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AGRONOMIC RESPONSE OF FOUR *Dahlia pinnata* Cav. (Asteraceae) VARIETIES IN THREE PRODUCTION ENVIRONMENTS

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ABSTRACT

Flower cultivation has increased nationwide. Currently, species of the *Dahlia* genus (known colloquially as Dahlias) are grown for ornamental purposes, with central Mexico having the highest production rate. Due to its importance, we sought to evaluate the effect of three different methods of cultivation (shade net, greenhouse, and open field) on the growth and development of four dahlia varieties in Saltillo, Coahuila, Mexico. The experiment was carried out at the Horticulture Department of the Universidad Autónoma Agraria Antonio Narro. Tuberous roots of four *D. pinnata* varieties were sown directly into the soil and covered with mulch. The shade netting production environment proved to be the best in production, with the best results in plant height, stem diameter, number of leaves, and days to flowering. The highest-performing cultivar was the Antje variety. On the other hand, the Antje variety (cultivated under shade netting) had the longest flower stalks, the Boy Mick variety (cultivated in the greenhouse) had the heaviest flowers, and the Canby Centennial variety (cultivated in open field) had the flowers with the thickest stalks. The results show that Dahlias can be grown in northeastern Mexico because the area meets suitable conditions for crop development and production.

Keywords: Protected agriculture, production, Dahlias, flowers.

INTRODUCTION

Mexico's diversity of climates provides ample opportunities for the development of first-rate floriculture (Tejeda-Sartorius *et al*., 2015). The cultivation of flowers has shown a growth rate of 9 %, while the cultivation of grain corn only increased by 1 % during 2016 (Orozco-Hernández *et al*., 2017). This demonstrates that this area of horticulture is booming and has a high economic potential (Soriano-Melgar *et al*., 2018). As an example, it is possible to cite the commercial success of lisianthus (*Eustoma grandiflorum* (Raf.) Shinners), a plant native to northern Mexico that has gained importance within the international market (Fernández-Pavía and Trejo-Téllez, 2018). Additionally, the case of pascuilla (*Euphorbia strigosa* Hook and Arn), which has ornamental potential

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due to its red or crimson bracts and, because of its resemblance to the poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch), it can be considered a dwarf version of the latter (Valdez-Hernández *et al*., 2018).

One of the most diverse botanical families native to Mexico is Asteraceae (Carrasco-Ortiz *et al*., 2019), which includes 417 genera and 3113 species (Villaseñor, 2018). Within this large number of genera is *Dahlia*, which is characterized by its peculiar inflorescences, or flower heads, with showy ligulate flowers located around the outside. *Dahlia* has been widely explored and diversified in terms of ornamental varieties abroad (Şekerci and Gülşen, 2016) and is a genus subject of diverse studies, both taxonomic (Castro-Castro *et al*., 2012), phylogenetic (Sánchez-Chávez *et al*., 2019), biogeographical (Carrasco-Ortiz *et al.*, 2019), and biochemical (Hernández-Epigmenio *et al*., 2022). An example of the ornamental value of *Dahlia* is the more than 61 000 validated and accepted cultivars reported by the Royal Horticultural Society of the United Kingdom. In contrast, in Mexico there are only 25 cultivars reported as registered in the National Catalogue of Plant Varieties 2022 (SNICS, 2022).

The Dahlia was designated the national flower of Mexico in 1963 owing to its ornamental and economic value (DOF, 1963; Mera-Ovando *et al*., 2008). It is a symbol of Mexican floriculture due to its 38 species, all of which grow in Mexico (35 of which are endemic) (Carrasco-Ortiz *et al*., 2019). Currently, the Dahlia is mainly used as an ornamental plant, and its use has been promoted by utilizing its medicinal and nutritional benefits (Mera-Ovando *et al*., 2008).

Cultivation of these plants occurs primarily in central Mexico, in the states of Puebla, Mexico, and Mexico City, although there is production potential in other entities (Heredia-Hernández and Baltazar-Bernal, 2017), since their distribution includes most of the Mexican territory, with the exception of the Yucatán and Baja California peninsulas (Carrasco-Ortiz *et al*., 2019). The main propagation methods used in producing areas are seed and tuberous roots (Jiménez-Mariña, 2015; Mera-Ovando and Bye-Boettler, 2006), although methods by cuttings and *in vitro* culture have also been described (Jiménez-Mariña, 2015).

The temperature requirements for dahlia cultivation range from 18 to 23 °C (Jiménez-Mariña, 2015), although however some research studies manage to bring production even at temperatures of 45 °C (Heredia-Hernández and Baltazar-Bernal, 2017). This clearly demonstrates that the range of temperature tolerance is very broad. The city of Saltillo, Coahuila, is located at an altitude of 1600 m, has a dry, semi-warm climate with cool winter and summer rains (Molar-Orozco *et al*., 2020; Sánchez-Herrera *et al*., 2022), with annual average precipitation and temperature of 125 to 400 mm and 14 to 18 °C, respectively (Marroquín-Morales *et al*., 2018). These favorable conditions make Saltillo a good candidate for Dahlia production.

In this study, the growth and development of the plants and quality of the cut flowers of four dahlia varieties subjected to three varying production environments (open field, greenhouse, and shade net) for their cultivation in Saltillo, Coahuila, Mexico, were evaluated.

MATERIALS AND METHODS

Experiment site

The research was carried out in three production environments: open field (c), semi-automated greenhouse (i), and black shade net with 30 % shading (m). This took place at the Experimental Agricultural Field of the Horticulture Department of the Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila, Mexico, located exactly at 25° 21′ 23″ N and 101° 01′ 54″ W, with an altitude of 1610 m and a mean annual temperature ranging between 12 and 18 °C, during the spring-summer 2020 agricultural cycle.

Plant material

Tuberous roots of four varieties of *Dahlia pinnata*, obtained in the municipality of Huamantla, Tlaxcala, Mexico, were collected during the autumn of 2019. They were classified after being described (plant habit and growth habit, stem, leaf, flower head, and tuberous root), according to the Graphic Manual for Dahlia Varietal Description (Laguna-Cerda, 2007). For this purpose, 10 catalogs of varieties for this species were reviewed, identifying the presence of the four varieties used. The inflorescence's group, color, and size, as well as the curvature of the ligule, were all taken into account. As a result, the Dahlia Catalog Listing of Varieties (Crocoll *et al*., 2023) was chosen.

Crop management

The tuberous roots of the four varieties were kept under greenhouse conditions until the day of planting. The planting of Dahlias was carried out directly in the soil on March 10, 2020, in 12 m long culture beds, which were covered with silver-colored mulch on the outside and black mulch on the inside. Eight tuberous roots were used per variety and per environment, resulting in a total of 96 roots, which were planted 60 cm apart in single rows, and the distance between planting lines between beds was 90 cm.

The crop was grown in three environments: open field (c), semi-automated greenhouse (i), and black shade net with 30 % shading (m). Prior to crop establishment, the ground was heavily irrigated with water only. After planting, the crops were irrigated every third day until the beginning of plant emergence, which occurred 7 days after planting (DDS). Then, the plants were fertilized with a Steiner nutrient solution (Steiner, 1961), which was adjusted based on the analysis of water used during the crop cycle. The nutrition was modified according to the phenological stage of the crop: during the post-emergence stage of the plant, the Steiner solution was used at 25 %, during vegetative development at 50 %, at the appearance of flower buds at 75 %, and during flowering at 100 %. Drip irrigation was applied every third day, for 45 to 60 min, depending on the already present soil moisture.

Variables evaluated

The following variables were evaluated in each of the three environments: plant height (ADP) with a flexometer, basal stem diameter (DBT) with a Steren® HER-411 digital vernier, and number of leaves (NH) expressed in units. The variables listed above were evaluated weekly until the appearance of the first flower bud in all environments (72 DDS). The total number of inflorescences (NTI) was estimated at the end of the last harvest (143 DDS), and the number of days between sowing and the appearance of the first expanded inflorescence on each plant (DAF) was estimated for all varieties. The number of tuberous roots (NRT) was evaluated at the end of the production cycle, once they were removed from the experimental area (167 DDS).

The variables evaluated in the inflorescences were: length of floral stem (LTF) using a flexometer, fresh weight of inflorescence (PFF) with an OHAUS CS analytical balance with a capacity of 3000 g, diameter of inflorescence (DF), and floral stem (DTF) measured with a Steren® HER-411 digital vernier. These variables were evaluated on the day the flower stalk was cut.

Statistical analysis

There were 12 treatments as a result of the combination of two factors: the dahlia variety (four varieties) and the production environment (greenhouse, shade net, and open field) (Table 1). A completely randomized experimental design (DCA) was used to distribute the treatments. Each treatment had four replicates, each with two experimental units. Each plant was considered an experimental unit. Analysis of variance (ANOVA) was performed with the variable mean values; for the comparison of means, a Tukey test was applied (Tukey, $\alpha \leq 0.05$). A data correlation analysis (Pearson's coefficient) was performed for the variables ADP, NH, NRT, and NTI, using the statistical software JMP Ver. 15 (Sall, 2020).

Table 1. Treatment description for four *Dahlia pinnata* Cav. varieties evaluated in three production environments in southeastern Coahuila de Zaragoza, Mexico.

Environment	Variety	Treatment Key
Open Field	Antje	c-A
	Babylon	c-B
	Boy Mick	c-BM
	Canby Centennial	c-CC
Greenhouse	Antje	i-A
	Babylon	i-B
	Boy Mick	i-BM
	Canby Centennial	i-CC
Shade Net	Antje	m-A
	Babylon	m-B
	Boy Mick	m-BM
	Canby Centennial	m-CC

RESULTS AND DISCUSSION

The varieties used in the present work were classified as Antje, Babylon, Boy Mick, and Canby Centennial (Figure 1).

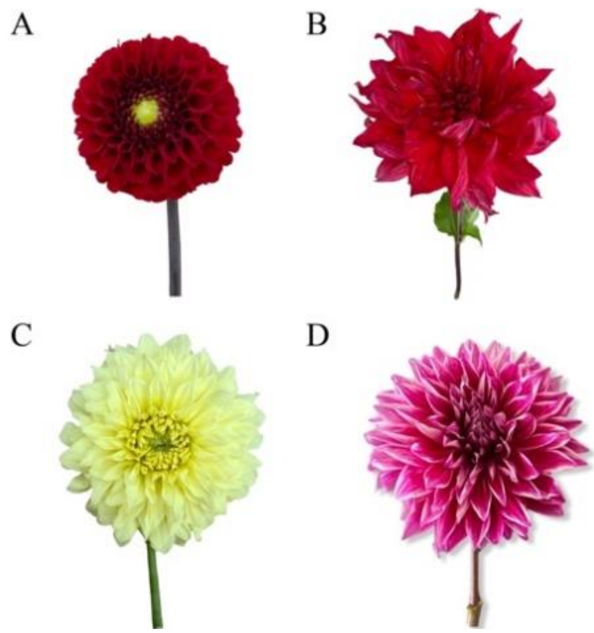

Figure 1. Photographs of four *Dahlia pinnata* Cav. varieties evaluated in three production environments in southeastern Coahuila de Zaragoza, Mexico. A: Antje; B: Babylon; C: Boy Mick; D: Canby Centennial.

The mean test performed on the agronomic variables evaluated showed significant differences ($p \leq 0.05$). For 6 out of 8 variables, better results were reflected in the shade net production environment (Table 2).

For the ADP variable, the Antje variety grown in the shade netting environment was the tallest, which could be the result of elongation caused by low exposure to light (Heredia-Hernández and Baltazar-Bernal, 2017), exceeding by 500 % the Canby Centennial variety, which presented the lowest value. Plants grown in shade netting were larger in size, showing significant differences with those obtained in open field and greenhouse. Plants with these characteristics represent an alternative for the producer, since a reduction in size can improve handling and presentation as potted plants (Laguna-Cerda *et al*., 2004). This variable is relevant for both crop management and inflorescence selection, since they are classified according to stem length (Flores-Ruvalcaba *et al*., 2005).

On the other hand, for the DBT variable, the Boy Mick variety grown in the shade net production environment had the thickest stems (27.13 mm), exceeding

Table 2. Test of means for the interactions between the two factors and the variables evaluated in plants and inflorescences of four varieties of *Dahlia pinnata* Cav.

Treatment	ADP (cm)	DBT (mm)	NH	NTI	DAF (days)	NRT
c-A	23.69 cd	12.39 cd	39.25 bcd	5.50 de	102.75 c	10.04 ab
c-B	31.92 cd	16.13 bcd	31.79 cd	11.33 b-e	86.00 ab	15.00 a
c-BM	39.19 bcd	20.40 abc	48.71 abc	16.06 a-d	80 a	13.42 ab
c-CC	24.28 cd	11.84 cd	49.86 abc	5.58 de	102.75 c	10.92 ab
i-A	35.25 cd	10.80 d	31.71 cd	12.31 a-d	87.50 abc	8.25 ab
i-B	20.23 cd	13.86 cd	19.33 d	6.79 cde	82.00 a	9.92 ab
i-BM	16.38 d	11.71 cd	17.19 d	11.38 b-e	101.25 bc	10.44 ab
i-CC	15.00 d	7.19 d	17.25 d	3.22 e	99.50 bc	5.63 b
m-A	91.31 a	20.58 abc	72.63 a	17.79 abc	76.75 a	11.42 ab
m-B	67.44 ab	23.38 ab	52.88 abc	19.88 ab	75.00 a	11.94 ab
m-BM	67.08 ab	27.13 a	65.23 ab	27.67 a	79.25 a	10.04 ab
m-CC	45.33 bc	16.32 bcd	62.61 ab	14.94 b-e	81.75 a	7.42 ab
CV	29.21	23.2	25.4	37.58	7.47	31.11

[†]Means with a common letter are not significantly different (Tukey, $p \leq 0.05$). CV: coefficient of variation; ADP: plant height; DBT: basal stem diameter; NH: number of leaves; NTI: total number of inflorescences; DAF: days to flowering; NRT: number of tuberous roots. c-A: Open field-Antje; c-B: Open field-Babylon; c-BM: Open field-Boy Mick; c-CC: Open field-Canby Centennial; i-A: Greenhouse-Antje; i-B: Greenhouse-Babylon; i-BM: Greenhouse-Boy Mick; i-CC: Greenhouse-Canby Centennial; m-A: Shade Netting-Antje; m-B: Shade Netting-Babylon; m-BM: Shade Netting-Boy Mick; m-CC: Shade Netting-Canby Centennial.

by 270 % the Canby Centennial variety grown in the greenhouse environment, which had the thinnest stems. Dahlia stems are hollow, which gives them a weak constitution (Jiménez-Mariña, 2015) when compared to other species; for example, *Tithonia diversifolia* (Hemsl.) A. Gray stems can measure 3.5 cm and have up to 36 vascular bundles, providing greater support (González-Castillo *et al*., 2014). Therefore, it is recommended that the Dahlia crop be protected from wind currents or rain. In contrast, Chrysanthemum stems show lower values (6 mm); however, their stems are not hollow (Gaytán-Acuña *et al*., 2006), giving greater consistency and support to the inflorescence (Flores-Ruvalcaba *et al*., 2005).

In terms of NH, the Antje variety had the highest values, with an average of 72.63 leaves for plants grown in the shade netting environment. This is consistent with the results obtained by Callejas-Chavero *et al.* (2020), who found a higher leaf production in closed sites than in open ones, which may be related to the absence of a canopy since they are exposed to environmental factors and, therefore, are vulnerable to various factors such as strong gusts of wind, rain, and hailstorms. On the other hand, the lowest values were expressed in plants grown in greenhouses, demonstrating that the high temperature in this environment induced stress on the plants, resulting in lower production of this organ (Heredia-Hernández and Baltazar-Bernal, 2017).

The most productive variety, regarding NTI, was the Boy Mick variety grown in shade netting, with an average of 27.67 inflorescences. The Canby Centennial variety, grown in greenhouses, produced 750 % less than the first. The Boy Mick variety was the second variety with the highest leaf production in the shade-mesh cover; since there was no thinning of this organ, the passage of light to the stems was limited, a factor that influences flowering (Sánchez-Vidaña *et al*., 2018). This also coincides with the fact that when grown under shade netting, this variety was the earliest in terms of the DAF variable. Fertilization is a factor that influences the flowering process, which was supplied under the same conditions in the three environments, inferring that the result could be due to other factors such as the temperature and humidity of the environments (Sánchez-Herrera *et al*., 2022).

The shade netting environment induced more precocity in DAF, since the four varieties had their first inflorescence before 82 days, with statistically significant differences ($p \leq 0.05$) when compared to the rest of the treatments. This demonstrates that this environment is ideal for producing inflorescences in a short period of time. Studies by Heredia-Hernández and Baltazar-Bernal (2017) report that Dahlias flowered 6 weeks after transplanting; however, the cultivation was carried out in 6" pots, whereas the present work was carried out in soil. Other species, such as sunflower (*Helianthus annuus* L.), may flower earlier (66 days after planting) (Carrillo-Criollo and Yumbla-Orbes, 2022), but the number of inflorescences varies from one for the latter and more than two for dahlias.

There were statistically significant differences ($p \leq 0.05$) in NRT. The Babylon variety produced the most units per plant in an open field environment, averaging 15 units per plant. Similar values were obtained by Lopera-Marín *et al*. (2020) in a study carried out on Yacon plants (*Smallanthus sonchifolius* (Poepp.) H. Rob.), which were established in similar conditions of distance between rows and between plants to those of the present study, and the high productivity may have been due to the generous distance during their development.

Pearson's correlation analysis applied to the variables showed a positive relationship ($p \leq 0.05$) between all of them (Figure 2), with the strongest relationship (r = 0.82) between ADP and NH, followed by ADP and NTI (r = 0.75). Previous studies have shown that when stems elongate, nodes appear, leading to an increase in the production of leaves and flower stems (Garzón-Solis *et al*., 2009). On the other hand, it could have been due to the use of shade netting, as it has been demonstrated that by reducing total radiation and photosynthetically active radiation, leaf area increases, resulting in a greater number of leaves (Ayala-Tafoya *et al*., 2011).

On the other hand, the variables LTF, PFF, and DTF showed significant differences ($p \leq 0.05$) (Figures 3, 4, and 5). The LTF presented by the Anje variety in the shade netting environment expressed the highest values (22.33 cm), significantly exceeding the behavior of the same variety produced in open field (Figure 3). The plants were not debudded, which was presumably the cause of the stem length, since doing so allows the main flower to reach stems of 60 to 70 cm long (Jiménez-Mariña, 2015), in addition to obtaining flowers with greater diameter (López *et al*., 2017).

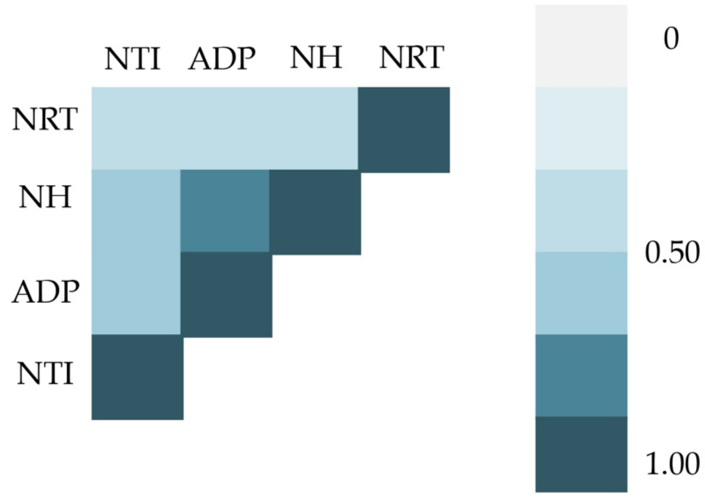

Figure 2. Pearson correlation matrix of the variables evaluated. Significant values ($p \leq 0.05$). NRT: number of tuberous roots; NH: number of leaves; ADP: plant height; NTI: total number of inflorescences.

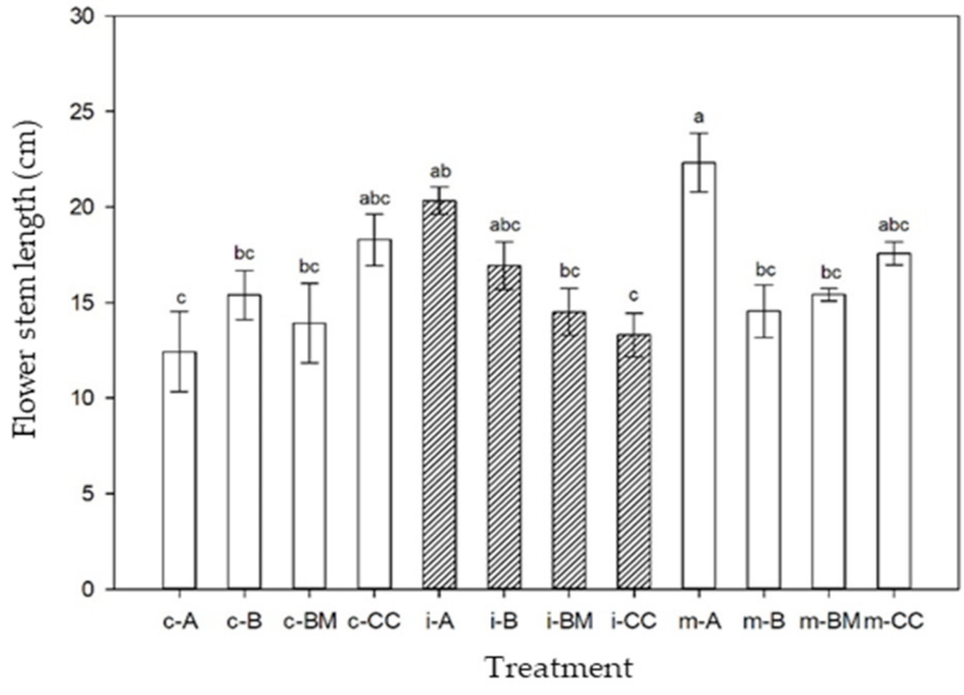

Figure 3. Differences in floral stem length of four varieties of *Dahlia pinnata* Cav. grown in three environments in southeastern Coahuila de Zaragoza, Mexico. Means with a common letter are not significantly different (Tukey, $p \leq 0.05$). c-A: Open field-Antje; c-B: Open field-Babylon; c-BM: Open field-Boy Mick; c-CC: Open field-Canby Centennial; i-A: Greenhouse-Antje; i-B: Greenhouse-Babylon; i-BM: Greenhouse-Boy Mick; i-CC: Greenhouse-Canby Centennial; m-A: Shade Netting-Antje; m-B: Shade Netting-Babylon; m-BM: Shade Netting-Boy Mick; m-CC: Shade Netting-Canby Centennial.

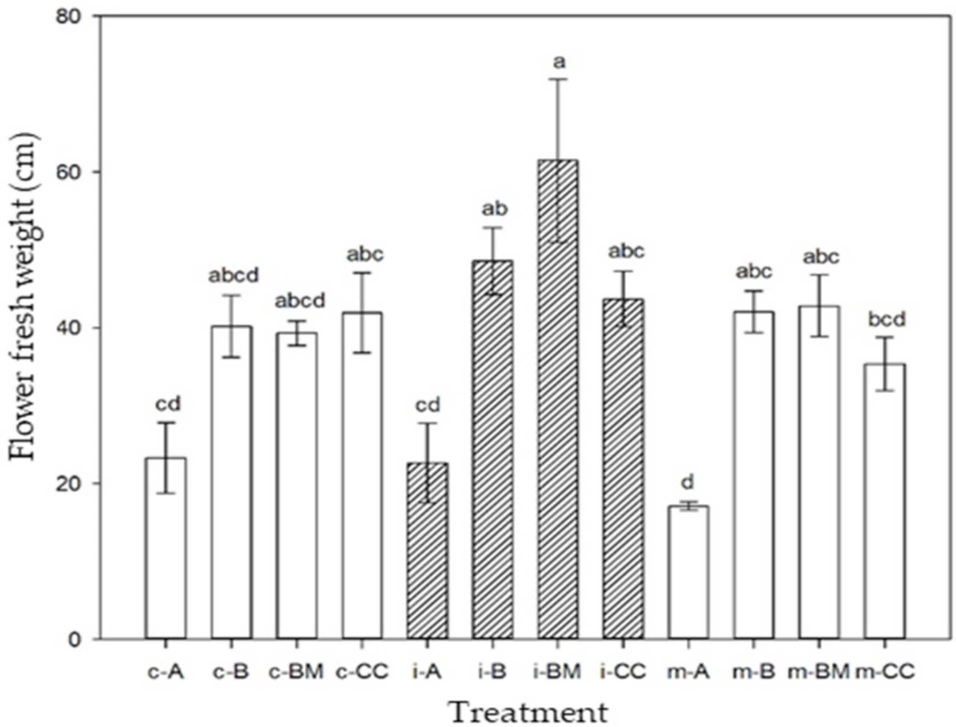

Figure 4. Influence of environment and variety of *Dahlia pinnata* Cav. on fresh weight of flowers produced in southeastern Coahuila de Zaragoza, Mexico. Means with a common letter are not significantly different (Tukey, $p \leq 0.05$). c-A: Open field-Antje; c-B: Open field-Babylon; c-BM: Open field-Boy Mick; c-CC: Open field-Canby Centennial; i-A: Greenhouse-Antje; i-B: Greenhouse-Babylon; i-BM: Greenhouse-Boy Mick; i-CC: Greenhouse-Canby Centennial; m-A: Shade Netting-Antje; m-B: Shade Netting-Babylon; m-BM: Shade Netting-Boy Mick; m-CC: Shade Netting-Canby Centennial.

The PFF was higher in flowers of the Boy Mick variety produced in the greenhouse, which increased by 250 % more than the variety with the lowest flower weight (Antje in shade netting) (Figure 4). The greenhouse had higher humidity than the open field and shade netting, promoting greater water absorption and resulting in higher fresh weight (Morales-Pérez *et al*., 2014).

There were no significant differences in the DF variable among the variables evaluated in the floral stems; however, the Antje variety grown in the greenhouse outgrew the same variety grown in the shade netting environment by more than 250 %, demonstrating that the supply or reduction of light does not affect the average diameter of the inflorescence (Chica-Toro and Correa-Londoño, 2005). Flores-Ruvalcaba *et al*. (2005) obtained a similar response, indicating that the genetic factor may be responsible for biomass accumulation in the flower.

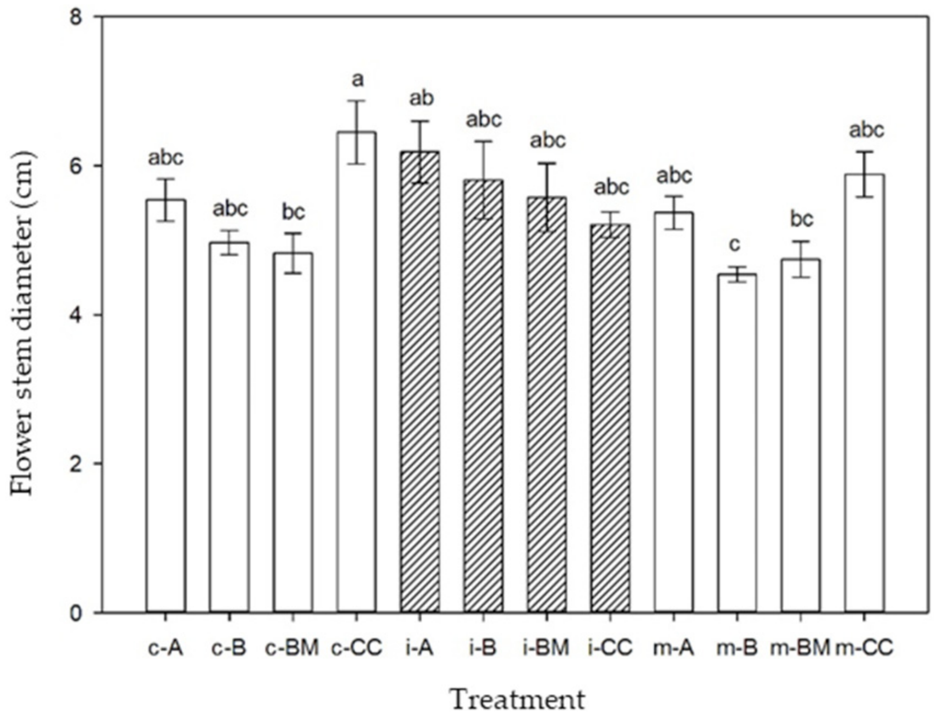

Figure 5. Difference in floral stem diameter of *Dahlia pinnata* Cav. flowers from three environments and four varieties of dahlias grown in southeastern Coahuila de Zaragoza, Mexico. Means with a common letter are not significantly different (Tukey, $p \leq 0.05$). c-A: Open field-Antje; c-B: Open field-Babylon; c-BM: Open field-Boy Mick; c-CC: Open field-Canby Centennial; i-A: Greenhouse-Antje; i-B: Greenhouse-Babylon; i-BM: Greenhouse-Boy Mick; i-CC: Greenhouse-Canby Centennial; m-A: Shade Netting-Antje; m-B: Shade Netting-Babylon; m-BM: Shade Netting-Boy Mick; m-CC: Shade Netting-Canby Centennial.

The thinnest DTF was shown by the inflorescences of the Babylon variety produced in the shade netting environment (4.54 mm). In contrast, the Canby Centennial variety grown in open field had 40 % thicker stems (Figure 5). Studies on flowering stems of *Freesia × hybrida* (Miranda-Villagómez *et al*., 2014) showed similar values to those in this experiment, indicating that even when the stems are hollow, their thickness is superior to other species, promoting greater support to the flower. On the other hand, the flower stalk of sunflower (*Helianthus annuus*) is a relevant parameter since it serves as a food reservoir for the formation of future organs (Carrillo-Criollo and Yumbla-Orbes, 2022).

CONCLUSIONS

Dahlia cultivation in northeastern Mexico produces better results when using a shade netting production environment since it promotes plant productive development, flowering in less time, and flowers with longer stems. However, the open field and greenhouse environments favor a higher production of tuberous roots and a higher fresh flower weight (in the BM variety), respectively. It is worth mentioning that this information represents an important turn in Dahlia production due to the economic and social significance it represents, in addition to the little information available on the same crop in southeastern Coahuila de Zaragoza, Mexico.

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