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Production and quality of zinnia under different growing seasons and irrigation levels

Produção e qualidade de zínia em diferentes épocas de cultivo e níveis de irrigação

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ABSTRACT

Zinnia (*Zinnia elegans* Jacq.) is a fast-growing and easy to cultivate plant that has flowers of different colors. This species has become an option to be introduced commercially in many countries as cut flower and its floral quality is influenced by different cultivation techniques. We evaluated the production and the quality of floral stems of zinnia (*cv*. Red California Giant) in response to growing seasons and irrigation levels. In a greenhouse located in Rio de Janeiro (Brazil), zinnia plants were grown in two cycles (autumn-winter and winter-spring) in pots with water replacement corresponding to 46, 64, 75 and 100% of their water requirement. Based on the stem length and diameter and on the flower diameter, there was variation in the quality of the stems produced in the growing seasons evaluated. All stems from the autumn-winter cycle were classified as A1 (high quality), while almost 9% of the stems from the winter-spring cycle were classified as A2 (medium quality). There was a linear growth trend in the production and quality of zinnia stems with the increase of the irrigation level in most cases, as well as significant effect of the growing seasons, with the best results of number of stems, fresh weight, length and diameter of the stem and flower diameter found in the autumn-winter cycle. The weather conditions of this cycle favor the production and quality of zinnia floral stems, and the replacement of 100% of the specie's water requirement is recommended in both cultivation cycles.

Index terms: Cut flower; water deficit; classification standard.

RESUMO

A zínia (*Zinnia elegans* Jacq.) é uma planta de rápido crescimento e fácil cultivo que apresenta flores de variadas colorações. Essa espécie tem se tornado uma opção a ser introduzida comercialmente em vários países como flor de corte e sua qualidade floral é influenciada por diferentes técnicas de cultivo. Neste trabalho, nós avaliamos a produção e a qualidade de hastes florais de zínia (*cv*. Gigante da Califórnia Vermelha) em resposta a épocas de cultivo e níveis de irrigação. Em casa de vegetação localizada no Rio de Janeiro (Brasil), plantas de zínia foram cultivadas em dois ciclos (outono-inverno e inverno-primavera) em vasos com reposição de água correspondente a 46, 64, 75 e 100% da sua necessidade hídrica. Com base no comprimento e diâmetro de hastes e no diâmetro de flores, houve variação na qualidade das hastes florais produzidas nas épocas de cultivo avaliadas. Todas as hastes do ciclo outono-inverno foram classificadas como A1 (alta qualidade), enquanto, aproximadamente, 9% das hastes do ciclo inverno-primavera foram classificadas como A2 (média qualidade). Houve tendência de crescimento linear na produção e qualidade das hastes florais de zínia com o aumento do nível de irrigação na maioria dos casos, assim como efeito significativo dos ciclos, sendo os melhores resultados de número de hastes, peso fresco, comprimento e diâmetro de haste e diâmetro de flor encontrados no ciclo outono-inverno. As condições meteorológicas deste ciclo favorecem a produção e a qualidade de hastes florais de zínia, e a reposição de 100% da necessidade hídrica da espécie é recomendada em ambos ciclos de cultivo.

Termos para indexação: Flor de corte; déficit hídrico; padrão de classificação.

INTRODUCTION

The floriculture sector is very dynamic and the introduction of new species attracts consumers and provides new options for the producers (Beckmann-Cavalcante et al., 2017). In this context, zinnia (*Zinnia elegans* Jacq.), an annual plant of the Asteraceae family, stands out, because it has flowers with diversified colors and petal shapes (Elhindi et al., 2016) and it can be cultivated throughout the year (Stimart; Boyle; Terry-Lewandowski, 1987), in regions of mild or tropical temperature (Lorenzi, 2015). Besides that, it can be grown in garden compositions and it is proposed to be commercialized as cut flower and potted plant (Pinto et al., 2005; Szopińska; Politycka, 2016), which makes it as a species with multiple possibilities of uses. Zinnia holds a prestigious position in the flower cut industry for its versatility, numerous colors and low maintenance in the field (Iqbal et al., 2012). Besides that, the longevity of its flowers, which can reach 21 days, is an important characteristic for the cut flower market (Martins et al., 2021).

In general, plant species respond to the amount of water applied, but for ornamental plants, including cut flowers, not only the quantity of stems produced, but also the final quality is fundamental for the commercialization of the product. They have higher market values according to the aesthetic aspect such as the stem and flower sizes with the least possible number of visual defects (Cooperativa Veiling Holambra, 2021; Wu et al., 2021). According to Farias and Saad (2005), deficient irrigations cause a decrease in production and excessive irrigations affect the quality of the flowers. To make this process more efficient, the use of localized irrigation in their cultivation has increased (Baloch; Chacha; Panhwar, 2010). However, the association of a localized method with an automated irrigation management is advantageous in comparison to traditional systems, as it does not require operators and avoids excessive water applications (Santos et al., 2015). The automatic irrigation controller (AIC), developed by Medici et al. (2010), is a low-cost alternative that has been successfully used in crops grown in the field or under greenhouse conditions (Batista et al., 2013; Gomes et al., 2014; Oliveira et al., 2018). In addition to activating the irrigation system, the AIC provides the amount of water in response to the crop's water requirement, contributing to the optimization of water use.

The water requirement and the influence of different irrigation levels are known only for species traditionally cultivated as cut flower such as rose (Cavalcante Júnior et al., 2013), gerbera (Piroli et al., 2019), alstroemeria (Girardi et al., 2017) and chrysanthemum (Viana et al., 2004). The effect of irrigation levels on the production and quality of floral stems of zinnia has been evaluated in countries with arid or semi-arid climate (El-Deen et al., 2018; Heidari et al., 2016), but this is not found under other climatic conditions, which reinforces the need for studies on this ornamental crop that has a diversified and still little explored market potential. Besides that, it is known that the sowing time influences the duration of the cycle of zinnia (Gonçalves; Pedro Júnior; Castro, 2008).

Considering that floral stem quality is decisive for the final value of the product, the evaluation of different irrigation levels and growing seasons becomes essential for the producers who wish to introduce the cultivation of zinnia in their properties. Nonetheless, there is not a defined quality criterion for zinnia, therefore it is necessary to establish a specific standard to assess the quality of the floral stems produced.

Given the considerations above, the objective of the work was to evaluate the production and the quality of floral stems of zinnia (*Zinnia elegans* Jacq.) obtained from plants grown in a greenhouse in response to growing seasons and irrigation levels.

MATERIAL AND METHODS

Two cultivation cycles were conducted in a greenhouse (latitude 22º 45'48" S; longitude 43º 41' 19" W; altitude of 33.0 m) located in the state of Rio de Janeiro (southeast of Brazil). The greenhouse was 35.0 m long and 8.0 m wide, it had 2.5 m of central height and it was built using lumber, involved with a shade screen and covered with 100-micron thick transparent plastic, without any cooling or artificial temperature control system. The autumn-winter cycle (AW) was conducted from March to June and the winter-spring cycle (WS) from July to October of 2019, both without any photoperiodic control.

The meteorological monitoring inside the greenhouse was carried out through the use of a weather station, model WatchDog 2000 Series (Spectrum Technologies Inc., Illinois/USA), by recording data of air temperature and relative humidity (RH).

The cultivation cycles (AW and WS) were conducted with four different irrigation levels (46, 64, 75 and 100% of the species' water requirement), applied by emitters of different discharges, and six replicates. The experiment was carried out with split plots in time, in a randomized block design, with the cycles defined as the subplots and the irrigation levels as the plots. The experimental area of each cycle was divided into 6 blocks, corresponding to each sowing row, and each block was composed of a plot with 3 pots, spaced 0.2 m apart, that received a different volume of irrigation, totalizing 24 experimental plots, with 216 plants in each growing cycle.

The seedlings were obtained from seeds (ISLA Sementes / Brazil) of the cultivar (*cv.*) Red California Giant, sown in 200-cell trays containing organic substrate composed of 83% vermicompost, 15% charcoal and 2% castor bean cake kept inside a greenhouse. At 21 (AW cycle) and 28 (WS cycle) days after sowing (DAS), the seedlings had two to three pairs of leaves, reaching the ideal point of transplanting.

The transplanting, which marked the beginning of the experimental period, was carried out into 8-L pots filled with substrate composed of sandy clay soil and powdered coconut fiber in a 1:1 ratio (v/v). According to Oliveira et al. (2018), in the cultivation of ornamental plants, it is common to use substrates made from agro-industrial wastes, such as coconut fiber, because it reduces the density and it is highly available in the region. The substrate had bulk density of 0.83 g cm^{-3} and soil water retention at 10 hPa of 0.590 cm^3 cm^{-3} (Brasil, 2007). Table 1 shows the chemical properties of the substrate.

Three plants were transplanted per pot, spaced 0.15 m apart, in a triangular arrangement. The seedling production period was not considered as part of the experimental period, and the amount of water applied during it was not evaluated.

A drip irrigation system was installed, with 16-mm-diameter polyethylene lines containing spaghetti microtubes (PDAEXT001000018/Plasnova Tubos) with average diameter of 0.8 mm and different lengths, in order to apply the different irrigation levels. One microtube was used per pot and, according to tests carried out before the beginning of each cultivation cycle, the discharges of 1.5, 2.1, 2.5 and 3.3 L h^{-1} were obtained with microtubes of 80, 50, 35 and 20 cm of length, respectively, for an operating pressure of 18 kPa. The discharge of 3.3 L h^{-1} was considered the control treatment, representing 100% of the water requirement of the species, while the others represented percentages of 46, 64 and 75%, respectively. For all treatments, the uniformity distribution coefficients were greater than 95%.

From transplanting to the apical pinching, all the pots in the experiment were irrigated with the highest flow rate in order to favor the establishment of the seedlings. The application of the different irrigation levels started 2 (AW cycle) and 6 (WS cycle) days after transplanting (DAT), with the irrigation management performed by the AIC, which operates in response to soil water tension and is regulated by the level difference between a porous cap, a sensor installed into the substrate, and a pressure switch (Medici et al., 2010). In each cultivation, two sets of controllers were used independently, which were installed in the 100% treatment pots (control). Thus, when the plants of this treatment needed water, the entire system was activated, irrigating the set of pots of the other irrigation levels.

The controller was composed of handmade microcaps, which were buried vertically in the substrate at a depth of approximately 0.1 m. The gap between the microcap and the pressure switch was 0.4 m, which regulated the system's activation for the soil water tension of approximately 4.0 kPa. The system was supplied with water from a 500-L tank installed inside the greenhouse that was pressurized by a 0.37-kW pump. The volumes applied during the cycles were quantified by daily readings of a flow meter installed in the water distribution line.

The apical pinching was carried out keeping only one pair of leaves per seedling, in order to induce the formation of more than one marketable floral stem per plant. The gradual staking of the plants was also performed, starting from the 15th DAT, totalizing 2 lines of plastic strips attached to bamboo stakes that were added according to their growth in height. On the 16th (AW cycle) and on the 23rd DAT (WS cycle), a fertilization was performed with the Peters® 20-20-20 commercial fertilizer, with the application of 30 mL of solution per pot, at the concentration of 1.5 g L^{-1}, as recommended by the manufacturer.

A division of the experimental period into phases was proposed: phase I comprised the period from the transplanting process until the establishment of the seedlings in the pots, when they were at the ideal pinching point, which coincided with the beginning of the application of the different irrigation levels; phase II represented the beginning of the experiment itself, since the different irrigation levels started to be applied in their respective pots until the beginning of floral differentiation, which was the moment in which each plot had 5 visible floral buds; and phase III, from the beginning of floral differentiation to the end of the experimental period, when the plants had begun the process of senescence in the pots. Thus, phases I and II represent the vegetative period of the cycle, while phase III is the production period of the species.

Table 1: Chemical properties of the substrates used in the autumn-winter (AW) and winter-spring (WS) cycles.

Cycle	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	P	pH (H_2O)	EC
	$cmol_c$ dm^{-3}			mg dm^{-3}			μS cm^{-1}
AW	0.10	3.41	1.36	658.68	137.49	5.34	383.00
WS	0.12	3.43	1.41	437.54	126.82	5.38	237.30

EC, electrical conductivity.

The commercial cycle of zinnia was considered the period from sowing to the end of the experimental period. The harvest moment was established when the flower petals were fully open, with the true central flowers beginning to open and when the stems were at least 30 cm long, defined in this study as the minimum marketable length. It is important to note that there are no official standards for the length of floral stems of cut zinnia, and the stem length proposed in this study was based on values commonly used for this species in previous studies (Carlson et al., 2015; Martins et al., 2021).

When the floral stems reached the harvest point, from the 27th DAT (AW cycle) and 37th DAT (WS cycle), the maximum plant height, chlorophyll contents (*a*, *b* and total), maximum number of leaves, number of marketable and non-marketable floral stems, diameter of the marketable flowers, and the length, diameter and fresh weight of the marketable floral stems were evaluated. Plant height and number of leaves were considered the respective maximum values found in those plants that had more than one floral stem harvested. The Chlorophyll Falker Index was obtained using the chlorophyll meter ClorofiLOG (mod. CFL 1030, Falker), in the fully expanded and non-shaded young leaves of all plants. The fresh weight was obtained through the individual weighing of 8 stems, randomly selected in each plot, on an analytical balance with precision of 0.2 g. Floral stem diameter was obtained in its median portion using a digital caliper.

In addition, the leaf area and the total dry weight of the plants were measured, using one plant per pot in the evaluations. Leaf area was determined by a leaf area integrator (mod. Li-Cor 3100) and total dry weight (stem, leaves and flowers) was measured with an analytical balance with precision of 0.01 g, after drying the plants for 48 h in an oven at 65 ºC.

The methodology proposed to classify the floral stems of zinnia was based on the combination among the stem length, stem diameter and flower diameter, taking as a reference the results observed in the stems evaluated and on standards already established of other species of the Asteraceae family (Table 2). The classification was proposed according to the quality of the stems, in which A1 represents high quality and A2, medium quality, and to their length (P_{30}, P_{40} and P_{50}). Minimum stem diameters were determined for each established standard, and these were considered adequate for their satisfactory support.

In order to ascertain the basic assumptions of the analysis of variance (ANOVA), the normality and homogeneity of the residuals were verified using Shapiro-Wilk's and Bartlett's tests, respectively, at 5% probability level of error. As a result, the chlorophyll contents data were transformed into Box-Cox ($\lambda = -2$). When the null hypothesis was rejected during ANOVA, by the use of the F test at 5% probability level of error, regression analysis was carried out using the Student's t test to verify the fit of the linear and quadratic models to the data of biometric parameters, chlorophyll contents and number of flowers, in response to the irrigation levels. The model was chosen considering the one with the lowest level of significance (p-value) and the highest coefficient of determination.

For the proposed classification standards (P_{30}, P_{40} and P_{50}), the Scott-Knott's test was performed at 5% probability level of error, but the percentages of stems classified as A1 and A2 were submitted to the Kruskal-Wallis' non-parametric analysis at 5% probability level of error, because their residuals did not show normal and homogeneous distribution even after data transformation. When significant, the comparative analysis of the medians was performed using Dunn's test (with Bonferrone's correction), at 5% probability level of error. All analyses were performed using the computer programs R (3.6.0) and Sisvar (5.6).

Table 2: Classification standard proposed for the commercialization of zinnia, *cv*. Red California Giant, based on stem length (cm), stem diameter (mm) and flower diameter (cm).

Classification	Standard	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)
A1	P_{30}	30.0 ≤ L ≤ 40.0	≥ 1.0	> 4.0
	P_{40}	40.0 < L ≤ 50.0	≥ 1.5	
	P_{50}	L > 50.0	≥ 2.0	
A2	P_{30}	30.0 < L ≤ 40.0	≥ 1.0	2.5 ≤ D ≤ 4.0
	P_{40}	40.0 < L ≤ 50.0	≥ 1.5	
	P_{50}	L > 50.0	≥ 2.0	
Non-standard stems		< 30 cm	< 1 mm	< 2.5 cm

RESULTS AND DISCUSSION

In the AW cycle, the initial average temperature was higher (29.1 ºC until the 25th day of cultivation) than from the middle to the end of the cycle (26.3 ºC from the 26th day to the end of the experimental period). In these periods, the averages of RH were 59.4 and 62.4%, respectively. In the WS cycle there were greater variations in temperature and RH, but the mean values were similar in the same periods (25.9 and 27.1 ºC; and 57.8 and 62.0%). In this cycle, the RH was lower than 50% in 6 days and higher than 70% in 3 days.

The experimental period started after transplanting the seedlings to the pots and the AW cycle of zinnia, *cv.* "Red California Giant", was 49 days, while the WS cycle lasted 64 days. Adding the seedling production to the experimental period of each cycle in the greenhouse, the average commercial cycle of zinnia obtained in the AW cycle was 70 days, while in the WS cycle, it increased to 92 days.

Throughout the experiments, the irrigation system was activated 18 times in the AW cycle (Figure 1A) and 28 times in the WS cycle (Figure 1B), totalizing, respectively, 13.43 and 12.01 L per pot, in the treatment with 100% of water replacement. The highest volumes of water were applied on April 29th (1.78 L per pot) and May 10th (1.75 L per pot) in the AW cycle, and on September 17th (0.83

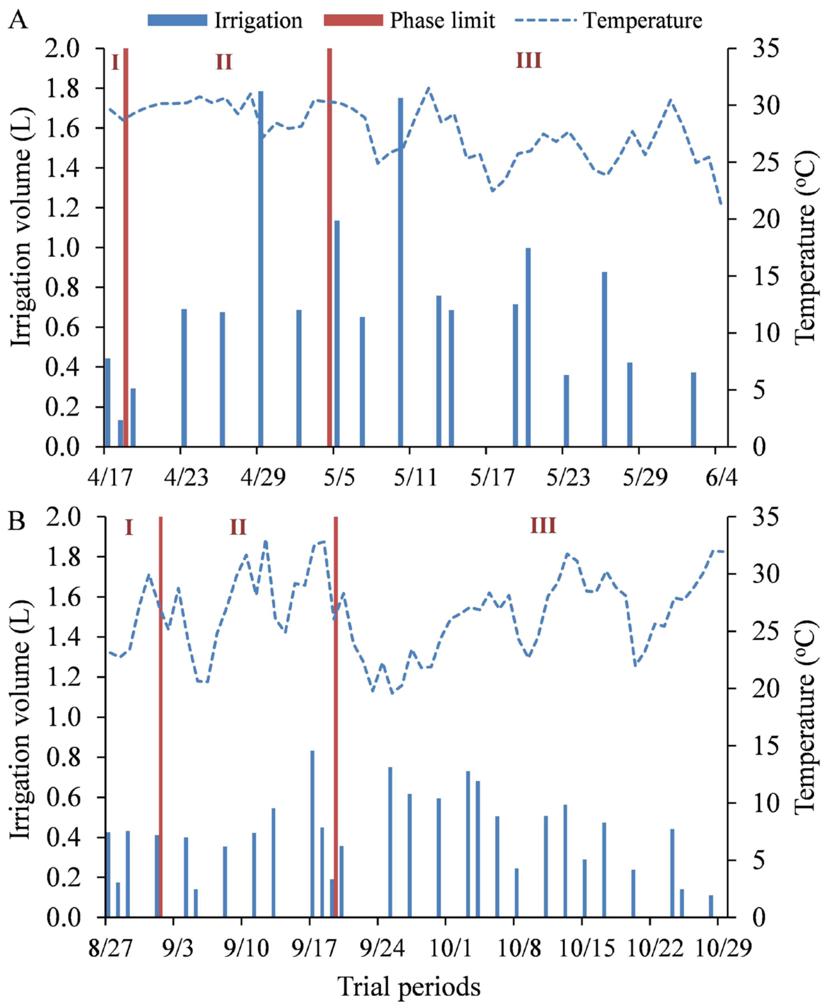

Figure 1: Mean temperature (ºC) and volume applied per irrigation (L) in pots with 100% of the water replacement of zinnia, *cv*. Red California Giant, in the three phases of the autumn-winter (A) and winter-spring (B) cycles. Phase I: transplanting - pinching; phase II: pinching / beginning of the water deficit application - beginning of floral differentiation; phase III: beginning of floral differentiation - beginning of the senescence of plants.

L per pot) and September 25th (0.75 L per pot) in the WS cycle. The final volumes of water applied at each irrigation level during both cultivation cycles ranged from 2.08 to 4.48 L plant^{-1} (Table 3).

When evaluating the period from seedling transplanting until the beginning of the application of the different irrigation levels (Phase I), it can be observed that the winter-spring cycle required 4 days more than the autumn-winter cycle to reach the point of pinching (Figure 1). It probably happened because the average temperature of this phase in the WS cycle (25.6 ºC) was lower than the one of the AW cycle (29.2 ºC), which promoted the slower development of the seedlings. By analyzing the phases in which the different irrigation levels were applied (II and III), it can be seen that they were also longer in the WS cycle (Figure 1). This fact can also be justified by the lower average temperatures found in this cycle, mainly in phase II, with averages of 27.5 ºC and 29.6 ºC, respectively, for the WS and AW cycles, which extended the period for floral initiation, and consequently, increased the crop cycle.

When working with zinnia, *cv*. "Profusion Cherry", Gonçalves, Pedro Júnior and Castro (2008) observed longer cycles when sowing was carried out between May and June (91 to 98 days) when compared to February and March (60-75 days). Although the sowing months were not the same ones adopted in this work, the authors also observed that the decrease in temperature increased the time necessary for floral opening, extending the cycle of the species.

Although the WS cycle was longer compared to the AW cycle (Figure 1), the volume of water applied per plant was lower (Table 3). It can probably be explained by the average air temperature, which was lower in the WS cycle, reducing the atmospheric steam demand and, consequently, the volume of water per irrigation, despite the greater number of activations of the system (Figure 1).

The water requirement tends to increase during the plant growth period, having its peak between the floral differentiation and the floral opening. The first floral stems of the AW cycle were harvested on May 14th, approximately 9 days after the start of phase III (beginning of floral differentiation) and the peak in demand happened in the fourth week of cultivation (Figure 1A), which preceded the harvest. In the WS cycle, this fact was repeated, as the first stems were harvested on October 3rd, approximately 13 days after the beginning of phase III and the peak in demand happened in the fifth week of cultivation (Figure 1B), when the floral opening occurred, preceding the harvest again.

The greatest water requirement occurs close to the harvesting period in the different seasons evaluated, because until the formation of the flowers there is an increase in the translocation of photoassimilates for their development, and leaf area is higher during this phase of production (Girardi et al., 2016), which increases the evapotranspiration rates, promoting a more frequent activation of the irrigation system. After the beginning of harvesting, the water requirement tends to decrease, as the plants reach their mature stage and the removal of the floral stems reduces their leaf area, reducing their transpiration. In rose, Oliveira et al. (2014) also verified that while the plants were producing floral stems, their water consumption was higher, until the moment of harvest, which decreased the water requirement of the system since the potential evapotranspiration of the crop was reduced.

There was a significant effect of the different growing seasons on plant height (Figure 2A), number of leaves (Figure 2B), leaf area (Figure 2C) and total dry weight (Figure 2D), which were respectively 28, 25, 64% and 64% higher in the AW cycle than in the WS cycle. Regarding the irrigation levels, there was a significant effect in both cultivation cycles for plant height and leaf

Table 3: Volume of water (L per plant) applied in zinnia, *cv*. Red California Giant, plants in the autumn-winter and winter-spring cycles.

Irrigation level (%)	Cycle							
	Autumn-Winter				Winter-Spring			
	Phase			Total volume	Phase			Total volume
	I	II	III		I	II	III	
46	0.19	0.63	1.32	2.14	0.48	0.50	1.10	2.08
64	0.19	0.88	1.85	2.92	0.48	0.71	1.54	2.72
75	0.19	1.04	2.20	3.44	0.48	0.84	1.83	3.15
100	0.19	1.38	2.91	4.48	0.48	1.11	2.41	4.00

area, for number of leaves in the WS cycle and for total dry weight in the AW cycle, with a linear growth in response to the increase in the amount of water applied.

One of the factors that can affect the development of zinnia plants among validated seasons is the photoperiod. Zinnia is a short-day plant that blooms only when the night length is longer than the critical length (Runkle et al., 2012). Previous studies have recommended 8 hours of inductive photoperiod for zinnia; in these conditions, zinnia plants have greater growth and flourish earlier (Sawhney; Sawhney, 1976; Wahocho et al., 2016), however, even under natural photoperiod (12 hours), the plants can flourish.

During the experimental period, the natural photoperiod varied from 10 to 11 hours in the AW cycle and from 11 to 12 hours in the WS one. In the region where the experiment was conducted, zinnia has been cultivated throughout the year with ornamental purposes and in organic system productions as an attractive plant (Pêgo; Antunes; Silva, 2019) under natural photoperiod. It is possible that the photoperiodic management can improve the quality of the floral stems and increase the number of zinnia flowers (Gonçalves; Pedro Júnior; Castro, 2008). However, this is one of the first studies on the cultivation of zinnia for cut flower purposes, and future studies can be carried out to evaluate the viability of the photoperiod management in the production and quality of zinnia flowers.

Plant growth is influenced by water availability and growing season. The vegetative development of the species increases as temperature approaches its ideal level (Hatfield; Prueger, 2015), while water limits the plant growth, as it is the most vital factor in physiological reactions (Hazrati et al., 2016). Thus, the reduction observed in the growth parameters of zinnia can be justified by the decrease of water availability in the substrates, which negatively influenced the vegetative development of the plants. In addition, the mild temperatures at the beginning of WS cultivation also reduced plant growth (Figure 2), meaning that the AW cultivation approaches the ideal condition for the growth and development of zinnia.

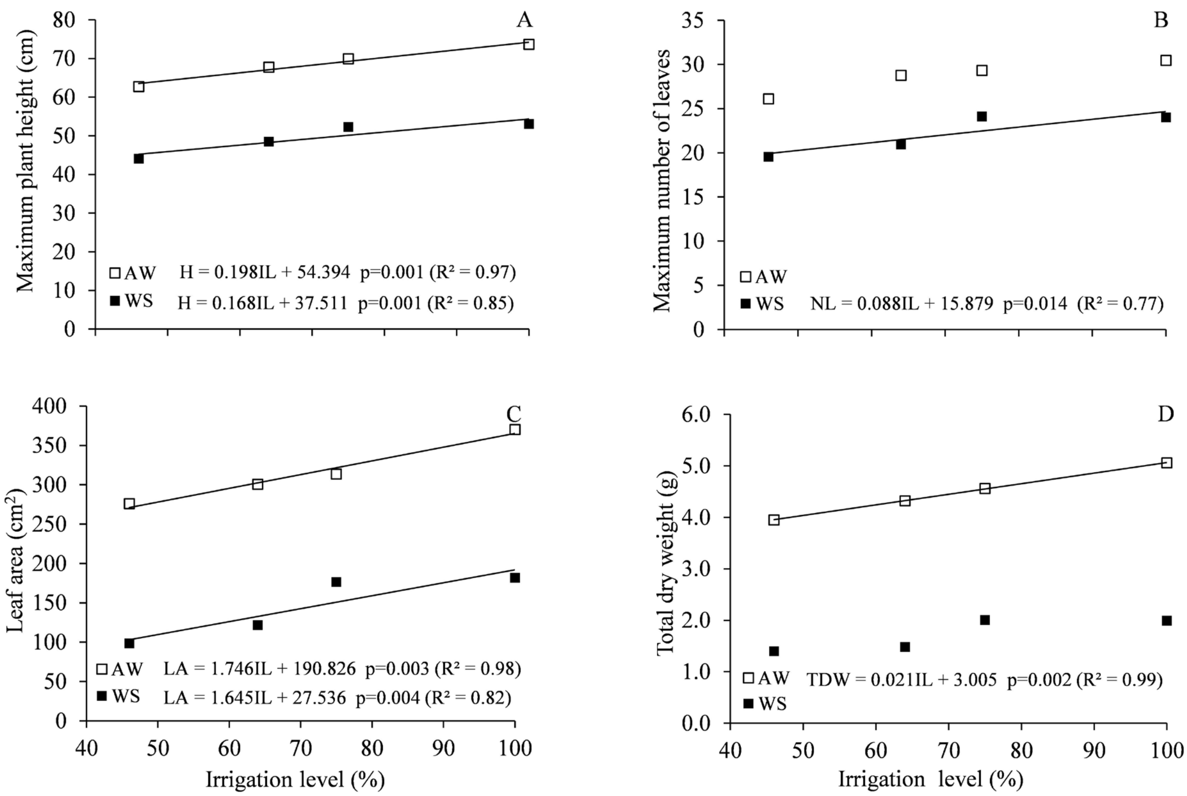

Figure 2: Maximum plant height (cm) (A), maximum number of leaves per plant (B), leaf area per plant (cm^2) (C) and total dry weight (g) (D) of zinnia, cv. Red California Giant, grown under the irrigation levels of 46, 64, 75 and 100% of the crop's water requirement in the autumn-winter and winter-spring cycles.

Taller plants tend to form longer stems, which is essential in the production of cut flowers. Leaf area and number of leaves are also important parameters in the evaluation of plant growth. Under water stress conditions, the leaves tend to expand less than if they were under adequate water conditions (Farias; Saad, 2011), which can influence the final production. Therefore, these parameters work as markers of the effect of water stress on crops and should always be taken into consideration.

The adequate amount of water available to the plants in the substrate is essential for the growth and development of ornamental species grown in pots, being crucial for the production of cut flowers (Girardi et al., 2014). The irrigation level of 46% led to average reductions on the order of 15.7, 16.2 and 32.1% in plant height, number of leaves and leaf area in comparison to the 100% treatment, indicating that the water supply below the requirement of the crop is not recommended for the cultivation of zinnia.

The results found corroborate with those reported by El-Deen et al. (2018), who found a significant reduction in the height of zinnia plants with the increase in water deficit. However, Viana et al. (2004) did not find significant differences among the treatments of 50, 75, 100 and 125% of the Class A pan evaporation for the leaf area of chrysanthemum, *cv*. "Calabria", species of the same family of zinnia. Therefore, the evaluation of the influence of different water availabilities on ornamental species is necessary since it indicates their drought tolerances and their responses under less favorable water conditions.

Plant height, number of flowers, leaf area and branches affect the total dry weight of the plants, which is influenced by the water availability in the substrate and by the weather conditions along the cycle. However, despite the effect of the irrigation levels in the WS cycle for the growth parameters, such as plant height, number of leaves and leaf area (Figure 2), the total shoot dry weight was not influenced by the amount of water applied during this cycle (Figure 2D). When working with zinnia, *cv*. "Dreamland Red", in Iran (average temperature and RH of 29 ºC and 45%, respectively), Heidari et al. (2016) observed a significant effect of the levels of irrigation (40, 70 and 100% of the field capacity of the pot) on the shoot dry weight of the plants, with a linear trend of reduction with the increase of water stress.

The total chlorophyll content indicates the efficiency in the solar radiation absorption by the leaves, influencing the photosynthetic rate (Mahama et al., 2016). The elevation in the chlorophyll contents promotes an increase in light absorption, which consequently increases the transmission of electrons in the photochemical phase of photosynthesis (Rodrigues et al., 2016), which can cause an increase in production. However, there was no significant difference in the chlorophyll contents for the different irrigation levels and cultivation cycles. On average, the values were 30.18, 6.43 and 36.61 CFI (Chlorophyll Falker Index) for the chlorophyll *a*, chlorophyll *b* and total chlorophyll (*a* + *b*) contents, respectively.

The number of marketable floral stems was 32% higher in the AW cycle compared to the WS cycle. There was a significant effect of the irrigation levels only in the AW cycle, with a linear growth trend as more water was applied. There was no significant difference in the number of non-marketable floral stems for the different levels of irrigation and cultivation cycles (Figure 3).

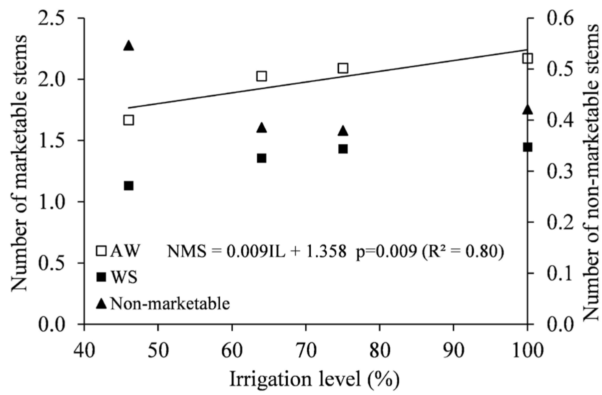

Figure 3: Average number of floral stems per zinnia plant, *cv*. Red California Giant, obtained in cultivation under the irrigation levels of 46, 64, 75 and 100% of the crop's water requirement in the autumn-winter and winter-spring cycles.

Plants respond positively under favorable water conditions in the soil, producing greater amounts of photoassimilates, which implies better growth and greater productivity (Alves et al., 2008). Meanwhile, larger leaf areas benefit the photosynthetic process, because the larger the leaf area, the better the development and the net photosynthesis, which can cause greater productivity of the species (Reis et al., 2013). Although the chlorophyll content did not vary significantly among cycles and irrigation levels, the number of marketable stems varied in the AW cycle (Figure 3), probably due to the larger leaf area found in response to the increase in the amount of water applied and the higher results compared to the WS cycle (Figure 2C).

The lower accumulation of total dry matter and the non-significant effect of the irrigation levels on this parameter in the WS cycle (Figure 2D) promoted inferior results of number of flowers, which did not vary significantly among the levels of water applied in this cycle (Figure 3). However, this result can be considered positive, because it was possible to produce a satisfactory number of stems with lower volumes of water in the WS cycle, since the different volumes did not cause significant effect. Therefore, it was observed that zinnia responded positively in productivity under greater water availabilities in the substrate only under more favorable weather conditions for its growth and development (AW cycle).

In the floriculture sector, not only the number of floral stems is important, but also their quality is essential for the producer, due to the best sales prices. The fresh weight of floral stem (Figure 4A), stem diameter (Figure 4B), stem length (Figure 4C) and flower diameter (Figure 4D) were, respectively, 39, 19, 14 and 15% higher in the AW cycle compared to the WS cycle. There was a linear growth trend with the increase of the irrigation level for stem length in both cultivation cycles, for stem diameter in the WS cycle and for flower diameter in the AW cycle. For the other quality parameters evaluated, there was no significant effect of the different irrigation levels applied.

The weather conditions of the AW cycle were more favorable to the development of zinnia than those of the WS cycle, promoting higher fresh weight, diameter and length of stems, and flowers with larger diameters (Figure 4). Thus, it is understood that, for the better quality of stems, higher means of air temperature during the vegetative growth of zinnia favor the formation of floral buds, allowing the production of flowers with better quality.

There is a direct correlation between the length and the diameter of stems. For cut flowers, firm stems, which provide support for the flower, allow a longer post-harvest life (Piroli et al., 2019). Very thin and long stems tend to break, reducing their commercial value. Therefore, it is necessary to evaluate this correlation and establish a minimum diameter for the commercialization of floral stems. For zinnia, stems of the standards P_{30}, P_{40} and P_{50} must have at least 1.0, 1.5 and 2 mm of diameter to ensure good support during their transport and marketing.

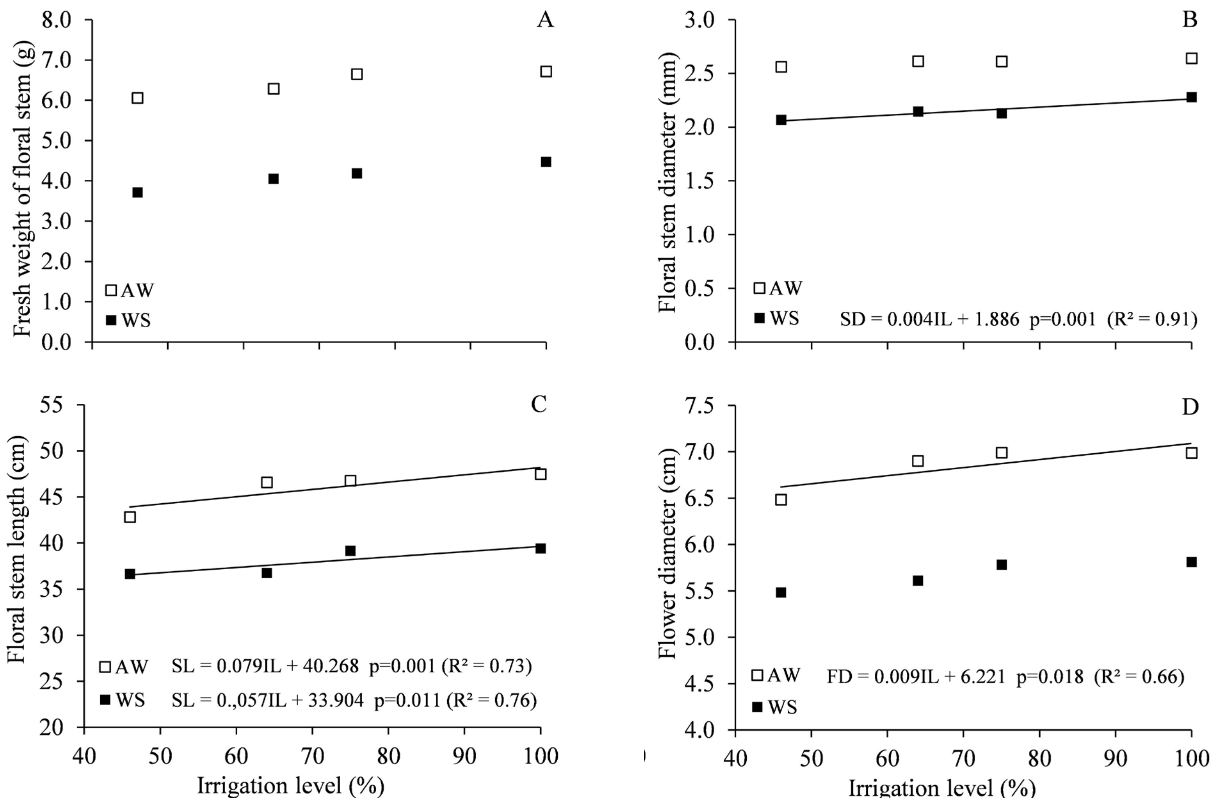

Figure 4: Quality of floral stems of zinnia, *cv*. Red California Giant, obtained from cultivation under the irrigation levels of 46, 64, 75 and 100% of the crop's water requirement in the autumn-winter and winter-spring cycles: fresh weight of floral stem (g) (A), floral stem diameter (mm) (B), floral stem length (cm) (C) and flower diameter (cm) (D).

Water deficit conditions cause stomata to close, which reduces the assimilation of CO_2 by the leaves and causes less production of photoassimilates and plant tissues (Viana et al., 2004). Hence, the lower water availability in the substrate may explain the reduction observed in the quality parameters, mainly of stem length (Figure 4C). Girardi et al. (2017) also observed a reduction in the length of alstroemeria stems under lower water availability.

The flower diameter was influenced by the irrigation levels only in the AW cycle, indicating that flowers with a larger diameter in this growing season are obtained with the replacement of 100% of the water requirement of the plant. However, this fact was not observed in the WS cycle, indicating that even under conditions of water deficit, zinnia is capable to produce flowers with a satisfactory diameter during this time of the year. Heidari et al. (2016) observed that the increase in water deficit promoted a decreasing linear trend in the diameter of "Dreamland Red" zinnia flowers. Similar results to those found in the AW cycle were found in chrysanthemum by Viana et al. (2004), who, despite the polynomial quadratic adjustment in relation to the diameter of flowers, observed better results in the treatment with the replacement of 100% of the Class A pan evaporation.

The average number of stems per plant classified in the different standards varied according to the cycle, with the exception of the irrigation level of 100% in the standard P_{30} and the 75% level in the standard P_{40} (Table 4).

In the AW cycle, all the evaluated stems were classified as A1, and this result was significantly superior to that obtained in the WS cycle (Table 5), since the second one promoted the formation of stems classified as A2.

Table 4: Average numbers of floral stems of zinnia, *cv*. Red California Giant, per plant, classified as standard P_{30}, P_{40} and P_{50} obtained from cultivation under the irrigation levels of 46, 64, 75 and 100% of the crop's water requirement in the autumn-winter and winter-spring cycles.

Irrigation level (%)	P_{30}		P_{40}		P_{50}	
	AW	WS	AW	WS	AW	WS
46	0.59 Ab	0.89 Aa	0.70 Aa	0.19 Bb	0.37 Ba	0.06 Ab
64	0.51 Ab	0.91 Aa	0.76 Aa	0.40 Ab	0.76 Aa	0.04 Ab
75	0.60 Ab	0.86 Aa	0.68 Aa	0.45 Aa	0.82 Aa	0.13 Ab
100	0.64 Aa	0.85 Aa	0.68 Aa	0.43 Ab	0.86 Aa	0.17 Ab
CV (%)	27.31		34.29		55.32	

Averages followed by the same lowercase letter in the columns and capital letter in the rows do not differ by the Scott-Knott's test at 5% probability level.

Table 5: Medians of the percentage values of floral stems classified as A1 and A2 obtained from zinnia plants, *cv*. Red California Giant, grown under the irrigation levels of 46, 64, 75 and 100% of the crop's water requirement in the autumn-winter and winter-spring cycles.

Irrigation level (%)	A1 (%)		A2 (%)	
	AW	WS	AW	WS
46	100.0	90.5*	0.0	9.5*
64	100.0	91.9	0.0	8.1
75	100.0	100.0	0.0	0.0
100	100.0	93.0	0.0	7.0
Average value	100.0 a	93.9 b	0.0 a	6.2 b
$\chi^2_{(3)}$	---	1.6562	---	1.6562
p	---	0.6467	---	0.6467

Medians followed by different lowercase letters in the column differ from each other at 1% probability level by the Kruskal-Wallis' test. *Not significant by Dunn's test (with Bonferroni's correction) at 5% probability level.

The irrigation levels did not promote significant variation regarding the percentage of stems classified as A1 and A2 within each cycle.

The quality characteristics are also influenced by the water availability and the growing season, leading to stems with better or worse classification standards. Under water deficit conditions, there is a reduction in the shoot development, affecting the length and the diameter of the stems, and consequently, their stiffness (Piroli et al., 2019).

The smallest plant growth observed in the WS cycle (Figure 2) promoted a greater number of shorter stems (P_{30}) compared to the AW cycle (Table 4). The negative effect on stem length, due to the reduction of water availability in the substrate (Figure 4C), resulted in a smaller number of stems classified as P_{40} (WS) and P_{50} (AW) at the 46% level (Table 4), in response to the lower growth in height compared to the other levels (Figure 2A).

Although the irrigation levels did not significantly affect the flower diameter in the WS cycle, the weather conditions reduced it (Figure 4D), resulting in stems classified as A2 (Table 5), decreasing their market value. The water supply did not influence the obtaining of more A2 stems; however, the levels of 46 and 100% led to a higher average percentage of stems of this classification, which can be explained by the lower water availability at the level of 46%, which influences the decrease of size of the flowers, and the higher flower production observed at the level of 100% (Figure 3), which increases the competition for light and water, causing the production of flowers of smaller sizes.

In gerbera (*cv.* Caribá), of the same family as zinnia, Piroli et al. (2019) verified that all the irrigation levels evaluated produced flowers with marketable diameter, all of them being classified as A2 (stems from 30 to 45 cm in length). However, in zinnia, the obtaining of floral stems of better quality, with greater length (Standards P_{40} and P_{50}) and flower diameter (classification A1), was possible even under less adequate meteorological conditions for its growth and under more pronounced water deficits. Therefore, it can be inferred that zinnia is more tolerant to lower water availability conditions than other species of the Asteraceae family.

Despite the relevant importance of zinnia in the world market, few studies on the management of this crop have been carried out. This work shows new and important contributions to the production of zinnia and it gives support to understand the effects of the floral quality of plants grown under water deficit conditions and different seasons in tropical climate.

The cut flower market is demanding and producers must be able to harvest quality flowers throughout the whole year, therefore, future studies should be carried out to improve its cultivation techniques. One of the factors that can improve the quality of zinnia stems, especially in the cultivation under the climatic conditions of WS, is the photoperiod. Some studies show that the quality of zinnia is higher when cultivated under short-day seasons, or even under artificial short-day photoperiod. However, there is still no clear definition of the critical photoperiod that should be used for the production of its flowers (Gonçalves; Pedro Júnior; Castro, 2008; Runkle et al., 2012). Future studies should be conducted to clarify it and make it possible to harvest quality flowers throughout the year.

CONCLUSIONS

The weather conditions of the autumn-winter cycle promote better production and quality of floral stems of zinnia in comparison to the winter-spring cycle. Regarding the irrigation levels, it is recommended the replacement of 100% of the specie’s water requirement to obtain a greater production associated with better floral quality, in both cultivation cycles.

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