 12 September, 2nd harvest: 19 September, 3rd harvest: 26 September, 4th harvest: 3 October, 5th harvest: 10 October, 6th harvest: 17 October, 7th harvest: 24 October, 8th harvest: 31 October, 9th harvest: 7 November, 10th harvest: 15 November, 11th harvest: 21 November, 12th harvest: 2 December, 13th harvest: 14 December and 14th harvest: 28 December.

The characteristics investigated included the number of flowers per plant (flowers plant^{-1}), fresh weight of flowers per plant (g plant^{-1}), dry weight of flowers per plant (g plant^{-1}), flower fresh yield per hectare (kg ha^{-1}), and flower dry yield per hectare (kg ha^{-1}) obtained in the 14 different harvest periods. The total number of flower per plan (flowers plant^{-1})t, total fresh weight of flowers per plant (g plant^{-1}), total dry weight of flowers per plant (g plant^{-1}), total flower fresh yield per hectare (kg ha^{-1}) and total flower dry yield per hectare (kg ha^{-1}) were calculated as the totals from the 14 harvest periods.

Statistical Analysis: The data obtained were analyzed using JMP (version pro-16) statistical program. When the plants reached harvest maturity, the number of flowers, fresh and dry flower yields per plant, and fresh and dry flower yields per hectare were analyzed using a randomized block split-plot experimental design. Total yields were analyzed using a randomized block split-plot experimental design, with differences between implementations grouped by letters using the least significant difference (LSD) test.

3. Results and Discussion

3.1. Result of planting density and harvest time

The variance analysis results for the yield and yield components of pot marigold for inter row, intra row, harvest time, and their double and triple interactions are given in Table 1.

Table 1. ANOVA mean squares for the effects of inter-row, intra-row, harvest time, and their interactions on yield and yield components of pot marigold

VS	df	NFPP	FWFPP	DWFPP	FFYPH	FDYPH
Rep.	2	0.91	1.74	0.06	4973.7	188.2
InterR.	2	47.39**	23.19**	0.86**	73417.4**	3673.2**
Error 1	4	0.16	0.20	0.00	948.6	41.7
IntraR	2	364.48**	189.22**	7.89**	216486.0**	11098.8**
InterRxIntraR	4	2.12**	0.77**	0.05**	2325.3**	169.1**
Error 2	4	0.06	0.01	0.00	814.6	43.1
HT	13	90.92**	41.72**	1.66**	90313.3**	3715.2**
InterRxHT	26	0.28	0.20**	0.01**	1958.0**	137.1**
IntraRxHT	26	1.81**	1.49**	0.05**	6311.5**	315.3**
InterRxIntraRxHT	52	0.27*	0.18**	0.01*	593.2**	52.1**
Error	242	0.18	0.08	0.00	278.6	22.4
Total	377	5.65	2.78	0.11	5552.9	263.0
CV		6.49	7.69	11.60	9.90	13.51

VS: Source of Variation, Rep: Replication, InterR: Inter Row, IntraR: Intra Row, HT: Harvest Time, CV: Coefficient of Variation, df: Degree of Freedom, *, ** Significant at 0.05 and 0.01 probability levels, respectively, NFPP: Number of Flowers Per Plant, FWFPP: Fresh Weight of Flowers Per Plant, DWFPP: Dry Weight of Flowers Per Plant, FFYPH: Flower Fresh Yield Per Hectare, FDYPH: Flower Dry Yield Per Hectare.

3.1.1. Number of flowers per plant

According to the variance analysis results, apart from inter-row × harvest time, all other implementations and their double and triple interactions had statistically significant effects on the number of flowers (Table 1). When the inter-rows are investigated, as the inter-rows increase, the number of flowers increases significantly in a stepwise manner. At 50 cm intervals, 7.20 flowers plant^{-1} were obtained, while at 30 cm intervals, 5.98 flowers plant^{-1} were obtained. A similar trend was observed for distances within rows, and an increase in flower numbers was identified. The highest average was obtained with 30 cm intervals within rows, and the lowest average was obtained with 10 cm intervals within rows. For the inter-row × intra-row interaction, the highest mean number of flowers was observed at a 50 × 30 cm planting density (Figure 2). This planting density may ensure that plants access ideal resources. In contrast, the lowest number of plants was observed at the 30 × 10 cm density. This shows that dense planting caused excessive competition and suppressed generative development. The increase in the number of flowers per plant with increasing inter row and intra row can be explained by decreased interplant competition. Reduced competition for light, water, and nutrients at wider planting intervals may have contributed to the preservation of photosynthetic efficiency and increased assimilate production. The higher values obtained at wider intervals, in particular, may have supported flower formation by increasing the growing area per plant. Conversely, increased shading and root zone competition at narrower intervals may have limited flower formation. This indicates that planting density is a determining factor in resource use efficiency and generative organ development. Literature findings support the trend of increasing yield with increasing planting distances in marigold plants (Mili & Sable, 2003; Yetiş, 2019). The effect of harvest time was pronounced. The lowest number of flowers was obtained at the 1st harvest, with the highest value obtained from the 12th harvest (Figure 3). The low yield obtained in the first harvests may be due to the incomplete generative development. In subsequent harvest periods, the observed changes in flower number with harvest time are thought to be driven by environmental conditions. In particular, rainfall during weeks with high flower numbers may have prevented the plants from experiencing water stress. This indicates that flower number is closely related to environmental factors (especially temperature and rainfall) and that changes in harvest time are shaped not only by phenological progress but also by environmental conditions. Similarly, it was reported that the number of pot marigold flowers varied according to planting time and harvest dates (Ayran, 2017). When the effect of inter row x intra row x harvest time is investigated, the highest yield was obtained with 50 × 30 cm density from the 9th harvest. In contrast, the lowest yield was recorded at the 30 × 30 cm density in the 1st harvest (Figure 4). These results show that the number of flowers on the plant is not linked to a single factor but requires the management of planting norms and harvest timing together.

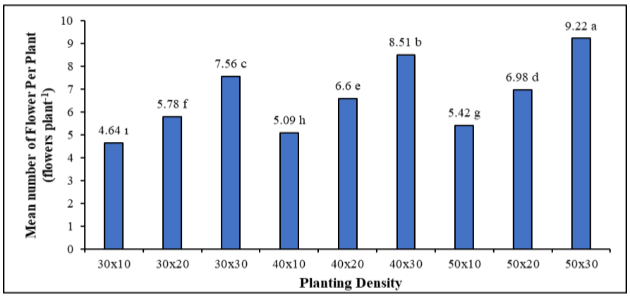

Figure 2. Effect of planting density on mean number of flowers per plant. Different letters indicate significant differences among means (LSD = 0.185, P ≤ 0.01).

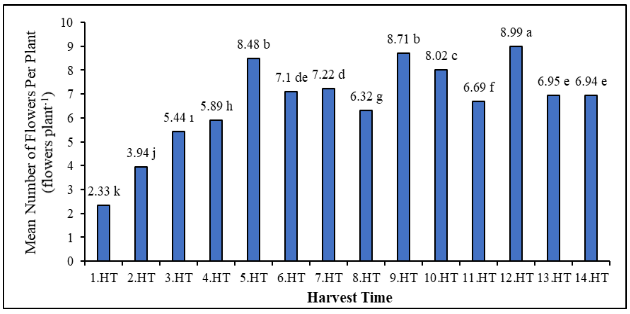

Figure 3. Effect of harvest time on mean number of flowers per plant. Different letters indicate significant differences among means (LSD = 0.231, P ≤ 0.01).

3.1.2 Fresh weight of flowers per plant

According to the variance analysis results for fresh weight of flowers per plant in pot marigold, inter-rows, intra-rows, harvest time, and their double and triple interactions caused statistically significant differences (Table 1). When the inter-row distance was investigated, the fresh weight of flowers per plant increased as the distance increased. The lowest fresh weight of flowers per plant was obtained with 30 cm inter-rows, while the highest weight was obtained with 50 cm inter-rows. A similar trend was observed for intra-rows. The fresh weight of flowers per plant was lowest with 10 cm intra-rows and highest with 30 cm intra-rows. The interaction between rows × intra-rows was found to be statistically significant, and the highest fresh weight of flowers per plant was obtained at a 50 × 30 cm planting density. In contrast, the lowest fresh weight of flowers per plant was recorded at a 30 × 10 cm planting density (Figure 5). The increase in fresh weight of flowers per plant with increasing planting distance can be explained by decreased interplant competition. The increased growing area per plant at wider row and plant spacing may have allowed for more efficient use of light, water, and nutrients. This could have contributed to the preservation of photosynthetic capacity and greater biomass accumulation in generative organs. Conversely, increased shading and root-zone competition at narrower planting distances may have limited flower development and fresh-weight formation. In studies of pot marigold, it was reported that larger row spacing and within-row spacing increased flower yield (Milli & Sable, 2003; Dhaked et al., 2013; Jadhav et al., 2014; Chopde et al., 2015; Yetiş, 2019). In all these studies, it is notable that the largest distances between rows and within rows used in trials came to the forefront. The increased growing area per plant at wider row and plant spacing may have allowed for more efficient use of light, water, and nutrients. This could have contributed to the preservation of photosynthetic capacity and greater biomass accumulation in generative organs. Conversely, increased shading and root-zone competition at narrower planting distances may have limited flower development and fresh-weight formation. In studies of pot marigold, it was reported that larger row spacing and within-row spacing increased flower yield (Milli & Sable, 2003; Dhaked et al., 2013; Jadhav et al., 2014; Chopde et al., 2015; Yetiş, 2019). In all these studies, it is notable that the largest distances between rows and within rows used in trials came to the forefront.

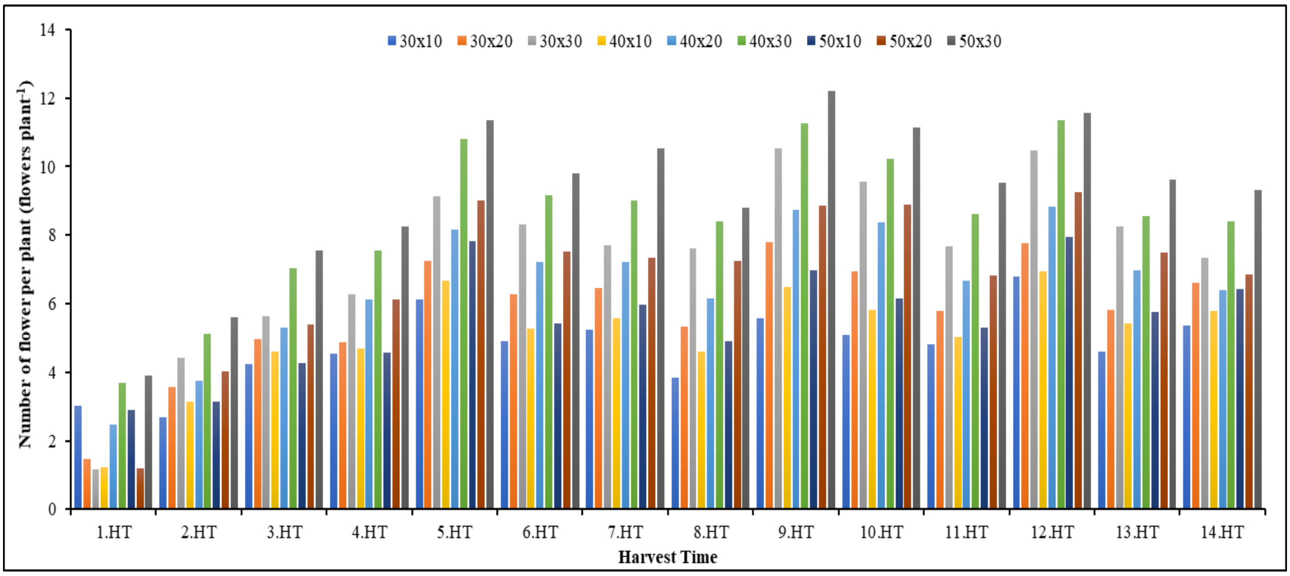

Figure 4. Effect of planting density and harvest time on the number of flowers per plant. The inter-row × intra-row × harvest time interaction was assessed using the LSD test ($P \leq 0.05$; LSD = 0.694). Letter annotations were omitted to improve visual clarity.

When harvest time is investigated, it is one of the most determinative variables for flower weight. The lowest flower weight was obtained at the 1st harvest time, with the highest flower weight obtained at the 12th harvest time (Figure 6).

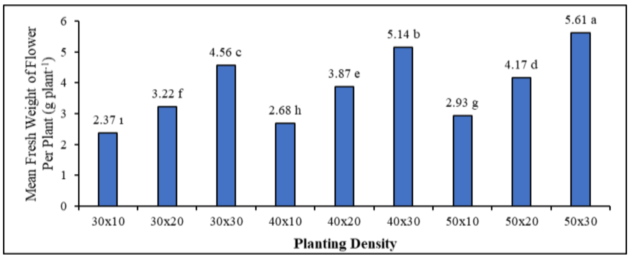

Figure 5. Effect of planting density on mean fresh weight of flowers per plant. Different letters indicate significant differences among means (LSD = 0.127, $P \leq 0.01$).

This trend shows an increase in the flowering of the plant and flower size over time and reveals that later harvest periods are more advantageous in terms of yield and quality. Low yields during the initial harvest periods may be related to the plant not yet having reached its full generative capacity. Biomass accumulation in the flower tissues may have increased over time. Flower weight may have increased as the plant reached physiological maturity. The differences observed during the mid- and late-harvest periods may be due to environmental conditions. Rainfall during the weeks when high yields were achieved may have increased fresh-flower production. Similarly, in studies on pot marigold, planting and harvest times were the most effective practices for determining the fresh weight of flowers per plant (Ayran, 2017; Biçen, 2020). When the triple interaction is investigated, the highest fresh weight of flowers per plant was obtained with 50 × 30 cm planting density at the 12th harvest period (Figure 7). This finding shows that production yield may reach the highest levels with the effects of suitable planting density and harvest timing, not just with the effect of a single factor. The lowest flower weight was obtained at a density of 30 × 10 cm during the 1st harvest period. This finding clearly reveals the degree of the negative effect on yield that may be induced by dense planting and early harvesting. When the results are evaluated overall, 50 × 30 cm planting intervals and the 12th harvest time emerged as optimal for fresh weight of flowers per plant under these climate conditions.

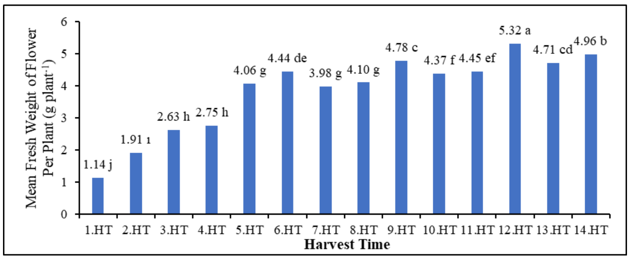

Figure 6. Effect of harvest time on mean fresh weight of flowers per plant. Different letters indicate significant differences among means (LSD = 0.158, P ≤ 0.01).

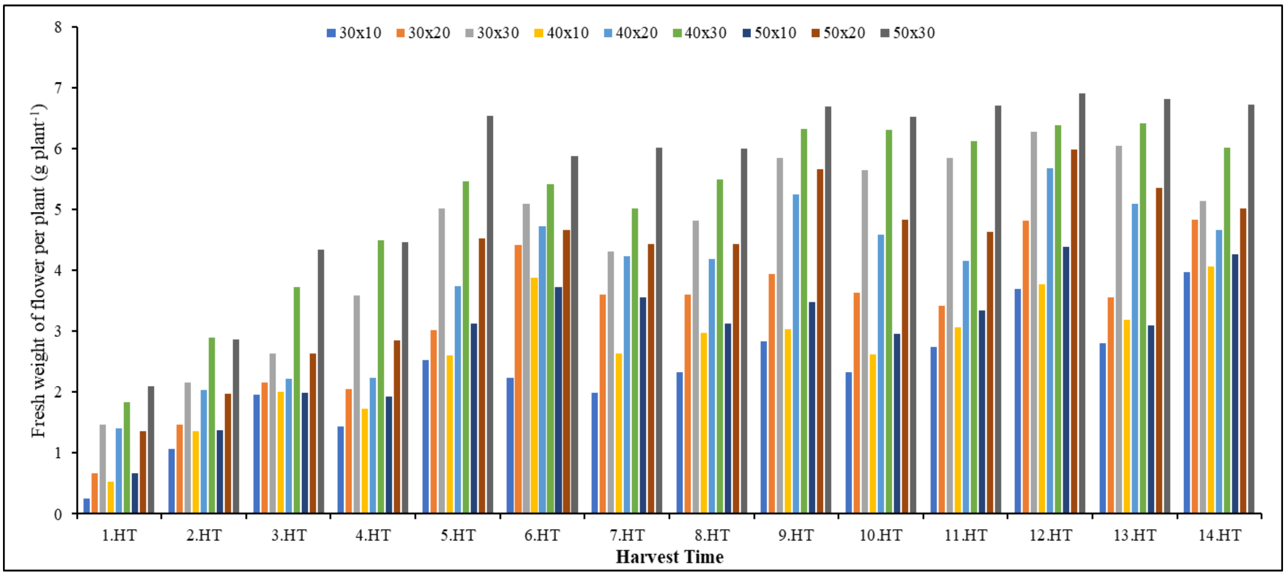

Figure 7. Effect of planting density and harvest time on fresh weight of flowers per plant. The inter-row × intra-row × harvest time interaction was evaluated using the LSD test (LSD = 0.475, P ≤ 0.01). Letter annotations were omitted to improve visual clarity.

3.1.3 Dry weight of flowers per plant

Variance analysis results revealed that the distance between rows, the distance within rows, harvest time, and their double and triple interactions affected the dry weight of flowers per plant at statistically significant levels (Table 1). For the distance inter rows, the dry weight of flowers per plant was highest when the distance was 50 cm. Similarly, in terms of distance within rows, a 30 cm spacing yielded higher yields, which may be associated with providing the optimal area for plant development. Narrow intra-row spacing (10 cm) increased competition among plants, which may have negatively affected flower formation. The dry weight of flowers per plant was highest under the 50 × 30 cm interaction (Figure 8). The lowest yield was obtained with the 30 × 10 cm planting norm, indicating the negative effects of intense competition. Wider plant spacing may have increased light, water, and nutrient availability per plant, supporting photosynthetic capacity and allowing for greater dry matter accumulation in flower tissues. Conversely, increased shading and root competition at narrower planting distances may have limited carbon assimilation, reducing dry matter accumulation in generative organs. Studies by other researchers obtained similar results (Berimavandi et al., 2011; Yetiş, 2019). This situation is consistent with our study's findings, which support the yield-enhancing effect of large planting intervals. However, in other studies, it was observed that the optimum planting norm may vary (Phetpradap et al. 2001). These differences may be due to factors such as the ecological conditions in the study region, the variety used, and agronomic practices. When harvest time was investigated, flower yield increased significantly over time. The lowest yield was obtained at the 1st harvest period (0.23 g plant^{-1}), with highest yield obtained at the 12th harvest period (1.09 g plant^{-1}), which shows the flowering of the marigold plant increases linked to the development process (Figure 9). The variation in dry weight of flowers per plant depending on harvest time can be explained by the increased accumulation of dry matter in the flower tissues as generative development progresses. Lower flower weights in early harvest periods may be related to the plant not yet having reached its full generative capacity, and assimilates being largely directed towards vegetative growth. The differences observed during mid- and late-harvest periods may be due not only to phenological progress but also to seasonal changes in temperature and precipitation. In particular, favorable humidity conditions may have supported photosynthetic activity, increasing dry matter accumulation. The literature includes a variety of studies supporting these findings. Barut (2022) and Ayran (2017) emphasized that different harvest times had significant effects on flower yield and that accurate determination of harvest time played a critical role in yield optimization. When interaction analyses were investigated, it appeared that dry flower yield was significantly affected not just by individual factors but also by the interactions of these factors. The 50 × 30 cm planting interval in the 12th harvest period interaction yielded the highest dry flower yield (Figure 10). This result shows that ensuring the optimum planting interval in both width and length created a synergistic effect on plant development and flower production. With the 30 × 10 cm planting at the 1st harvest period, yield values were observed to fall to minimum levels under restrictive conditions. This situation reveals that dense planting and early harvesting severely limit flower yield. In conclusion, large planting intervals and late-period harvesting emerged as the most appropriate practices for increasing dry flower yield in pot marigold cultivation.

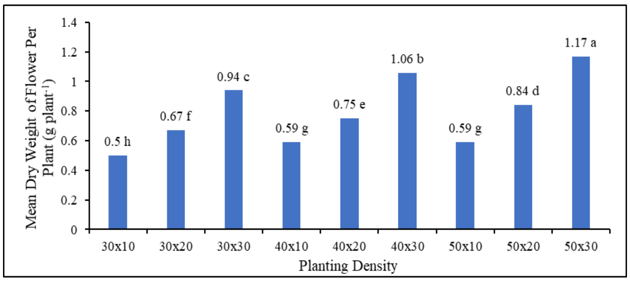

Figure 8. Effect of planting density on mean dry weight of flowers per plant. Different letters indicate significant differences among means (LSD = 0.039, P ≤ 0.01).

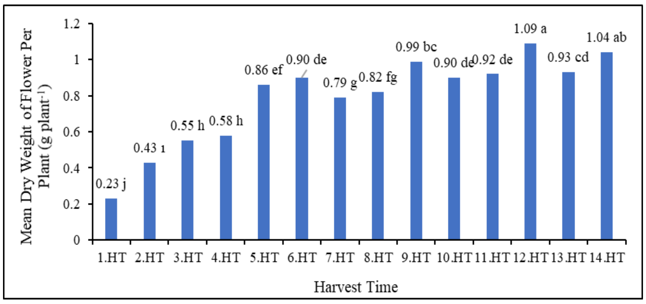

Figure 9. Effect of harvest time on mean dry weight of flowers per plant. Different letters indicate significant differences among means (LSD = 0.049, P ≤ 0.01).

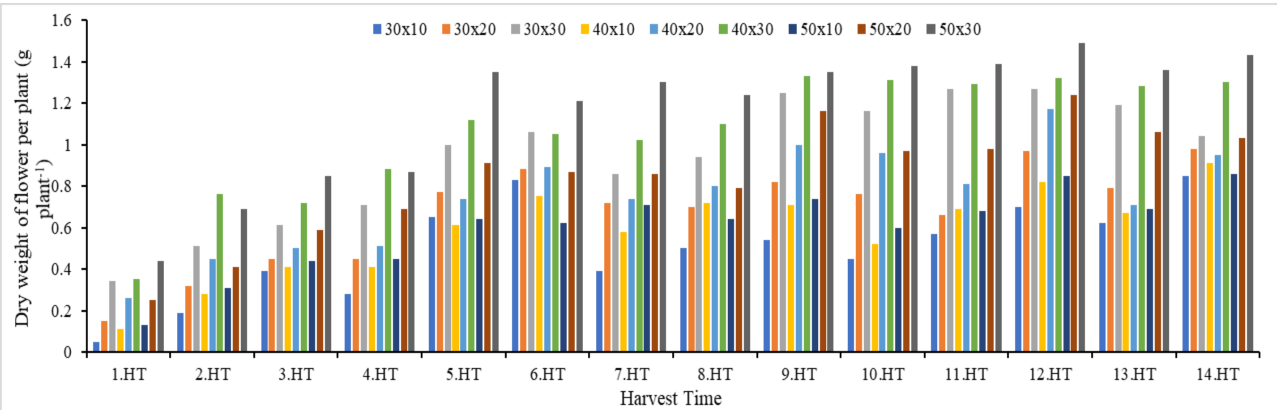

Figure 10. Effect of planting density and harvest time on dry weight of flowers per plant. The inter-row × intra-row × harvest time interaction was evaluated using the LSD test (LSD = 0.148, P ≤ 0.05). Letter annotations were omitted to improve visual clarity.

3.1.4. Flower fresh yield per hectare

According to the variance analysis results, the inter rows, intra rows, harvest time, and their double and triple interactions affected flower fresh yield per hectare at statistically significant levels (Table 1). When the distance between rows is investigated, the highest yield was obtained with the 30 cm interval. Similarly, when the intra was investigated, the highest yield was obtained with 10-cm intra rows. An increase in plant density increased the fresh flower yield per hectare. With intra-row spacings of 20 and 30 cm, although yield per plant increased, yield per hectare was limited by a reduction in total plant numbers. For the inter row × intra row interaction, the highest yield was obtained with the 30 × 10 cm interaction, with the lowest obtained with the 50 × 30 cm interaction (Figure 11).

The significant variation in flower fresh yield per hectare depending on planting density demonstrates the importance of plant density per unit area. As the number of plants per unit area increased, the total generative organ production may have also increased. Despite a decrease in resources per unit area, the increase in total leaf area and generative organ number may have increased yield per hectare. Conversely, while plants may have shown stronger individual development at wider planting intervals, the decrease in the total plant population may have limited per-hectare yield. This situation may result from the balance between individual plant performance and population-level resource-use efficiency for optimal yield. Previous studies about pot marigold (Milli & Sable, 2003; Kumar et al., 2011; Yetiş, 2019) support our findings. When harvest time is investigated, the highest fresh flower yield was obtained at the 12th harvest period, with the lowest yield obtained at the 1st harvest period (Figure 12). For the inter-row × harvest time interaction, the highest yield was obtained with 30 cm distance between rows at the 12th harvest time, with the 14th harvest time included in the same statistical group. The lowest value was obtained with 30 cm inter-row spacing at the 1st harvest. For the intra-row × harvest time interaction, the highest value was obtained with 30 cm intra-rows at the 14th harvest period, and the 30 cm intra-rows and 12th harvest period were in the same statistical group. The lowest yield was obtained with 20 cm intra-rows at the 1st harvest time and with 30 cm intra-rows at the 1st harvest time. The increase in fresh flower yield per hectare, depending on harvest time, can be explained by increased flower numbers and biomass accumulation as generative development progresses. Low yields during the early harvest periods may be due to flowering still being in its early stages. In the mid and late periods, the increase may be due to sufficient soil moisture from suitable temperatures and, especially, rainfall, which supports photosynthetic activity and promotes generative development. Conversely, water stress during weeks with high temperatures and low rainfall may be the main reason for the fluctuations in yield. For the triple interaction, the highest yield was obtained with 30 × 10 cm planting at the 14th harvest period, with the 12th harvest period in the same statistical group (Figure 13). This result indicates that when the optimum planting density is combined with regular and later harvesting, maximum yield is achieved.

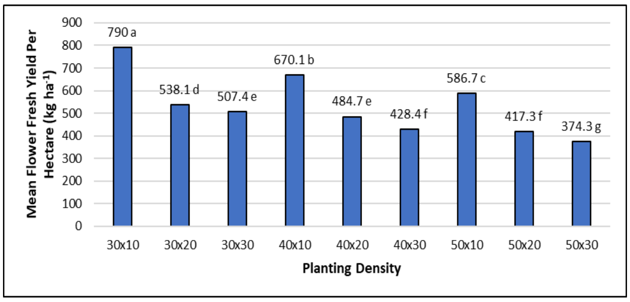

Figure 11. Effect of planting density on mean flower fresh yield per hectare. Different letters indicate significant differences among means (LSD = 22.68, P ≤ 0.01).

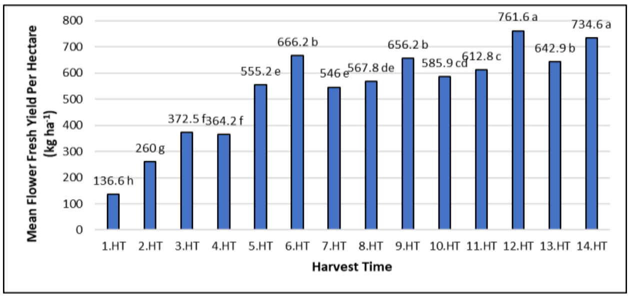

Figure 12. Effect of harvest time on mean flower fresh yield per hectare. Different letters indicate significant differences among means (LSD = 28.29, P ≤ 0.01).

3.1.5 Flower dry yield per hectare

The results show that inter-rows, intra-rows, harvest time, and their double and triple interactions significantly affected flower dry yield per hectare (Table 1). When the inter-row distance is investigated, the highest dry flower yield is obtained with 30 cm, with the lowest yield obtained from 50 cm distance. When intra-row spacing is investigated, the highest yield is obtained with 10 cm intra-row spacing, while the lowest yield is obtained with 30 cm intra-row spacing. Narrower intra rows increased flower dry yield per hectare by increasing plant density. Though larger intra rows increased individual plant yield, the total yield per hectare fell. When the interaction of inter rows × intra rows is investigated, the highest yield was obtained from the 30 × 10 cm interaction, with the lowest yield obtained from the 50 × 30 cm interaction (Figure 14).

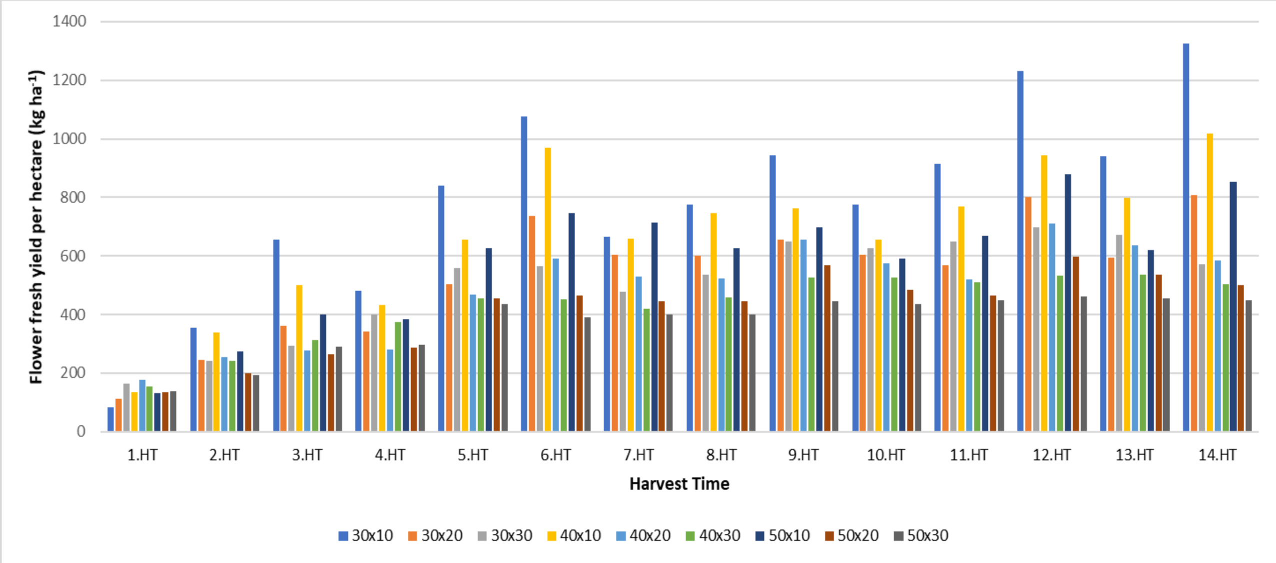

Figure 13. Effect of planting density and harvest time on flower fresh yield per hectare. The inter-row × intra-row × harvest time interaction was evaluated using the LSD test (LSD = 84.89, P ≤ 0.01). Letter annotations were omitted to improve visual clarity

The variation in flower dry yield per hectare depending on planting density can be evaluated with optimum plant density. Although larger row spacing increases individual plant yield, total yield decreases due to a reduction in the number of plants per unit area. The highest dry yield obtained in the 30 × 10 cm combination may be due to maximizing photosynthetic production at the population level and an increase in the number of generative organs. At this density, interplant competition may not yet have reached the critical threshold that would lead to yield loss. Although individual plants showed stronger development using more light, water, and nutrients at wider planting intervals, the decrease in the total number of plants limited the amount of generative organs per hectare. Conversely, if the density were increased further, yield could decrease due to light shading, root competition, and resource constraints. Similarly, Yetiş (2019) reported that dense planting increased total dry flower yield in a study of pot marigold. When harvest time is examined, the flower dry yield varies with it.

The highest yield was obtained at the 14th harvest period, with the 12th harvest period in the same group statistically, while the lowest yield was observed at the 1st harvest period (Figure 15). For the inter rows × harvest time interaction, the highest yield was provided by the 30 cm planting inter rows at the 14th harvest period. The lowest value was obtained with 30, 40, and 50 cm inter rows at the 1st harvest time. For the interaction of intra rows × harvest time, the highest yield was obtained with 30 cm intra rows at the 14th harvest time, with the lowest yield from 20 cm intra rows at the 1st harvest time and 30 cm intra rows at the 1st harvest time. The variation in flower dry yield with harvest time can be explained by both phenological development and environmental conditions. Low yields in the early harvest periods may be related to the early stages of flowering and the limited number of generative organs.

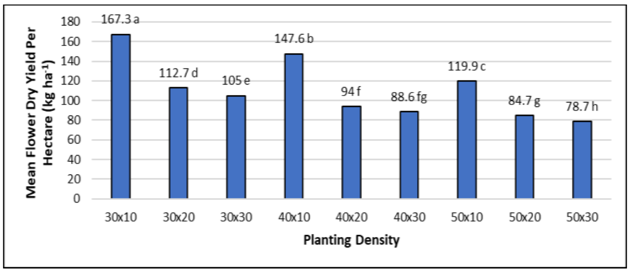

Figure 14. Effect of planting density on mean flower dry yield per hectare. Different letters indicate significant differences among means (LSD = 6.44, P ≤ 0.01).

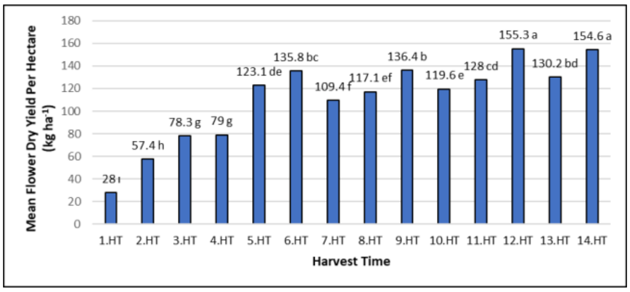

Figure 15. Effect of harvest time on mean flower dry yield per hectare. Different letters indicate significant differences among means (LSD = 8.03, P ≤ 0.01)

The increase in yield observed during the mid- and late-harvest periods is linked to the redirection of photosynthetic products to generative organs and to increased dry matter accumulation. Furthermore, the preservation of soil moisture during periods of sufficient rainfall may have increased dry yield by supporting carbon assimilation. Conversely, water stress during weeks with high temperatures and low rainfall may have limited photosynthetic capacity, causing fluctuations in yield. For the triple interaction, the highest flower dry yield was obtained with 30 cm inter-rows and 10 cm intra-rows at the 14th harvest period (Figure 16). This result revealed that yield can be maximized by combining optimal planting distances and harvest times.

3.2. Results for planting density and total harvest

The variance analysis table for the total number of flowers, fresh and dry flower weights per plant, and fresh and dry flower yields across all harvesting periods is presented in Table 2.

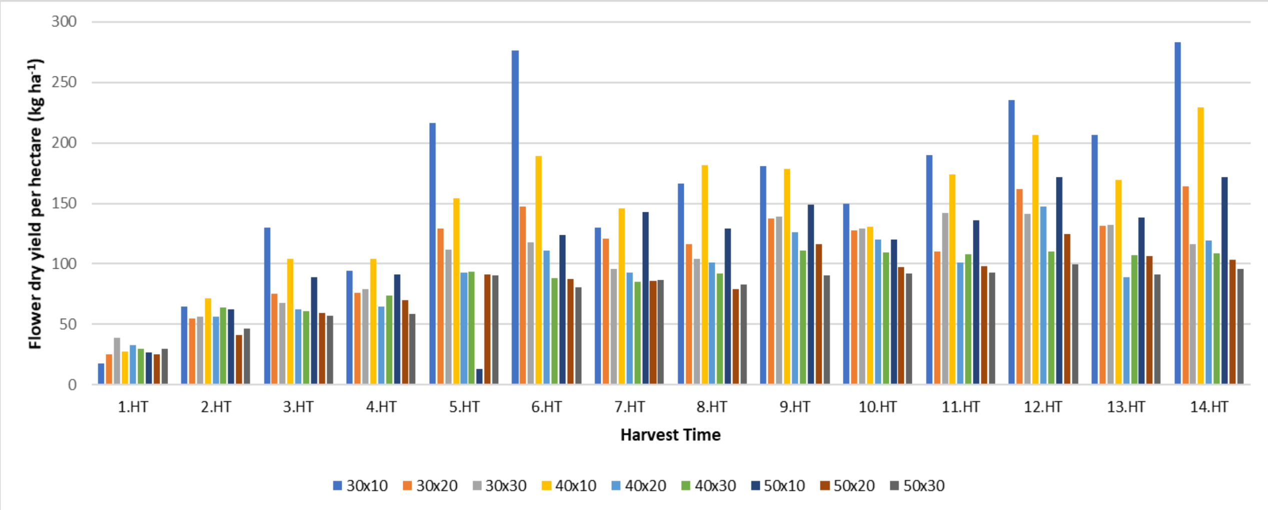

Figure 16. Effect of planting density and harvest time on flower dry yield per hectare. The inter-row × intra-row × harvest time interaction was evaluated using the LSD test (LSD = 24.11, P ≤ 0.01). Letter annotations were omitted to improve visual clarity.

Table 2. ANOVA mean squares for the effects of intra-row, inter-row, and their interaction on total yield and yield components of pot marigold

VS	df	TNFPP	TFWFPP	TDWFPP	TFFYPH	TFDYPH
Rep.	2	12.77	29.49	0.94	98026.0	2632.9
InterR	2	663.55**	356.40**	12.08**	859385.0**	51428.5**
Error	4	2.24	2.11	0.12	17743.1	584.8
IntraR	2	5102.74**	2730.16**	110.46**	2703200.0**	155397.0**
InterRxIntraR	4	29.81**	6.18	0.73**	9542.1	2367.7**
Error	12	1.68	2.14	0.08	21591.0	497.3
Total	26	450.25	241.96	9.67	295748.1	16795.9
CV		1.39	2.72	2.05	6.27	4.54

VS: Source of Variation, Rep: Replication, InterR: Inter Row, Intra R: Intra Row, CV: Coefficient of Variation, df: Degree of Freedom, ** Significant at 0.01 probability levels, TNFPP: Total Number of Flowers Per Plant, TFWFPP: Total Fresh Weight of Flowers Per Plant, TDWFPP: Total Dry Weight of Flower Per Plant, TFFYPH: Total Flower Fresh Yield Per Hectare, TFDYPH: Total Flower Dry Yield Per Hectare.

3.2.1 Total number of flowers per plant

Variance analysis results identified statistically significant differences in inter-rows, intra-rows, and the interaction between these two factors (Table 2). When the inter-row distance was investigated, the highest total number of flowers per plant was obtained at a 50 cm distance, while the lowest was obtained at a 30 m distance (Table 3). When examined in terms of distance between rows, the highest total number of flowers per plant was obtained from 30 cm intra rows, with the lowest obtained from 10 cm intra rows. The inter-row × intra-row interaction was determinative in terms of the total number of flowers per plant. For this interaction, the highest total number of flowers per plant was observed at a 50 × 30 cm planting density. In contrast, the 30 × 10 cm planting density reduced the total number of flower heads to 64.96 per plant. This shows that when both the interrows and intra-rows are narrow, in other words, when the plants grow densely, the combination negatively affects flower production. Increasing inter-row spacing may have increased the growing area per plant, thereby enhancing light-capturing capacity and, in turn, photosynthetic efficiency. Similarly, increasing intra-row may have reduced water and nutrient competition in the root zone, allowing for greater redirection of assimilates to generative organs. Obtaining the highest number of flowers in large planting combinations demonstrates that plants can reach their maximum generative potential under low competition conditions. This result reveals a positive effect of large row spacing on total yield and aligns with findings by researchers such as Mili & Sable (2003) and Yetiş (2019).

3.2.2 Total fresh weight of flowers per plant

When the variance analysis results are investigated, the interrows and intrarows had statistically significant effects on total fresh weight of flowers per plant, while the interrow x intrarow interaction was insignificant (Table 2). When inter-row spacing was investigated, the highest total fresh weight of flowers per plant was obtained with 50 cm inter-rows, while the lowest yield was observed with 30 cm inter-rows (Table 3). Larger distances between rows may be considered to reduce competition among plants and allow better development. For the distance intra-rows, the highest total fresh weight of flowers per plant was obtained at the 30 cm interval. The lowest value was obtained from the 10 cm interval. The significant effect of both inter-row and intra-row competition on the total fresh weight of flowers per plant indicates that generative biomass production is sensitive to interplant competition. The increase in total fresh weight of flowers per plant with increasing interrow can be explained by increased light capturing capacity and photosynthetic production due to increased growing area. Similarly, increasing intra row may have reduced root and crown competition, leading to greater redirection of assimilates to generative organs. Conversely, at narrow spacings such as 10 cm, intense competition and shading may have limited carbon assimilation, thus reducing flower biomass. Studies about pot marigold and similar plants support our results (Karavadia & Dhaduk, 2002; Sreekanth et al., 2006; Tiwari et al., 2010; Yetiş, 2019).

3.2.3 Total dry weight of flowers per plant

According to the variance analysis results, the inter-rows, intra-rows, and inter-row × intra-row interaction were statistically significant for the total dry weight of flowers per plant (Table 2). When the inter rows are investigated, the highest total dry weight of flowers per plant was obtained from 50 cm inter rows, while the lowest yield was obtained from the 30 cm norm (Table 3). For intra-row distances, the highest yield was obtained from 30 cm intra-rows, with the lowest yield recorded for 10 cm intra-rows. When the interaction interows × intra rows is considered, the highest value in terms of yield was obtained from the 50 × 30 cm planting norm. The increase in dry weight with increasing spacing can be attributed to greater light, water, and nutrient availability per plant, leading to increased photosynthetic production and greater assimilate allocation to the generative organs. The highest value observed, particularly in the 50 × 30 cm interaction, indicates that maximum dry matter accumulation occurs under low-competition conditions. In narrower spacings, increased shading and root competition may have limited carbon assimilation, thus reducing dry weight of flowers per plant. Studies about flower dry yield based on plants similar to pot marigold like chrysanthemum and marigold support our findings (Phetpradap et al., 2001; Karavadia & Dhaduk, 2002).

3.2.4 Total flower fresh yield per hectare

According to the variance analysis, the inter-row and intra-row effects significantly affected flower yield, while the inter-row × intra-row interaction was insignificant (Table 2). According to the findings, the highest yield was obtained with 30 cm inter-rows and 10 cm intra-rows (Table 3). With larger inter-row spacing (40 and 50 cm), total yield fell as the number of plants per hectare decreased. Similarly, with 10 cm intra-rows, total yield was highest, while with 20 cm and 30 cm intra-rows, yield clearly decreased due to a reduction in the total number of plants, despite better development of each plant. When the inter-row × intra-row interaction is investigated, the highest yield was obtained with 30 × 10 cm planting, while the lowest yield was obtained with 50 × 30 cm planting. This result shows that optimal yield may be achieved by appropriately adapting both the inter-rows and the intra-rows. The highest yield can be explained by an increase in the total number of generative organs per hectare due to a higher plant population. When plants are cultivated more densely, total yield increases; however, very dense planting may create competition between plants for light, water, and nutrients. Although narrower planting distances may reduce yield per plant, the higher total number of plants increased the area yield. Conversely, while individual growth was encouraged by increasing inter-row and intra-row spacing, the decrease in the number of plants per hectare limited the total yield. These findings are consistent with previous studies reporting that more frequent planting increased total flower yield (Karavadia & Dhaduk, 2002; Milli & Sable, 2003).

3.2.5 Total flower dry yield per hectare

According to variance analysis results, the inter-row, intra-row, and inter-row × intra-row interaction had statistically significant effects on total dry flower yield per hectare (Table 2). When the inter-row distance was investigated, the highest mean yield was obtained at a 30 cm distance, while the lowest yield was obtained at a 50 cm inter-row distance (Table 3).

Table 3. Mean comparisons of the effects of intra-row, inter-row, and interactions on yield and yield components of pot marigold.

Inter Row	Intra Row			
	10	**20**	**30**	**Mean**
	Total number of flowers per plant (flowers plant^{-1})			
30	64.96^{i}	80.93^{f}	105.92^{c}	83.94^{c}
40	71.30^{h}	92.43^{e}	119.23^{b}	94.32^{b}
50	75.90^{g}	97.83^{d}	129.20^{a}	100.97^{a}
Mean	70.72^{c}	90.40^{b}	118.11^{a}	
LSD	InterR: 1.961	IntraR: 1.333	InterR × IntraR: 2.309	
	Total fresh weight of flowers per plant (g plant^{-1})			
30	31.57	45.21	63.93	46.90^{c}
40	37.53	54.29	71.98	54.60^{b}
50	41.07	58.43	78.62	59.37^{a}
Mean	36,72^{c}	52.64^{b}	71.51^{a}	
LSD	InterR: 1.902	IntraR: 1.503	InterR × IntraR: ns	
	Total dry weight of flowers per plant (g plant^{-1})			
30	7.03^{h}	9.46^{f}	13.24^{c}	9.91^{c}
40	8.26^{g}	10.52^{e}	14.89^{b}	11.22^{b}
50	8.39^{g}	11.86^{d}	16.41^{a}	12.22^{a}
Mean	7.89^{c}	10.61^{b}	14.85^{a}	
LSD	InterR: 0.466	IntraR: 0.295	InterR × IntraR: 0.512	
	Total flower fresh yield per hectare (kg ha^{-1})			
30	10523.20	7534.60	7104.00	8387.20^{a}
40	9382.50	6786.20	5998.60	7389.10^{b}
50	8214.60	5843.30	5241.20	6433.00^{c}
Mean	9373.40^{a}	6721.40^{b}	6114.60^{c}	
LSD	InterR: 551.31	IntraR: 477.25	InterR × IntraR: ns	
	Total flower dry yield per hectare (kg ha^{-1})			
30	2343.20^{a}	1577.70^{cd}	1471.40^{d}	1797.40^{a}
40	2066.60^{b}	1315.80^{e}	1241.00^{ef}	1541.20^{b}
50	1679.30^{c}	1186.00^{fg}	1094.10^{g}	1319.80^{c}
Mean	2029.70^{a}	1359.80^{b}	1268.80^{c}	
LSD	InterR: 100.09	IntraR: 72.34	InterR × IntraR: 125.45	

LSD: Least Significant Difference; Means followed by different letters differ significantly according to the LSD test at the 5% significance level. ns: non-significant

This situation shows that total yield increased as plant density per unit area increased, with narrower planting intervals. Although broader planting intervals provided an advantage to each plant, total yield fell due to a reduction in the number of plants per hectare. When intra-row spacing was investigated, the highest yield was obtained with 10 cm intra-row spacing, followed by 20 cm and 30 cm. Narrowing the intra-row spacing increased total flower yield per hectare by increasing plant density. Though larger intra-row spacing increases the yield of individual plants, the total yield per hectare decreases. For the interaction of the inter rows × intra rows, the highest yield was obtained from 30 × 10 cm interaction with lowest yield from 50 × 30 cm interaction. The highest dry matter yield obtained in the 30 × 10 cm combination can be explained by the increase in population level carbon assimilation due to the increased number of plants per unit area. Although dry weight per plant may decrease in narrow planting spacing, more light may have been captured per unit area due to the increased leaf area index, and total photosynthetic production may have increased. This increased dry matter accumulation per hectare. In wider planting spacing, although photosynthetic capacity per plant and the amount of assimilated carbon directed to generative organs increased, the decrease in the total number of plants limited the population-level dry matter yield. The significant interaction effect shows that dry matter production is shaped by the plant density created by the combination of inter row and intra row. The findings are similar to the findings of Yetiş (2019). The results of the study show that optimum organization of distances both inter rows and intra rows is critical to increase yield.

4. Conclusion

This study investigated the effects of different inter-row and intra-row spacings and different harvest times on flower yield and yield criteria in the pot marigold plant. The results revealed significant differences associated with both planting density and harvest time in yield values obtained per plant and per unit area. The number of flowers per plant and the fresh and dry weights of flowers per plant had the highest values at 50 × 30 cm planting intervals, with the lowest values at 30 × 10 cm intervals. In terms of yield per unit area, the highest value was obtained from 30 × 10 cm intervals, while the lowest was obtained from 50 × 30 cm intervals. Similar results were obtained for the total yield and for yield criteria from the full 14-week harvest period. When evaluated by harvest time, flowering density increased over successive weeks, with the highest flower numbers and weights observed in the 12th and 14th harvest periods and the lowest in the 1st harvest period. The results of a single-year study indicate that different planting densities should be selected based on the intended production purpose. In situations where the aim is the highest total flower yield, frequent planting is recommended, whereas if the target is to obtain larger, higher-quality flowers, sparser planting is appropriate. Furthermore, it was observed that environmental and agronomic factors such as temperature, rainfall, and regular harvesting significantly affected yield by promoting new flower formation. These findings indicate that the results may vary with environmental conditions, highlighting the need to repeat the study across different years and ecological settings. When planning production targeting increased yield, it is necessary to consider the possibilities of mechanization, disease risk and labor requirements.

Authorship contribution statement

İ.M.U and Y.E: Planning, conceptualization, methodology, data curation, investigation, writing-original draft, editing and software. Y.E. and S.B.G.: writing-review and editing.

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Conflict of interest

The authors declare no conflicts of interest.

Ethical Statement

There is no need to obtain ethics committee approval for this study.

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