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Effect of open field crop management on the floral development of gardenia (*Gardenia jasminoides* Ellis)

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ABSTRACT

Objective: To analyze the effect of open field crop management on gardenia flower development.

Design/Methodology/Approach: A randomized block design was used with a factorial arrangement of two factors conformed by field management (four levels: M1=old plant in natural shade; M2 and M3=old plant in full sun and M4=mature plant in full sun) and the floral stages (eight levels: tender, lemony, striped, white, star, caracolled, open and yellow). Eight morphological descriptors were measured: flower weight, perianth length, perianth diameter, calyx length, calyx diameter, corolla width, number of sepals, and length of sepals.

Results: The analysis of variance allowed to identify highly significant differences ($P \leq 0.05$) in the variables weight, perianth length, calyx length and diameter, number of sepals, and length of sepals for the management-stage interaction. In handling M1 and M2, the caracolled flower reached a weight greater than 2.94 ± 0.08 g with a perianth diameter of 60.66 ± 1.23 mm. The open flower presented the largest corolla width of 37.39 ± 1.07 mm. The white button cataloged from the commercial point of view in the category of buttons, according to weight, perianth diameter, and width of the corolla, presented flower characteristics, thus classifying the floral development in three stages for buttons and five for flowers.

Findings/Conclusions: Crop management with natural shade increases the size of the flowers in terms of weight, perianth diameter, and corolla width. These descriptors can be used as quality criteria when selecting the flower. In addition, the open and caracolled flower can contain the largest reserve of volatile components and, as they are not commercial qualities, it could be used in the extraction of compounds to produce cosmetics.

Keywords: Flower stages, *Gardenia jasminoides* Ellis, morphological descriptors, quality criteria.

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INTRODUCTION

Gardenia jasminoides Ellis (Rubiaceae) is native to central China and has a cultivation history of over 2,000 years. It grows in many temperate regions, so it is commonly found in several regions of the world and stands out for its white and fragrant flowers (Mei *et al.*,

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2015, Zhao *et al.*, 2017). In the last decade, gardenia cultivation has been identified as an alternative for the economic development of municipalities in the central zone of the state of Veracruz, Mexico. In this region, the gardenia production area is comprised by the municipalities of Atzacan, Ixtaczoquitlán, Ixhuatlancillo, Mariano Escobedo, La Perla, Rafael Delgado and Fortín. In 2016, producers reported a production area for ornamentals of 103.32 ha, of which 48.9 ha are destined for gardenia cultivation, with the municipality of Atzacan being the main producer (Rodríguez-Deméneghi *et al.*, 2016).

In the state, there are only open field plantations with rudimentary management, without defined crop technology. Most of the plantations are less than ten years old and 64% of the producers consider gardenia cultivation to be the main primary economic activity. However, the problems reported by producers of this species are varied, such as the difficulty for its commercialization, obtaining good product quality, phytosanitary aspects, and agronomic practices (Murguía *et al.*, 2008, Alduci-Martínez *et al.*, 2016, Rodríguez-Deméneghi *et al.*, 2016).

For the commercialization of gardenia, growers classify the stages of the flower depending on the color and its amplitude according to the following criteria: a) tender: when the bud is small and green, b) lemony: when the bud is green, but lemon tones are observed, c) striped: when the flower bud begins to open, the edges have green petals and the rest is white, d) white: for the flower bud that is not yet fully open, e) star: when the flower has from one to six open petals, f) caracolled: it is the flower with all the petals of the first circular line, but keeping the center closed, g) open: is considered a full white opening of the flower in good condition, and h) yellow: when the flower starts to yellow, indicating the beginning of the end of the flower's life span (Murguía *et al.*, 2008, Alduci-Martínez *et al.*, 2016, Rodríguez-Deméneghi *et al.*, 2016, Çelikel *et al.*, 2020).

Growers mainly market the gardenia flower in lemony (slightly green), striped and white buds, in addition to the star flower, leaving the caracolled, open and yellow gardenia unused. This represents approximately 56% of the crop's production that has no commercial utility, which needs to be resolved. On the other hand, it has not been analyzed how floral development is influenced according to crop management. There are also no reports of morphometric descriptors that allow a description of the floral development of gardenia in the central zone of the state of Veracruz and allow growers to establish other quality criteria to classify flowers. The effect of open field crop management on the floral development of *Gardenia jasminoides* Ellis was analyzed, so that strategies for the commercial utilization of the flower can be improved in the short term.

MATERIALS Y METHODS

Study Area

The municipality of Fortín, Veracruz, Mexico, is located at an altitude of 1,000 masl and borders to the north with Chocamán and Tomatlán; to the northeast with Ixhuatlán del Café; to the east with Córdoba; to the west with Naranjal, Ixtaczoquitlán, Atzacan and La Perla. It has a regular temperate-humid climate, with an average temperature of 18.8 °C and an average annual rainfall of 1,832.7 mm. The plantation is located on the road to Villa Unión, Paso Timón, Fortín, Veracruz (18° 52' 53.3" N, 96° 59' 19.3" W). The producer fertilizes the plantation twice a year, applying approximately 20 g of urea (46N-0-0), there is no irrigation system, and old plants between 30 and 40 years old, mature plants between 10 and 20 years old and young plants less than 10 years old can be found. The plot had approximately 600 gardenia plants distributed over an area of 3,500 m^2, which is divided into two management units that are separated by a pasture unit and two management units. In unit I, management 1 (M1) corresponding to old plants in shade and management 2 (M2) corresponding to old plants in full sun were carried out; in unit II, management 3 (M3) corresponding to old plants in full sun and management 4 (M4) corresponding to mature plants in full sun were carried out. A total of 56 gardenia plants were randomly selected in the months of May to July 2019 and flowers from old plants aged between 30 to 40 years and mature plants aged between ten to 20 years were used.

Flower samples

Gardenia (*G. jasminoides*) flowers were collected from 14 plants chosen randomly for the four management types per plot in the morning (9 A.M.), for the floral stages: tender, lemony, striped, white, star, caracolled, open and yellow. All flowers from the sampled plants were kept in polyethylene bags with double seal and transferred to the School of Biological and Agricultural Sciences of the Universidad Veracruzana, where the characterization was carried out.

Morphometric descriptors

Eight morphometric descriptors were evaluated: weight, perianth length, perianth diameter, corolla width, calyx length, calyx diameter, number of sepals and length of sepals. Weight was determined with a Rhino BAPRE-3 electronic balance of 0.02 g precision (Rhino Maquinaria, Estado de México, Mexico); perianth, calyx and sepal length, perianth and calyx diameter, and corolla width were measured with a Steren HER-411 digital Vernier caliper with 0.02 mm precision (Electrónica Steren, Mexico City, Mexico) as described by Salinas and Suarez (2002).

Statistical analysis

A randomized block design was used with a two-factor factorial arrangement consisting of factor A: plot management (four levels) and factor B: flowering stages (eight levels), which resulted in 32 treatments with 14 replicates, the data were reported as mean ± standard error of the mean (SEM). To establish significant differences in the variation of morphological descriptors for the eight floral stages, an analysis of variance (ANOVA) followed by Tukey's means comparison ($P \leq 0.05$) was performed using SPSS for Windows, Version 25 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, version 25.0. Armonk, NY: IBM Corp.).

A principal component analysis (PCA) and cluster analysis was performed with the means of each variable per collection, including the 448 collections divided into four managements and the eight floral stages, which were normalized and transformed with fourth root. The estimation of principal components was done with the Euclidean distance similarity matrix, so that the variables involved in the analysis would have the same importance. From the similarity matrix, a cluster analysis was performed to group the eight floral stages of gardenia, in both cases using Primer 7 for-Windows, version 7.0.13 (PRIMER-e, 2017, Plymouth Routines in Multivariate Ecology Research, version 7.0.13, Albany, Auckland, New Zealand).

RESULTS AND DISCUSSION

The morphometric variables evaluated showed very little variation in gardenia floral development, with similarities in weight averaging 2.51 g, perianth length of 55.41 mm, calyx diameter of 5.81 mm, and between four and eight sepals with a length of 16.79 mm (Table 1).

The analysis of variance allowed identifying significant differences ($P \leq 0.05$) in the variables weight, perianth length, calyx length and diameter, number of sepals and length of sepals (Table 1) for the management-stage interaction. Likewise, the number of sepals was highly significant for plot management and for the floral stages.

The highest coefficients of variation (19.86 to 26.01%) were obtained for perianth diameter, weight, sepal length and corolla width, which indicate a high variability in the floral development of gardenia according to the management carried out in the plot under study.

The floral development of gardenia can be classified into floral stages according to the color of the bud or flower (Murguía *et al.*, 2008, Alduci-Martínez *et al.*, 2016) in eight stages and taking into account the floral opening in four stages (Watanabe *et al.*, 1993); however, recently Çelikel *et al.* (2020) divide it into twelve floral stages according to the stages of buds, floral opening and senescence.

Authors such as Watanabe *et al.* (1993) described the floral development of gardenia in protected cultivation taking into account the weight, perianth diameter and corolla width, finding that the flower presents the highest values for these variables just after opening, which coincides with the results obtained in this study, where the caracolled flower presented the highest weight and perianth diameter and the open flower showed the highest corolla width. When comparing the results obtained by these authors, it was observed that these three morphometric variables are higher in protected conditions, because temperature, light intensity, fertilization and other agronomic variables are controlled, factors that cannot be controlled in a rainfed crop.

Likewise, by treating these floral stages with crude enzymes, these authors identified the dominant precursors in the volatile components responsible for the fragrance of gardenia, of which they highlighted (Z)-3-hexenol, linalool, borneol, 1-phenylethanol and 2-phenylethanol. On the other hand, Hattori *et al.* (1978) reported that extracts of mature gardenia flowers (open flowers) presented about 130 volatile components and among these constituents, they mentioned jasmine lactone, cis-3-hexenol, cis-3-hexenol esters, cis-3-hexenoic acid and tiglic acid. For this reason, the caracolled and open flower should contain the largest reserve of water and volatile components responsible for the aroma of gardenia in rainfed conditions and since these are not commercial qualities in the state of Veracruz, they can be used in the extraction of these volatile components for the production of cosmetics as an alternative use.

Table 1. Morphometric descriptors of gardenia floral development in the central region of the state of Veracruz.

Stage	Weight (g)	Lperianth (mm)	Dperianth (mm)	Acorolla (mm)	Lcalyx (mm)	Dcalyx (mm)	Sepals	Lsepals (mm)
Tender	2.03 ± 0.07^{d}	50.56 ± 1.45^{d}	12.02 ± 0.16^{d}	3.84 ± 0.13^{f}	23.47 ± 0.77^{c}	6.54 ± 0.15^{a}	6.18 ± 0.07^{a}	17.70 ± 0.33^{a}
Lemony	2.27 ± 0.07^{cd}	57.61 ± 1.32^{ab}	13.43 ± 0.20^{d}	5.46 ± 0.21^{f}	29.24 ± 0.88^{b}	5.80 ± 0.17^{b}	6.20 ± 0.06^{a}	17.74 ± 0.89^{a}
Striped	2.46 ± 0.06^{bc}	62.44 ± 1.12^{a}	15.91 ± 0.32^{d}	8.70 ± 0.44^{e}	32.65 ± 0.88^{a}	5.69 ± 0.15^{b}	6.05 ± 0.07^{a}	17.50 ± 0.44^{a}
White	2.56 ± 0.07^{bc}	58.96 ± 1.25^{ab}	24.36 ± 0.58^{c}	19.85 ± 0.72^{d}	32.28 ± 0.80^{ab}	5.67 ± 0.14^{b}	6.05 ± 0.05^{a}	16.42 ± 0.47^{a}
Star	2.41 ± 0.08^{b}	54.58 ± 1.03^{bcd}	46.42 ± 1.53^{b}	24.89 ± 0.73^{c}	30.68 ± 0.72^{ab}	5.47 ± 0.12^{b}	6.05 ± 0.06^{a}	15.76 ± 0.41^{a}
Caracoled	2.94 ± 0.08^{a}	56.77 ± 1.10^{bc}	60.66 ± 1.23^{a}	28.18 ± 0.85^{b}	32.96 ± 0.73^{a}	5.86 ± 0.16^{b}	6.04 ± 0.06^{a}	17.32 ± 0.42^{a}
Open	2.73 ± 0.08^{ab}	52.24 ± 0.93^{dc}	58.54 ± 0.99^{a}	37.39 ± 1.07^{a}	30.49 ± 0.61^{ab}	5.72 ± 0.14^{b}	6.14 ± 0.05^{a}	16.12 ± 0.37^{a}
Yellow	2.68 ± 0.10^{ab}	50.14 ± 1.20^{d}	57.95 ± 1.68^{a}	35.14 ± 1.06^{a}	30.86 ± 0.67^{ab}	6.07 ± 0.14^{ab}	6.09 ± 0.05^{a}	15.78 ± 0.41^{a}
Mean	2.51	55.41	36.16	20.43	30.33	5.85	6.10	16.79
CV (%)	21.17	15.34	19.86	26.01	18.15	18.07	7.45	21.52
Management	0.000	0.000	0.000	0.027	0.000	0.000	0.346	0.000
Stage	0.000	0.000	0.000	0.000	0.000	0.000	0.372	0.003
Management*Stage	0.134	0.052	0.005	0.006	0.019	0.274	0.090	0.330

Mean ± standard error. Means with different letters in a column are statistically different (Tukey; $P\leq0.05$). Lperianth, perianth length in mm; Dperianth, perianth diameter in mm; Acorolla, corolla amplitude in mm; Lcalyx, calyx length in mm; Dcalyx, calyx diameter in mm; and Lsepals, sepal length in mm.

On the other hand, the following figures show the effect of plot management on the floral development of gardenia flowers. Figure 1 shows that the perianth diameter increases as the gardenia flower develops, reaching maximum values in the caracolled flower and decreasing towards the yellow flower. A difference can also be seen between plot management, reaching the highest values for this variable when management is in full sun with old planting (M2) for the stages of caracolled, open and yellow flowers; this may be due to the fact that the soil is enriched by the natural amendment of the falling leaves of the shade trees, conserving moisture both in the soil and in the plants. With respect to the tender, lemony and striped buds, it can be seen that the values of perianth diameter did not show many differences between the different management methods used in the plot. However, a considerable increase was found when passing from striped to white bud, probably due to the development of the internal organs of the flower.

Figure 2 shows that the increase in weight is variable in both buds and flowers, and this may be due to the fact that in the study area temperatures reached up to 36 °C and the

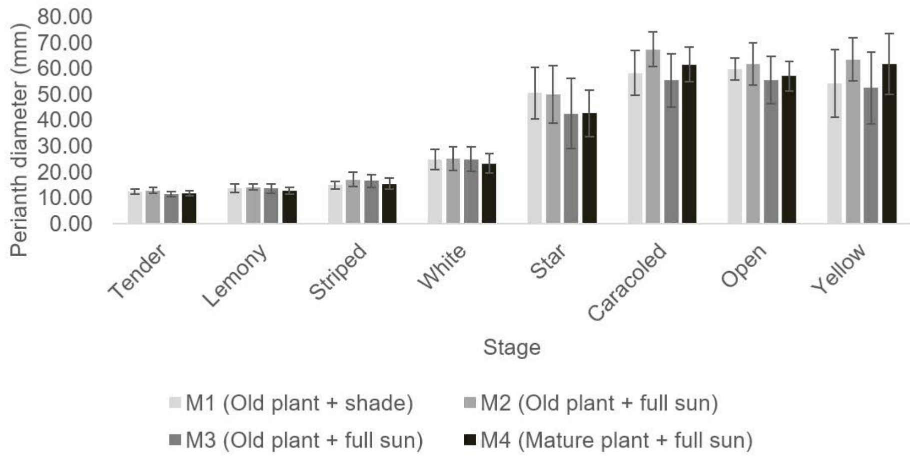

Figure 1. Perianth diameter (mm) of gardenia flower stages with respect to plot management.

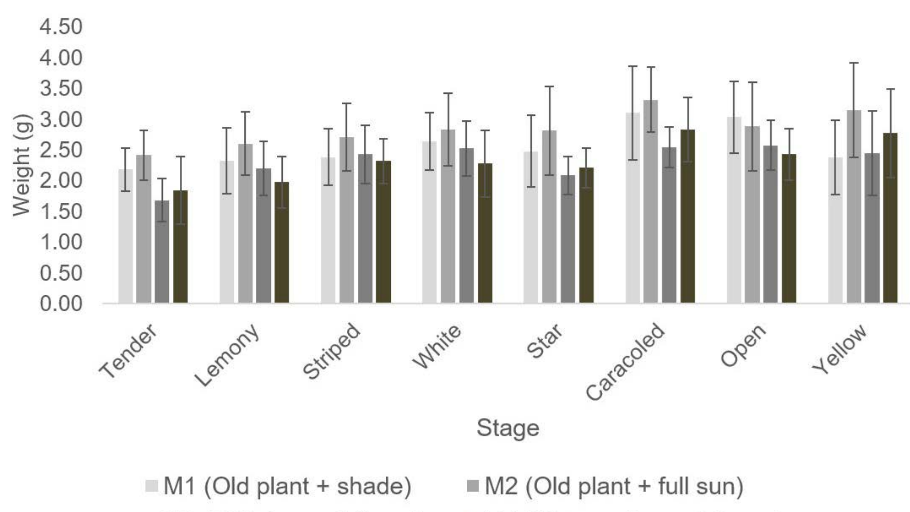

Figure 2. Weight (g) of gardenia flower stages with respect to plot management.

optimum temperatures in which gardenia develops and flowers are between 20 and 28 °C (Murguía, 2007); there was also relative humidity of 70%, subjecting the plants to water stress. However, it can be observed that the maximum weight is reached in the caracolled flower for the management with old plants in full sun (M2), followed by the management with old plants in shade (M1), due to the fall of the leaves of the shade trees that help to retain moisture in the plants. On the other hand, the weight slightly decreases in the open and yellow flower, because a greater loss of water and volatile components can happen due to the high temperatures recorded in the area.

Figure 3 shows that, like perianth diameter, corolla width increases as the flower develops, and reaches maximum values in the open and caracoled shaped flower. In the management with shade and old plant (M1), the best results were obtained in terms of corolla width and perianth diameter. This is important, because these floral stages, not being commercial qualities of high value, can be used for the extraction of essential oil, thus giving an alternative of added value to the crop. In addition, these two morphometric descriptors can be used as a quality parameter in the commercialization of gardenia flowers, in addition to the one used by the producers based only on the color of the flower and the buds.

The management of rainfed crops in the area studied greatly influences the floral development of gardenia, noting that in a crop provided with natural shade, the soil is enriched by the fall of the leaves of the trees, conserving moisture and providing nutrients to the plants. This benefits the development of buds and flowers, while in full sun plants are subjected to constant water stress, since there is no irrigation system, which causes the development of buds and flowers to be slower, even when the plants are mature.

The principal component analysis (PCA) showed that the first two components explain 98.9% of the total morphological variability (Table 2). PC1 accounted for 96.3% of the total variation, and the variables of greatest contribution were perianth diameter and corolla

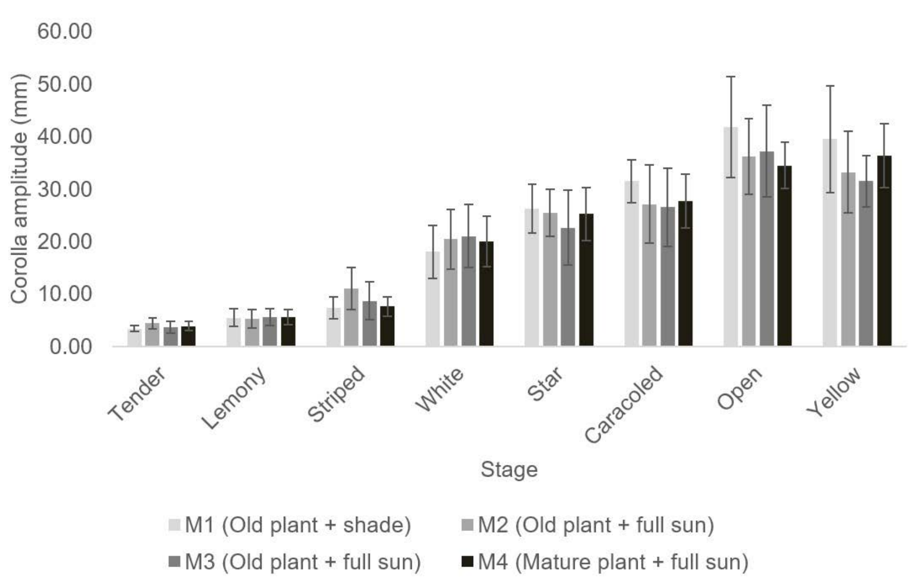

Figure 3. Corolla width (mm) of gardenia flower stages with respect to plot management.

Table 2. Vectors and eigenvalues from the principal component analysis and descriptive value of the total variance for floral development of gardenia.

Variable	PC1	PC2
Weight (g)	0.053	−0.094
Perianth length (mm)	−0.027	−0.391
Perianth diameter (mm)	0.694	0.586
Corolla amplitude (mm)	0.713	−0.537
Calyx length (mm)	0.061	−0.429
Calyx diameter (mm)	−0.014	0.142
Sepals	−0.004	0.018
Sepals length (mm)	−0.034	0.041
Eigenvalues	0.339	0.009
Explained variance (%)	96.3	2.6
Accumulated variance (%)	96.3	98.9

width. Corolla width describes the open flower, while perianth diameter describes the star, caracolled and yellow flower (Figure 4).

PC2 explained 2.6 % of the total variation in which the variables perianth diameter, corolla width and calyx length contributed positively to this component. Calyx length describes the white button (Figure 4). For both components the most important morphometric variables were perianth diameter and corolla width.

Figure 5 shows that the floral development of gardenia is separated into two groups corresponding to buds and flowers, showing that the white bud really presents more flower characteristics, because it increases the perianth diameter and corolla width considerably with respect to the striped bud, probably due to the development of the internal floral organs.

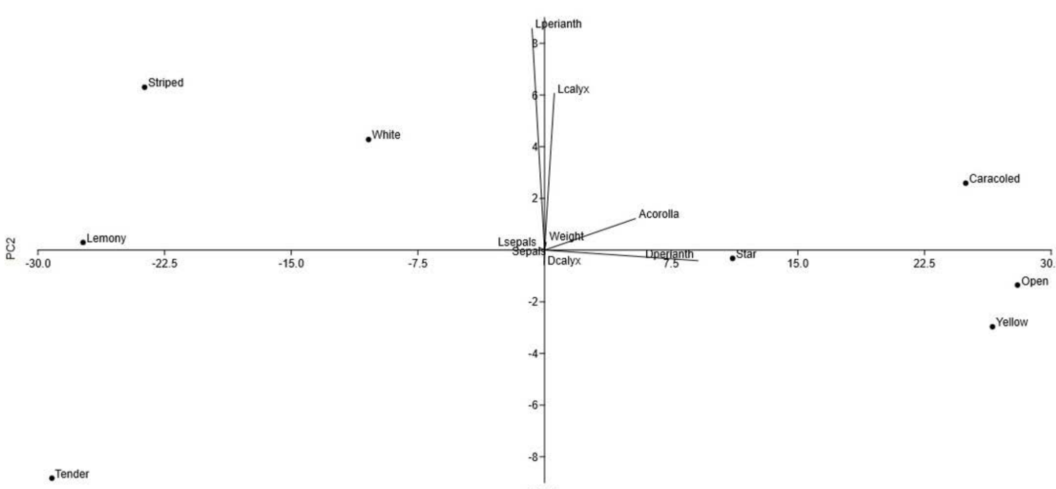

Figure 4. Morphological descriptors of gardenia flower development in rainfed crop.

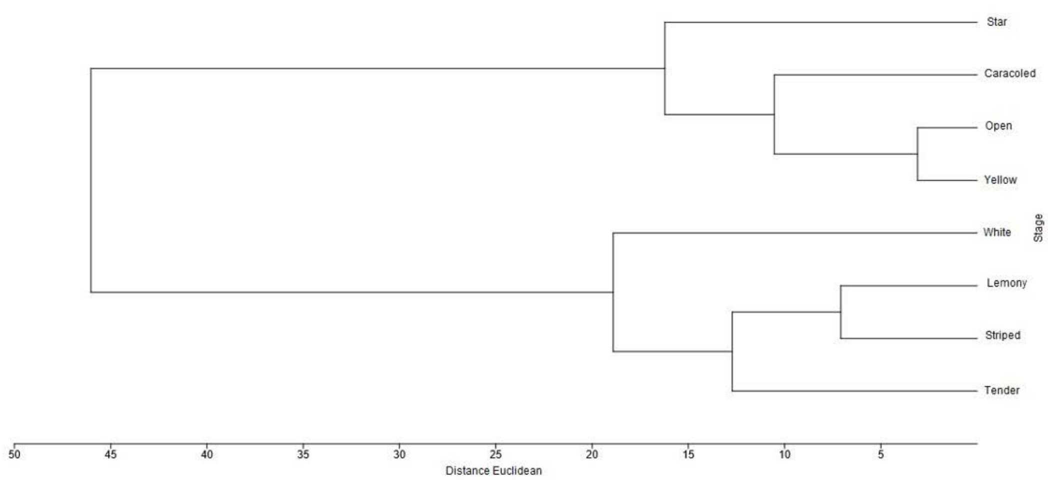

Figure 5. Dendogram of gardenia floral development behavior in rainfed crop.

It was also found that in the buds there is greater similarity between the lemony and striped buds, since the changes that occur between them are minimal with respect to weight, length and diameter of perianth and calyx, and the number of sepals and their length, so that greater importance can be given to the change in color for their classification and selection as established by Murguía *et al.* (2008) and Alduci-Martínez *et al.* (2016). In the flowers, there is a greater similarity between the open and yellow flower, not showing much difference with respect to weight, perianth diameter, corolla width and calyx length. This may be due to factors such as plot management, atypical weather conditions present in the study period, age of the plants and also the beginning of the senescence stage of the flower (Çelikel *et al.*, 2020). Taking into account each of these points, the classification of flower stages for the state of Veracruz proposes three stages for buds (tender, lemony and striped) and five stages for flowers (white, star, caracolled, open and yellow) similar to that established by Çelikel *et al.* (2020).

CONCLUSIONS

The floral development of gardenia in the state of Veracruz showed high morphological variability, which may be related to agronomic, climatic and plant age factors. The descriptors for weight, perianth diameter and corolla width can reach higher values in a plot management where plants are under shade; these descriptors can also be included by growers as quality criteria for the management, selection and marketing of gardenia flowers. The white bud, which is commercially catalogued within the category of buds, according to weight, perianth diameter and corolla width, presented flower characteristics, which allows classifying the floral development in three stages for buds and five for flowers. The largest reserve of water and volatile components responsible for the aroma of gardenia can be found in the caracolled shaped and open flower, since these reach the highest weight, perianth diameter and corolla width, and since they are not commercial qualities they could be used sustainably through the extraction of essential oil as an alternative to add value to the crop.

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