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# Effect of plant density on stem and flower quality of single-stem ornamental sunflower genotypes

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**Abstract:** The aim of this research was to determine the optimum planting density for the production of high-quality cut flowers with desirable characteristics. 25 single-stem ornamental sunflower genotypes were planted at different densities and evaluated for flowering time, flower diameter, and stem circumference and length over a two-year production cycle. Three spacing patterns were used: 25 × 25 cm, 30 × 30 cm, and 70 × 30 cm, which led to the planting densities of 160 000, 90 000, and 60 000 plants/ha, respectively. The plant density had the most important effect on the stem circumference, flower diameter, and stem length (total variation 52, 60, and 58%, AMMI analysis) and a small effect on the flowering time (total variation 1%, AMMI analysis). Based on environment-focused scaling, all high-density environments could be suitable for the production of single-stem sunflower genotypes. The results demonstrated the adaptation of several sunflower genotypes G9, G11, G12, G21, and G22 as the most suitable based on the optimum flower diameter, stem circumference, and stem length. These results may lead to progress in growing ornamental sunflowers as a cut flower.

**Keywords:** ornamental sunflower; plant density; genotype; cut flower

Cultivation of the ornamental sunflower (*Helianthus annuus* L.) has gained importance in recent years. At present, this species has a significant place on the cut flower market (Fambrini et al. 2003). When sunflower production shifted to the cut flower market, the traits desired in the agronomic sunflower crop were not conducive for cut flowers (Burnett 2017). This called for new breeding in sunflowers to create cultivars that will perform well as cut flowers (Schoellhorn et al. 2003). The criteria for the global cut flower trade are good plant growth, the maximum number of flowers, coupled with a good stem length and flower size (Nair et al. 2002; Gurav et al. 2005). There are some important factors that affect the cut sunflower marketability: the diameter of the inflorescence and length of the stem (Cvejić et al. 2017).

Two types of sunflower varieties are used for the cut flower market. The first type is a single-stem sunflower that tolerates dense planting. The second includes the branching varieties that are planted in 70 × 30 cm spacing, but the branching feature results in the production of 4–5 first-class flowers and 4–5 second-class flowers (Kaya et al. 2012). Single-stem plants are more desirable due to the longer and firmer stem and resistance to lodging despite dense planting. There is a presumption that resistance to lodging has been noted as an important and desirable

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characteristic and farmers have selected such genotypes from the natural populations during sunflower domestication (Lentz et al. 2008). Some studies have suggested that the plant density in the field may affect the morphological characteristics of the sunflower (Ibrahim 2012; Baghdadi et al. 2014). Tighter spacing may result in nicer looking flowers, but more nutrients and water will be necessary to maintain a healthy population of plants (Sloan and Harkness 2006). For the standard oil type of sunflower, the optimum recommended planting space is 70 cm between the rows and 20–30 cm within the row (Balalić et al. 2012). Kaya et al. (2012) suggested a plant spacing of 50 cm between the rows and 15 cm in the row for the ornamental sunflower. Vuppalapti (2005) used a 66 cm inter-row and a 20 cm intra-row spacing for testing different varieties of the ornamental sunflower. Also, for some other types of cut flowers such as the gerbera (*Gerbera jamesonii* Bolus ex Hook), Bhosale et al. (2012) recommended 30 × 30 cm spacing to obtain the maximum flower diameter and optimum stalk length. According to previous research, the plants were taller and with a smaller stem circumference and head diameter in high density planting (Süzer 2011). Rajcan et al. (2001) explained this as the adaptation of the plants and a survival strategy in terms of competition for light. Plants react to environmental and management interventions by undergoing architectural and structural modifications (Sher et al. 2018).

Breeding aims for the ornamental sunflower differ significantly from those for the oil sunflower. The aim of this research was to determine the optimum planting density for the production of high-quality cut flowers with desirable characteristics. The purpose of the selection in this case was not to obtain the maximum values of each trait, but their optimum values for use in flower arrangements. The optimum values are long stems, medium size flowers, and a medium early vegetation period. The objective was to evaluate diverse single-stem genotypes of ornamental sunflowers for their performance under different planting densities, in order to obtain plants with good quality flowers, as well as the optimal stem length.

## MATERIAL AND METHODS

**Plant material.** 25 single-stem ornamental sunflower genotypes were selected from the sunflower gene-pool of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. The initial material of the ornamental sunflower originated from China, Argentina, and France. The ornamental sunflower germplasm was developed by different breeding methods during the past 30 years. Six generations of selfing were carried out to insure the genetic purity of the developed genotypes. The genotypes were selected based on the flower characteristics and their single-stem properties (Mladenović et al. 2017). The selected genotypes had a yellow, lemon, or orange colour of the ray flower. The colour of disk flower was yellow, orange, or purple. All the genotypes were resistant to lodging.

**Experiment setting.** The experimental trial was conducted at the breeding nursery at the Institute of Field and Vegetable Crops in Novi Sad, Serbia (45.26°N, 19.83°E), during a 2-year period (2016–2017). According to the hydrometeorological reports, the year 2016 was wet and warm (in April–September, precipitation was 449 mm, No. days > 30 °C was 26 and > 35 °C was 0), while 2017 was warm and very dry (in April-September, precipitation was 315 mm, No. days > 30°C was 49 and >35°C was 16), http://www.hidmet.gov.rs.

The experimental plot was organised in a randomised complete block design with three replications. The experimental trial was planted in plots by applying different planting densities. Three spacing patterns were used: 25 × 25 cm, 30 × 30 cm, and 70 × 30 cm, which led to planting densities: 160 000, 90 000, and 60 000 plants/ha, respectively. The experiments were carried out under conventional tillage. The crops were kept free from weeds, insects, and diseases according to best local practices. Before sowing, the herbicide triflurolin (2 kg a.i. per ha) and the insecticide bifenthrin (0.8 kg a.i. per ha) were applied. After sowing and before emergence, the herbicide ammonium nonanoate (2 kg a.i. per ha) was used.

Four traits important for the ornamental market of cut-flowers were measured: flowering time (days), flower diameter (cm), stem circumference (mm), and stem length (cm).

**Statistical analysis.** The genotype by environment interaction (GEI) was tested using the AMMI (Additive Main Effects and Multiplicative Interaction) analysis by Zobel et al. (1998). Visualisation of the obtained results was undertaken using the which-won-where GGE (G – genotype effect, GE- genotype × environment interaction effect) biplot graphs (Yan, Tinker 2005). The GGE biplot was divided by an equality line into sectors in which different mega-environments could be detected (Yan, Tinker 2005; 2006). The cir-

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cles in the GGE biplot grouped the environments into mega-environments. The genotypes close to the mega-environments were the most suitable for the particular environment. In the study, a combination of years and densities were considered as an environment. Data processing was performed in GenStat 9th Edition VSN International Ltd (www.vsn-intl.com). Significant differences were calculated using the *F*-test.

## RESULTS

A total of 25 single-stem genotypes were evaluated in three different planting densities during the summer of 2016 and 2017 for four major quantitative traits important for the production and use of ornamental sunflowers (Table 1). All the tested genotypes varied in the examined traits: time of flowering

Table 1. The mean values (MV) of the three replication and interaction scores (IPCA1) for the ornamental single-stem sunflower genotypes (G1-G25) using the AMMI analyses

| Genotypes | Flowering time (days) | | Stem circumference (mm) | | Flower diameter (cm) | | Stem length (cm) | |
|---|---|---|---|---|---|---|---|---|
| | MV | IPCA1 | MV | IPCA1 | MV | IPCA1 | MV | IPCA1 |
| G1 | 78.61 | 0.66 | 18.22 | 0.26 | 18.42 | 0.71 | 139.4 | 2.66 |
| G2 | 79.22 | 1.31 | 15.94 | –0.05 | 19.03 | 0.30 | 131.3 | 3.46 |
| G3 | 79.44 | 0.70 | 13.39 | 0.32 | 15.53 | 0.52 | 131.3 | 3.46 |
| G4 | 69.94 | –0.28 | 15.50 | –0.80 | 15.89 | 0.45 | 140.2 | 0.85 |
| G5 | 62.94 | –1.05 | 11.33 | 0.67 | 16.89 | –0.47 | 90.8 | 1.42 |
| G6 | 64.44 | –1.49 | 11.56 | 0.31 | 14.92 | –1.69 | 119.0 | 1.09 |
| G7 | 76.39 | 0.50 | 19.11 | –1.33 | 18.75 | 0.38 | 131.0 | –2.42 |
| G8 | 74.83 | –0.13 | 15.56 | 0.94 | 16.53 | 0.08 | 130.9 | 1.28 |
| G9 | 80.50 | –0.92 | 16.39 | –0.14 | 17.22 | 0.26 | 140.1 | 1.86 |
| G10 | 62.28 | 0.12 | 16.39 | 0.82 | 16.47 | 0.62 | 111.1 | 0.39 |
| G11 | 75.44 | –1.21 | 17.44 | 0.39 | 14.97 | –0.35 | 125.6 | 1.70 |
| G12 | 81.44 | –0.24 | 16.22 | 1.01 | 15.11 | –0.79 | 128.6 | 0.15 |
| G13 | 71.28 | –1.10 | 12.67 | –0.03 | 15.67 | 0.43 | 110.6 | –2.98 |
| G14 | 75.33 | –0.54 | 13.11 | 0.33 | 17.42 | 0.02 | 114.1 | –2.77 |
| G15 | 74.56 | –0.73 | 13.44 | 0.08 | 17.28 | –0.27 | 146.2 | 0.41 |
| G16 | 73.56 | 0.25 | 16.00 | 0.48 | 15.72 | –0.03 | 133.9 | –1.29 |
| G17 | 73.33 | –0.30 | 17.78 | –1.33 | 15.25 | –1.75 | 116.4 | –1.28 |
| G18 | 78.89 | 2.93 | 19.50 | –0.86 | 16.64 | –0.01 | 138.0 | 0.39 |
| G19 | 69.89 | 0.01 | 14.67 | 0.23 | 16.33 | 0.16 | 111.6 | 0.24 |
| G20 | 68.00 | 0.34 | 17.56 | –0.20 | 15.44 | 0.55 | 115.4 | –1.14 |
| G21 | 61.67 | 0.23 | 17.11 | 0.14 | 21.22 | 0.50 | 113.5 | –1.73 |
| G22 | 71.00 | 0.81 | 15.89 | –0.32 | 17.81 | –0.31 | 157.8 | 1.26 |
| G23 | 61.28 | 0.26 | 14.94 | –0.62 | 17.72 | –0.19 | 89.4 | –1.80 |
| G24 | 69.17 | –0.18 | 13.56 | –0.78 | 14.61 | 0.22 | 101.8 | –2.03 |
| G25 | 60.61 | 0.04 | 15.06 | 0.50 | 16.22 | 0.66 | 112.9 | –3.17 |
| Mean | 71.76 | | 15.53 | | 16.68 | | 123.24 | |
| **LSD 0.05** | **1.44** | – | **1.27** | – | **1.19** | – | **7.24** | – |
| E1* | 71.71 | 3.21 | – | – | 20.07 | –2.03 | 123.3 | 1.58 |
| E2 | 72.4 | –1.18 | 19.12 | 2.61 | 19.19 | –1.59 | 91.3 | –4.18 |
| E3 | 72.19 | 1.01 | – | – | 16.47 | 1.19 | 144.8 | 4.91 |
| E4 | 71.28 | –1.16 | 14.42 | 1.36 | 15.63 | 0.80 | 105.6 | –4.01 |
| E5 | 72.35 | 0.57 | – | – | 14.91 | 0.80 | 157.4 | 4.77 |
| E6 | 70.65 | –2.45 | 13.06 | 1.25 | 13.82 | 0.82 | 117.2 | –3.0 |
| **LSD 0.05** | **0.71** | – | **0.44** | – | **0.58** | – | **4** | – |

*E1 – 2016 (70 × 30); E2 – 2017 (70 × 30); E3 – 2016 (30 × 30); E4 – 2017 (30 × 30); E5 – 2016 (25 × 25); E6 – 2017 (25 × 25);

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Table 2. The sources of the variation based on the AMMI analysis for the flowering time, stem circumference, flower diameter, and stem length of 25 single-stem sunflower genotypes tested in the different densities

| Sources of variation | Flowering time | | Stem circumference | | Flower diameter | | Stem length | |
|---|---|---|---|---|---|---|---|---|
| | MS* | VE (%) | MS | VE (%) | MS | VE (%) | MS | VE (%) |
| Environment (E) | 35.91** | 1 | 758.29** | 52 | 454.31** | 60 | 45 030** | 58 |
| Genotype (G) | 779.3** | 90 | 43.21** | 36 | 43.25* | 27 | 5 013** | 31 |
| GxE | 16.03** | 9 | 7.02** | 12 | 3.99 | 13 | 364** | 11 |
| IPCA 1 | 44.56** | 65 | 12.51** | 93 | 10.75** | 63 | 916** | 59 |
| IPCA 2 | 14.8** | 21 | 1.04** | 7 | 3.13 | 17 | 338** | 20 |
| IPCA3 | 7.2** | 9 | – | – | – | – | 199** | 11 |
| IPCA4 | 4.32** | 5 | – | – | – | – | 132** | 7 |
| Residuals | 1.17 | – | * | – | 1.46 | – | 78 | – |

MS – mean squares; VE – variation explained; G × E – genotype-by-environment interaction; IPCA – interactive principle component analysis; $^*P \leq 0.05$; $^{**}P \leq 0.01$

ranged from 60.61 (G25) to 81.44 days (G12), stem circumference from 11.33 mm (G5) to 19.50 mm (G18), flower diameter from 14.61 cm (G24) to 21.22 cm (G21), and stem length from 89.4 cm (G23) to 146.2 cm (G15). The variations in the traits according to the plant densities (environments) were from 70.65 days (E6) to 71.71 days (E1) for the flowering time, from 13.06 mm (E6) to 19.12 mm (E1) for the stem circumference, 13.82 cm (E6) to 20.07 cm (E1) for the flower diameter, and 91.3 cm (E2) to 157.4 cm (E5) for the stem length.

Table 1. The mean values (MV) of the three replication and interaction scores (IPCA1) for the ornamental single-stem sunflower genotypes (G1-G25) using the AMMI analyses.

The genotype had the most important effect on the flowering time, which explained 90% of the variation, whereas the environment did not have an effect on this trait (Table 2). However, the plant density carries the highest percentage of the total variation in the stem circumference, flower diameter, and stem length of 52, 60, and 58%, respectively. The highest stem circumference (19.12 mm) was in the low density spacing of 70 cm × 30 cm, and the stem circumference was the lowest (13.06 mm) with the increased plant density spacing of 25 × 25 cm. The tallest plants (157.4 cm in 2016 and 117.2 cm in 2017), were in the 25 × 25 cm spacing, while there were smaller plants in the low density spacing (123.3 cm in 2016 and 91.3 cm in 2017). The flowering diameter was the highest in the low density spacing (20.07 cm and 19.19 cm), while the flowers were the smallest in the high density spacing (14.91 cm and 13.82 cm). The effects of the genotype and GxE interaction were lower (Table 2).

The sources of the variation based on the AMMI analysis for the flowering time, stem circumference, flower diameter, and stem length of the 25 single-stem sunflower genotypes tested in the different densities.

The first two PCs (principal components) were attributed to 88.42%, 98.27%, 97.03%, and 89.78% of the total variation for the flowering, stem circumference, flower diameter, and stem length (Figure 1), respectively. For the flowering, the sector equality line divided the test environments into two mega-environments. The genotype G21 was the closest to the mega-environment one (E2, E3, E4, and E5) for the flowering. The genotypes close to this mega-environment were G1, G2, G9, G14, G15, and G22. For the stem circumference, the GGE biplot divided the environments into the high-density mega-environment (30 × 30 cm; 25 × 25 cm) and the low-density mega-environment (70 cm × 30 cm). The genotypes G1, G21 and G28 were the closest to the first environment, which makes them suitable for denser planting. The GGE biplot divided the environments into three groups according to the flower diameter. The genotypes G9, G11, G12, G13, and G14 were the most desirable for the E6 environment, while G1, G2, G3, G16, and G18 performed best in the E1 and E3 environment. There was no division in the environments, while the genotype G22 had the most suitable stem length.

## DISCUSSION

The number of plants per hectare is an important factor in the ornamental sunflower production. The compactness of the sunflower plants is closely asso-

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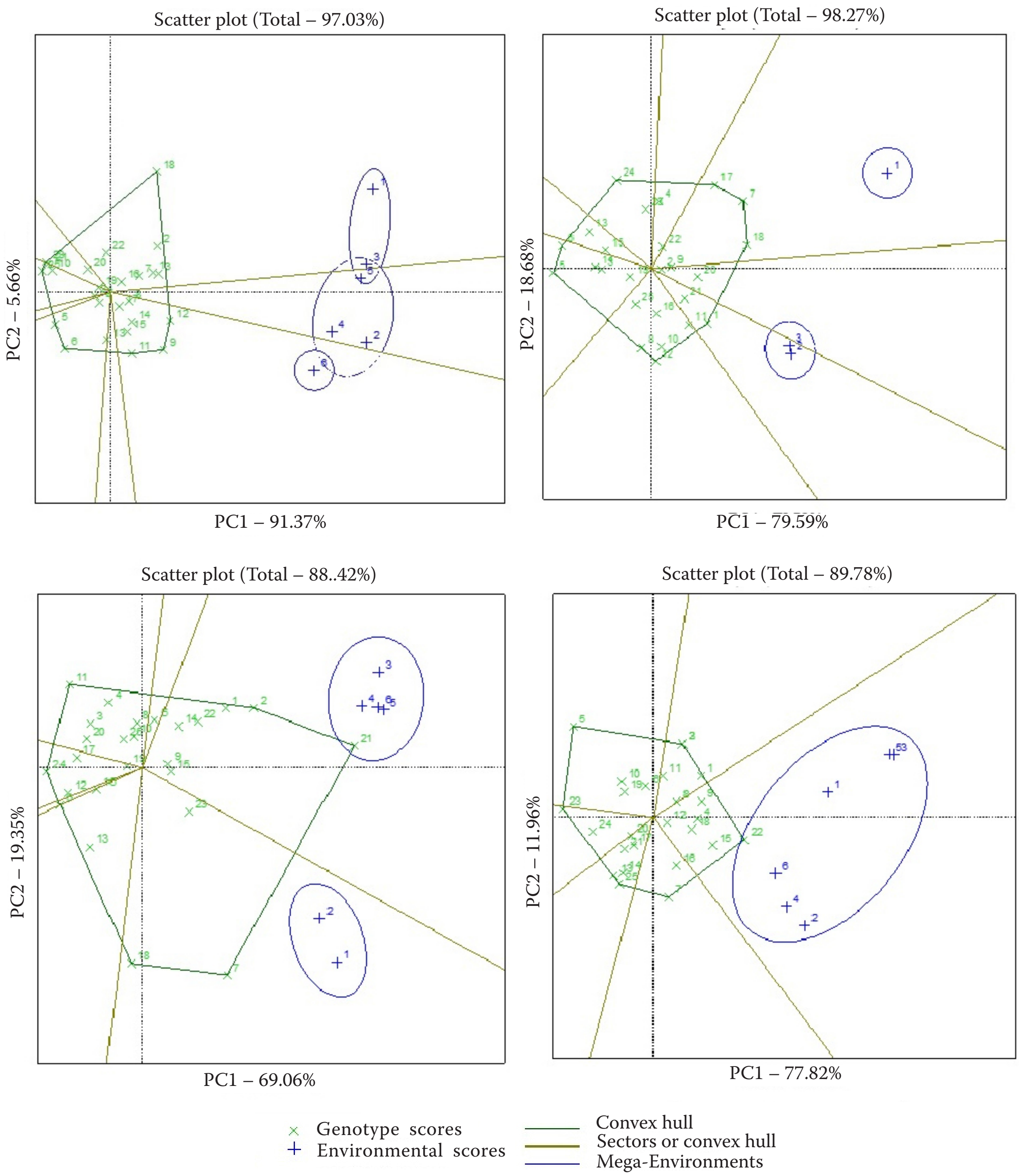


Figure 1. The which-won-where polygon view of the GGE biplot for the 25 sunflower genotypes (G) in the six environments (E) to show which genotype performed the best in which environment and the meaningful mega-environment: (A) flowering time, (B) stem circumference, (C) flower diameter, and (D) stem length

ciated with the space that they have and thereby affecting the light interception efficiency. The desired flower quality and yield can be achieved by manipulating the planting density. This will help sunflower producers to select the optimum planting density that will lead to the best quality cut flowers. Therefore, in order to evaluate the effect of the different densities on the single-stem sunflower genotypes, the stem circumference, flower diameter, and stem length were analysed in this paper.

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There are not many studies concerning the optimum plant density in the ornamental sunflower production as in other species. According to Kumar (2007), coriander (*Coriandrum sativum* L.) was taller when the density was 25 plants/$m^2$, while the highest branch number was at the density of 10 plants per $m^2$. Similar results were obtained for the lily (*Lilium longifolium* Thunb.), the safflower (*Carthamus tinctorius* L.) and coriander, when an increase in the altitude and the flower yield was observed in plants grown in close proximity (Amjad et al. 2012), an increase in the oil yield was observed in plants grown in denser planting (Roghayeh et al. 2012), and an increase in the grain yield was observed in plants grown in denser planting (Ghobadi et al. 2010; Moosavi et al. 2012), respectively. The opposite results were obtained by Kapczyńska (2013), where the plant spacing did not affect the flower characteristics of the *Lachenalia* cultivars. Khorshidi (2009) confirmed that a decrease in the density causes reduced branching in the fennel. In this study, the different planting densities affected the flower diameter, stem circumference, and stem length. The smallest flower diameter, the thinnest stem circumference, and the tallest stem were at the densest planting spacing (25 × 25 cm). However, the plant density did not affect the flowering time in this study. The results led to the conclusion that the genotype influence on the flowering is a stable trait, with minor oscillations depending of the environmental conditions

There is no official classification in the ornamental sunflower, but *Gerbera* inflorescences of 8–11 cm in diameter are commercialised as small flowers, those of 12–16 cm in diameter are commercialised as medium flowers, and those above 16 cm in diameter are commercialised as large flowers (Nair et al. 2002). The mean values for the flower diameter of 25 single-stem ornamental sunflower genotypes ranged from 13–20 cm and can be classified as medium to large flowers. However, the highest density (25 cm × 25 cm) flower diameter was smaller than in the lowest density (70 × 30 cm). The question is: what would the optimum size of a flower regarding its attractiveness and stability be? The smaller diameter is suitable for the production of cut sunflowers because those flowers are more suitable and easier to handle in different flower arrangements. In this research, the high density spacing of 25 × 25 cm had the most effect on the flower diameter. Similar results were obtained by Mojiri and Arzani (2003) where an increased plant population resulted in smaller flower heads. In the present study, the diameter of the flower differed significantly in the different environments, but G × E interaction was not significant. Based on the GGE biplot, the results obtained in the E1 and E2 environments show that the flower diameter is too large and not appropriate for cut flowers. The E6 environment, using the planting density of 25 cm × 25 cm in 2017, was the most suitable for a large group of genotypes. In this environment, G9, G11, and G12 were identified as the best specific adapted genotypes for the flower diameter.

The influence of the plant density (E) on the stem diameter was significant; it suggested that the plant density, as an environmental condition, has a strong influence on the stem diameter. Lower plant spacing causes the development of thinner stems, which is important for the production of cut flowers intended for use in flower arrangements and bouquets. In the research of Beg et al. (2007), higher plant populations produced thinner stems, which confirms our results where thinner stems were obtained in higher plant populations. Thinner, but at the same time, solid stems are more desirable and more decorative for use in flower arrangements. The most suitable genotypes for the dense environments were G1 and G28, along with G21 for the stem circumference.

Density as an environmental factor also influenced the stem length. Mojiri and Arzani (2003) stated that an increased plant population leads to an enhanced stem length and plant height. This can be explained by the fact that the plants compete for nutrients and light and have a higher root and stem length that is higher than the optimal in the presence of the competition (Ali et al. 2011; Craine et al. 2013). In this way, there is a change in the plant architecture, where the plants are elongated, which leads to a greater distance between the internodes (Ford 2014). Long stems are a desirable feature in the decorative sunflower, because cut flowers are cut several times to refresh them until they reach the consumer. In our study, the plants were generally taller in the 2016 environments, due to the higher rainfall compared to 2017. The most suitable genotype in all the examined environments was G22. This genotype showed high stability, both in the stem length and flowering.

Based on the environment-focused scaling, all the high-density environments could be suitable for the production of the single-stem sunflower genotypes.

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Thus, in order to produce cut flowers of the decorative sunflower, low density spacing of 25 cm × 25 cm should be used. In this way, a smaller diameter, thinner stems, higher plants, but also a higher number of plants per m$^2$ are obtained. According to the GGE biplot, environments with a planting density were the most suitable for the large genotype groups. The results demonstrated the adaptation of several sunflower genotypes G9, G11, G12, G21, and G22 as the most suitable based on the optimum flower diameter, stem circumference, and stem length. The obtained results may lead to recommendations for growing ornamental sunflower cultivars produced at the Institute of Field and Vegetable Crops in Novi Sad, Serbia. Sunflowers, as an ornamental crop, could be productive and profitable, provided that market infrastructures were developed.

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