The environmental supply and the planting density in the Chrysanthemum development

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ABSTRACT

The objective was to evaluate the influence of the annual behavior of some environmental factors and plant densities on *Chrysanthemum* plant growth. Four *Chrysanthemum* cultivars were grown at five densities and established a total of 23 experiments in 2018. The plant and climatic variables determined were the dry weight, height, flower buds, growing degree days (GDD) and daily light integrated (DLI) of each crop cycle of each assay, respectively, as well as the relative humidity. The effect of density on plant growth, as determined by crop cycles established throughout the year, was analyzed graphically and through analysis of variance, followed by a Scheffe post hoc test. It used the multivariate analysis to cluster the crop cycles identified by its week of planting and according to the similarity of plant variables and climatic. The growth reached by the crop cycles under the treatments in all cultivars along the year showed an unimodal behavior. The multivariate analysis lets us define two seasons (I, II) exhibiting significant differences in plant growth and climatic variables behavior. Period I had drier conditions and higher radiation than II and DLI was the most limiting factor in plant development, while the GDDs did not influence it.

Keywords: plant growth; modeling; *Dendranthema grandiflora*; crop flowers; greenhouse.

INTRODUCTION

In 2020, Colombia had 9,680 hectares cultivated with flowers, 194,975 t of production, and 19.2 t ha^{-1} of the average yield. These indicators place Colombian floriculture in the second row of the country's agricultural exports and world flower exports (Ministerio de Agricultura y Desarrollo Rural, 2020). In the tropics, flower crops are established under sheds to protect them principally from environmental rawness. The producer implemented the fertirrigation for managing water and nutrient requirements and light for regulate flowering, not as a complement to the photosynthesis process, and there is no control over the other environmental factors (Zheng & Van, 2018, Aliniaeifard S & Meeteren, 2016). This aspect places it as a passive infrastructure connected to its surroundings and influenced by the external environment; the result is the configuration of specific microclimatic conditions not controlled inside it, though dependent on external environmental behavior, but with evident proportional discrepancies. Inside a passive tropical greenhouse regarding the outside, several authors report lower ventilation, solar radiation, vapor pressure deficit, and higher temperature and relative humidity (Yang & Ryong, 2021; Aliniaeifard & Meeteren, 2016; Janka *et al*., 2015). Extreme or unfavorable environments can affect the yield and quality of the flowers; for example, the Colombian's Ministerio de Agricultura y Desarrollo Rural, (2020) reported a yield reduction from 29.6 to 19.2 t ha^{-1} between 2019 and 2020, with a total production from 254.82 to 194.974 t, despite the cultivated area increases

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from 8,597 ha to 9,680 ha. In the same sense, from July to October period, compared to the rest of the year, the Vegaflor company has observed increases in the weight (0.5 to 2 kg) of a box with the same number of stems. In the passive greenhouse, several authors have reported the effect of environmental factors on plant morphophysiology, too (Zhen & Van, 2018; Han *et al*., 2017; Weerakkody & Suriyagoda, 2015). The fluctuations of crop yield under protected environments authors, such as Villagran & Bojacá (2020) and Weerakkody & Suriyagoda (2015), explain due to environmental conditions shift interacting with agronomic strategies management. Specifically, Hisamatsu *et al*., (2017), studying the seasonal variability in dormancy and flowering competence in *Chrysanthemum* (*Chrysanthemum morifolium* Ramat), found high clout of the temperature of previous conditions in the shoot extension and flowering capacity. There is also evidence of the variability of the annual environmental supply in the tropics from agriculture under protected environments. In that direction, Rahayu *et al*., (2020) studied the effects of seasons on the *Chrysanthemum* flower (*Chrysanthemum indicum*) production in tropical conditions (Yogyakarta, Indonesia), finding the highest yield in the dry season. Conversely, during the rainy season, the farmers require the protection of the sheds from excessive rain intensity and strong winds.

Reducing the impact of environmental factors over the year on the quality of the *Chrysanthemum*, Van Der Ploeg and Heuvilink (2006) propose two alternatives, one controlling climate conditions and the second adjusting the plant density according to climatic characteristics behavior along the year. The same authors argue that the first alternative is expensive and requires high energy inputs. The plant density per unit area is an agronomic factor that influences the growth, development, and quality of plants, and it has a direct relationship with environmental factors. Typically, all crops have a planting density recommendation, allowing a balance between available resources and a profitable and quality yield (Yang & Ryong, 2021; Sun *et al*., 2019). This approach led producers to assume constant resources throughout the year; however, this is not the case for environmental factors under tropical flower crop conditions (Rahayu *et al*.,2020; Weerakkody & Suriyagoda, 2015). Consequently, the producers do not have the information to adjust the density of plants according to the annual environmental supply.

Therefore, this work addressed the influence of the annual behavior of some environmental factors and plant density in the *Chrysanthemum* plant growth. That will help the producers adjust crop management strategies throughout the year.

MATERIAL AND METHODS

Localization

We made the investigation on Flores de la Vega farm (FV), owned by the Vegaflor group. It is a farm located in the Llano Grande village (6°08’33.4”N 75°24’57.6”W), Municipality of Rionegro, Antioquia Department, Colombia, and an altitude of 2130 m.

Climatic characteristics

We characterized the study region’s climate by acquiring and analyzing the historical climatic information (1981-210) of the station La Selva, located in the Rionegro municipality and managed by the Instituto de Meteorologia y Estudios Ambientales (IDEAM). The minimum (Tmin), medium (Tmed), and maximum (Tmax) multimonth average temperature curves (1981-2010) range around 10, 17, and 25 °C, respectively, showing a soft decrease demeanor from June to August in Tmin and relatively stable throughout the year, the others. The precipitation (PP) curve displays the typical bimodal shape, with maximum peaks in May and October and minimums in July and January. The potential evapotranspiration (PET) curve oscillates around 100 mm per month and surpasses the PP only in the month of January. The relative humidity (RH) curve fluctuates about 80 %, decreasing from May and reaching the minimum RH during July and August. The sunshine curve shows the inverse behavior of the PP curve, with maximum peaks in January and July and minimums in April and November.

Farm crops

The FV farm has multi-span greenhouses with a ridge height of 2.3 m, an eave height of 3.1 m, and fixed roof ventilation of 0.6 m. The crop beds are distributed perpendicular to the central space that crosses the length of the greenhouse. The beds’ dimensions are a length of 30 m and a width of 1.35. Greenhouses are passive infrastructures where the inside environment is affected by external conditions. The climatic variables managed were the water for fertigation and the number of days with additional lighting (2.5 hours per day) added to simulate a long day. The long days added on this farm, according to the *Chrysanthemum* (*Dendranthema grandiflora* Tzvelev) cultivars, were 13 to Atlantis White (AtW), 20 to Maisy White (MW), 20 to Anastasia White (AnW), and 22 to Zembla Sunny (ZS). It's clear that on this farm, they produce the varieties Atw, MW, and ZS as sprite type (several inflorescences per stem) and AnW as spyder type (one inflorescence per stem), with a cycle duration of 73.14 ± 2.55, 78.10 ± 2.55, 79 ± 2.90 and 70 ± 2.11 days cycle^{-1}.

Experimental conditions

We evaluated the effect of density in the development of *Chrysanthemum* by growing the four cultivars mentioned (AtW, MW, ZS, AnW) at five planting densities (88.9, 79, 69.1, 59.3, and 44.4 plants m^{-1}). The quantity of 79 plants m^{-2} is the population used throughout the year for the farm. The experiment was distributed on both sides of the central greenhouse space. All planting densities of a cultivar were randomly installed in a crop bed (30x1.35m) in sections of 8.1 m^2 (6x1.5m) and established by triplicate with the rooted cuttings of eight leaves and eight centimeters of height. In total, 75 sections and 15 crop beds were used per experiment. We set up a weekly experiment between weeks 5 and18 and conducted fortnightly experiments between weeks 21 and 40, with a total of twenty-three experiments established in 2018.

Factors such as fertilization, phytosanitary and cultural practices were used by the farm routinely and homogeneously in all experiments. The effect of these factors is considered constant and distributed as part of the experimental error.

Experimental unit

The growth variables were determined when more than 50% of plant beds met the harvest quality requirements (weight: 80.0 ±9.3 g stem^{-1}, height: 90.0 ±11.3 cm, 7.0 ±1 flower plant^{-1} in spray varieties). The mean of 40 plants selected randomly from the middle part of each section constituted the experimental unit.

Growth variables. The variables determined were height from ground level to plant apex, with a tape measure, flower buds, and the fresh weight of the harvested plant.

Climatic variables. We used the data registered between January and December 2018 by an external climatic station located at the investigation center La Selva, Rionegro municipality (6°12'95.58" N, -75.41'43.81" W), and property of the Agrosavia Corporation. The variables used were temperature (°C), radiation (W m^{-2}), and relative humidity with daily resolution. Also, we calculated the growing degree days (GDD) based on the modification made by Ometto (1981) to the Lindsey & Newman (1956) method, which assesses the minimum and maximum daily and developmental threshold temperatures. The thresholds considered in this work were a lower of 10°C and an upper of 27°C, as proposed by Hidén & Larsen (1994). Table 1 shows different GDD expressions according to the behavior of maximum, minimum, daily, and threshold temperatures. The radiation was expressed as a daily light integrated (DLI) and is an accumulation of photosynthetically active radiation (PAR) over a day (24 hours) (Korczynski *et al.,* 2002). In the DLI estimation, we assume that 45% of the solar spectrum is in the PAR region (400-700 nm), and the factor of 4.48 μmol J^{-1} to transform the radiometric units (Wm^{-2}) reported by the sensor into quantic units (μmol m^{-2} s^{-1}) (Blonquist & Bugbee, 2017). As the register of the PAR reflects the average photons' flux per s^{-1} m^{-2} each hour, we accumulate the flux radiation in a day to obtain the DLI (Kjaer *et al.,* 2012). Finally, we integrate the daily registers of GDD and DLI into one, accumulating the heat and radiation corresponding to a growing cycle for each experiment, implemented throughout the year.

Table 1: Expressions for the Growing degree days calculation (Ometto 1981)

Situation	Expression	
TU > TM > Tm > Tb	$GDD = \left(\frac{TM - Tm}{2}\right) + (Tm - Tb)$	[4,1]
TU > TM > Tb >Tm	$GDD = \frac{(TM - Tb)^2}{2(TM - Tm)}$	[4,2]
TU > Tb > TM > Tm	$GDD = 0$	[4,3]
TM > TU > Tm > Tb	$GDD = \frac{(2(TM - Tm)(Tm - Tb)) + (TM - Tm)^2 - (TM - TU)^2}{2(TM - Tm)}$	[4,4]
TM > Tu > Tb > Tm	$GDD = \frac{1}{2}\left(\frac{(TM - Tb)^2 - (TM - TU)^2}{(TM - Tm)}\right)$	[4,5]

Where: TM = Daily maximum temperature (ºC), Tm = Daily minimum temperature (ºC), Tb = base or lower threshold temperature (ºC), TU = upper threshold temperature (ºC), GDD = growing degree days.

Analysis

Classical analysis. The planting week references the beginning of each growing cycle and ends between ten and eleven weeks later. The differences in planting density levels in the growth of each variety were detected employing the analysis of variance test and grouped with the multiple comparisons Scheffe test, considering a significance level of $p<0.05$. The growth achieved in the different crop cycles established throughout the year is presented by employing summary curves and differencing them by plant densities.

Multivariate analysis. The collinearity between response, height, weight flower buds and climatic variables, DLI and DGG, was determined using the principal components analysis method over the normalized variables (Husson *et al.,* 2017). We identified the assays established throughout the year by their planting week and cluster them based on the similarity or dissimilarity of the growth and climatic variables presented during the crop cycle. Using the hierarchical cluster analysis method, Euclidean distance, and maximum or complete linkage clustering. The groups' number was selected considering a low heterogeneity quantity (Euclidean distance ≥ 4.4) (Wishart, 2014). The grouping characteristic was used as a categorical variable, assigning a group identifier to each crop cycle which allowed us to analyze the behavior of both climatic and plant variables between groups.

The statistical procedures were executed in the R software using the functions aov and hclust of the stats package (R Core Team, 2022) and the Scheffe post hoc test of the agricolae package (Mendiburu, 2021).

RESULTS AND DISCUSSION

The crop cycles' fresh weight and height curves show unimodal and fluctuating behavior, respectively. The plants that begin their growth in the last weeks of the year exhibited a decreasing trend in weight, staying that way until the first eight weeks of the following year, from which the behavior was to increase (Figure 1).

All flower varieties exhibited a significantly strong inverse influence of plant density on the biomass accumulated and the number of flowers per plant in the crop cycle (Figures 2 A-D). However, on the plant height, the effect was weaker and not differentiated clearly in some cases (Figures 2 E-H). Lee *et al*., (2002), working in a temperate climate, also reported a decrease in the fresh and dry biomass and number of flowers per plant with plant density and the magnitude was different between seasons. On the contrary, the stem length hardly responds to plant density. The biomass and number of flowers results show a strong competence at high population densities by resource access impacting them negatively. On the other hand, there seems to be greater genetic control on the height, showing that the high densities have a weaker positive effect on the plant height (Lee *et al*. 2002). For example, Figures 2 E-H show that all varieties exceed the critical point of quality for height (> 800 mm) at all densities, with few differences. Although the sprite type of flowers involves the breakdown of the apical dominance, only the floral buttons that meet the size (> 5 cm) are left. Figures 2 I-K show that the ZS variety has the lowest number of flowers per stem and a significant effect of density in all varieties, as reported in the work of Caravalho (2003).

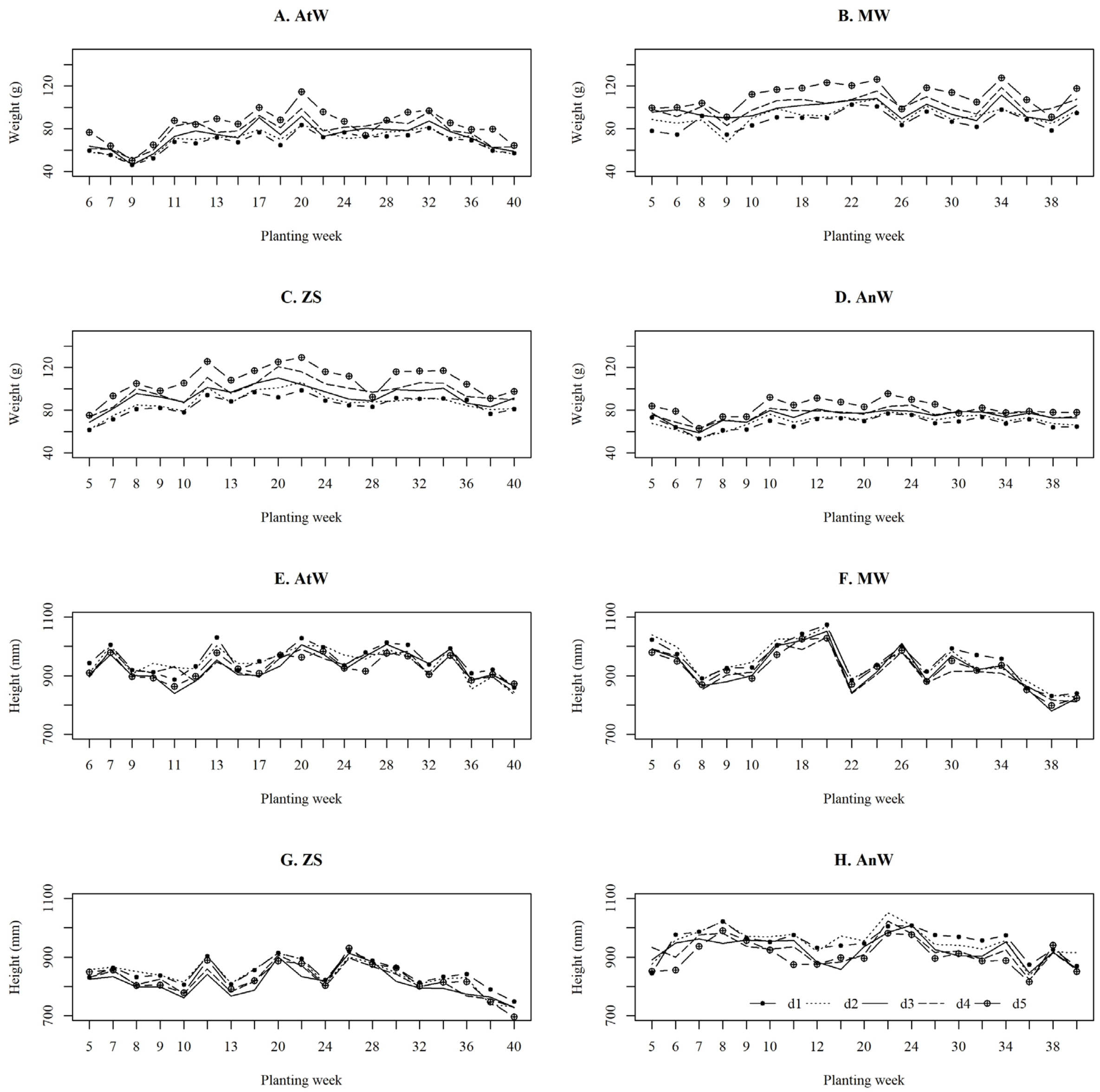
Multivariate component

The two first components in the principal components analysis explained more than 70% of the total variability of the information of all varieties, showing a low degree of collinearity within the groups of plant and climatic variables.

The selected Euclidean distance above 4.4 in the cluster analysis allowed the differentiation of two groupings of crop cycles in all varieties (Figure 3). Table 2 shows the chronological ordering according to the planting and harvest week of the two clustering of crop cycles. Except for the AnW cultivar in all others, cluster I categorized the crop cycles planted around weeks 13 and 30, while II those sowed at the end (> 34) and beginning (< 13) of the year. In the specific case of AnW, the groups had the following configuration: group I consisted of the cycles sown between weeks 22 and 24, while group II formed by cycles planted during the rest of the weeks. The narrowest period of group I and the fact that AnW is a cultivar cultured with a single flower could indicate a shorter season in which some variables could be limiting.

The behavior of climatic and growth variables according to seasons, as defined by the clusters

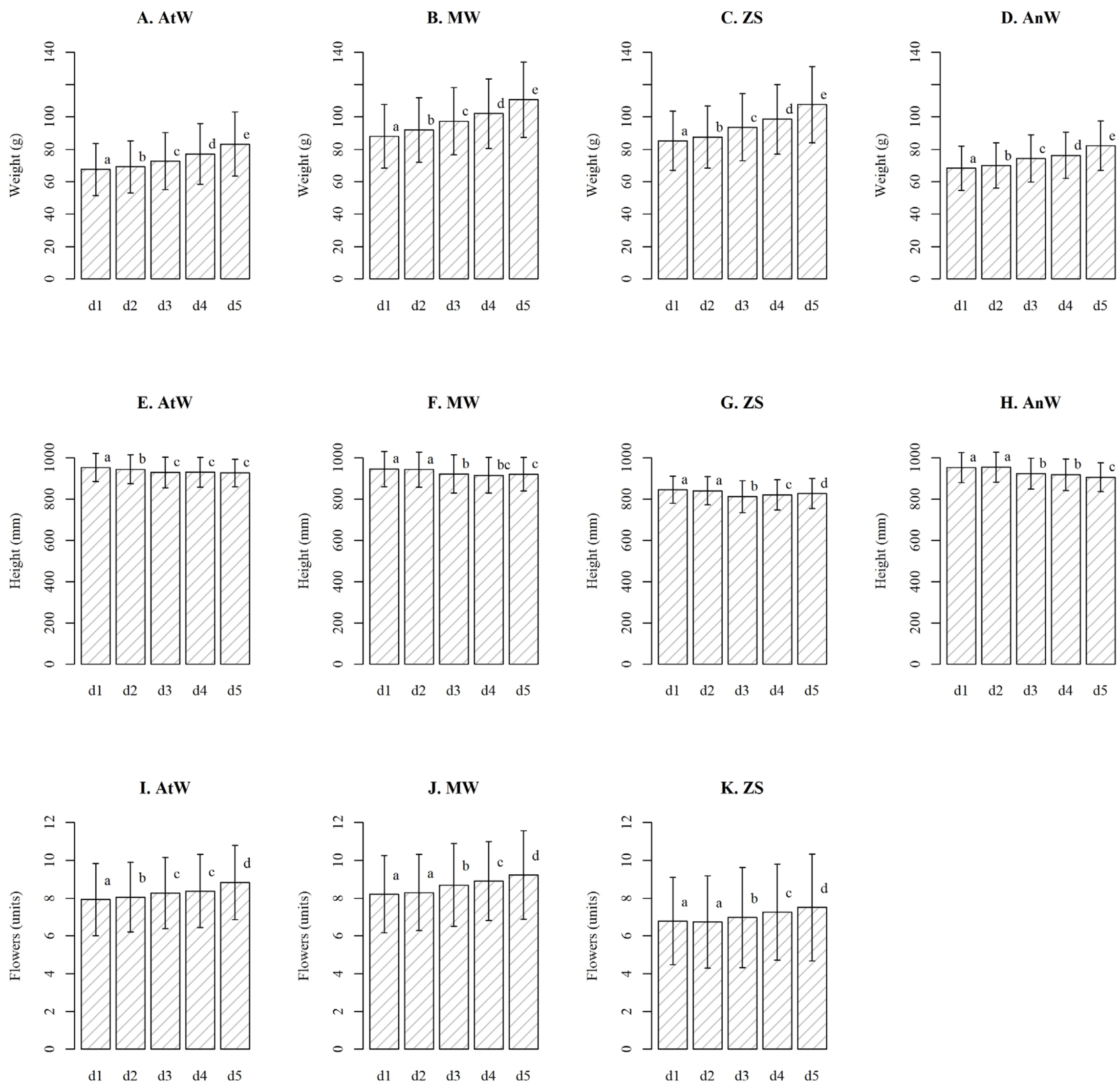
The two seasons defined by the cluster analysis show differences in the average behavior of the fresh biomass, plant height, and climatic variables, where grouping I compared to II demarcates a dryer period. In that sense, all *Chrysanthemum* cultivars in group I had the highest weights and heights compared to group II (Table 3).



Plant densities, d1: 88.9, d2: 79, d3: 69.1, d4: 59.3, and d5: 44.4 plants m^{-1}

Figure 1: Average weight and height reached for different crop cycles established throughout the year and according to planting density. AtW: Atlantis White. MW: Maisy White. C: Zembla Sunny. D: Anastasia White.

Regarding the climatic variables, periods I and II showed a higher maximum temperatures I: 25.7°C, II: 25.2°C and average temperature I: 17.1°C, II:16.7 °C; and lower minimum temperatures I: 10.1°C, II: 10.9°C and relative humidity, average I: 81.7%, II:84.5%. Under the before conditions, the demarked season by grouping I favored the DLI accumulation (I:3380.9 mol cycle^{-1}, II:2856.5 mol cycle^{-1}), becoming the most limiting factor in plant development and growth. On the contrary, the average GDD accumulated in the I period was lower (602.3) compared with the II (630). These results suggest that this factor is not limiting the biomass accumulation or the total height of the plants. The drier conditions and higher radiation defined by the group I seem to favor the growth and development of the *Chrysanthemum* cultivars. In this regard, Hosseinzadeh *et al*. (2021) found a direct relationship between biomass accumulation in both the stems and the flowers of *Chrysanthemum*, which depended on the availability of CO_2 and the intensity of radiation. Additionally, they observed a difference in the cultivation cycle, resulting in more rapid flowering, with a radiation intensity of 600 µmol/m²s (26 moles/day).



Plant densities, d1: 88.9, d2: 79, d3: 69.1, d4: 59.3, and d5: 44.4 plants m^{-1}

Figure 2: The behavior of the biomass, height and number of flowers per plant according to plants' density and varieties. AtW: Atlantis White. MW: Maisy White. ZS: Zembla Sunny. AnW: Anastasia White. The whisker reference one standard deviation and bars with different letters indicate significant differences in the average weight ($p < 0.05$).

DLI and GDD accumulated across the crop cycles throughout the year

Figure 4 presents the DLI and GDD accumulated during the different crop cycles established throughout the year. The DLI displays unimodal behavior, indicating a more significant accumulation of radiation for the crop cycles sowed between weeks 13 and 35 of the year. Additionally, the most marked differences in DLI accumulation between varieties occurred in this period, so the DLI curve of the AtW variety all the time was lower than the other varieties, while the ZS was above. These results suggest differences in varietal performance in the defined season by cluster I, principally. In the case of hours of heat accumulated during the crop cycle, these remain stable throughout the year, indicating that DGG is not a limiting factor in the flower-growing regions of the tropics. However, possibly due to varietal characteristics, the DGG curve of the AtW is below the others, requiring minor heat units to complete the crop cycle.

Figure 5 displays the interaction between crop cycle seasons, as defined by the clustering, and planting density of different varieties. Some *Chrysanthemum* varieties did not exhibit interaction, while others did between clustering and density; however, in general terms, the period

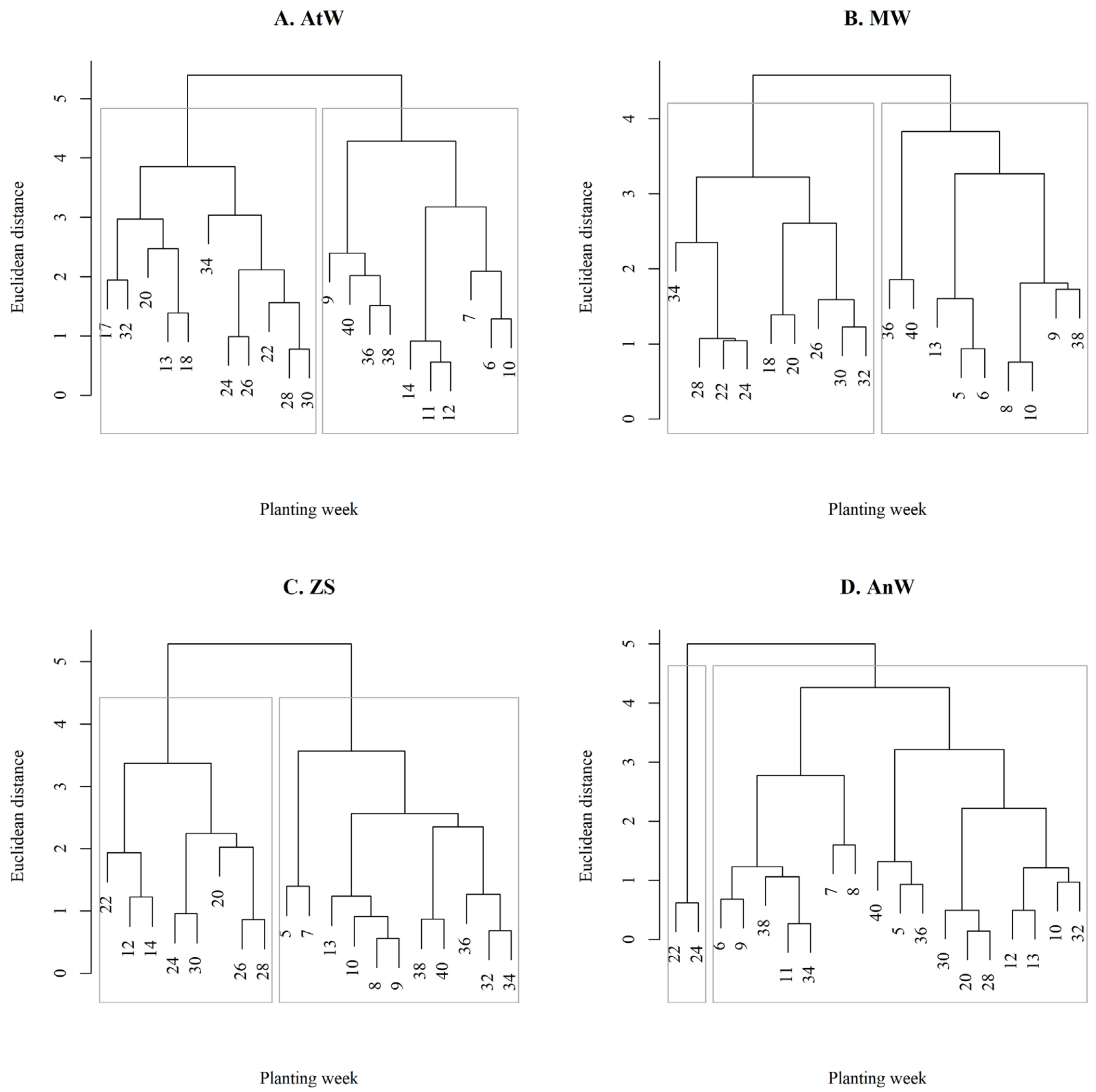


Figure 3: Grouping of the crop cycles, established at different weeks in 2018 and based on the climatic and plant variables. A: Atlantis White. B: Maisy White. C: Zembla Sunny. D: Anastasia White.

demarked by clustering I favored biomass accumulation of all varieties under all densities. The AtW variety exhibited a perfectly ordered inverse relationship between fresh biomass and plant density in each period, defined by the cluster. We highlighted the significant differences between the two periods in the biomass of plants grown at the same planting density. The other varieties show similar behavior; however, in some cases, plants grown at lower densities in period II had identical behavior in the fresh biomass to those grown at higher densities in the I period. In summary, during period I, it might be possible to plant crops at a higher density, thus achieving efficiency, while in period II, they might be established at a lower density while maintaining the quality of the plants. The drier conditions and higher radiation defined by the group I seem to favor the growth and development of the Chrysanthemum varieties. Under conditions of greater intensity, Esmaeili *et al*. (2022) found compensation for light intensity during nitrogen deficiency in vegetative growth, affecting biomass accumulation. Additionally, they observed positive effects of high radiation on chlorophyll content, photosynthesis, water use efficiency, and nitrogen use efficiency.

Hisamatsu *et al*. (2017) found that in temperate regions with well-defined seasons, differences in fresh and dry

Table 2: Chronological ordering of the two clustering of the crop cycles, according to varieties, calendar week of planting, and harvest

Calendar week	Planting	5	6	7	8	9	10	11	12	13	14	17	18	20	22	24	26	28	30	32	34	36	38	40
	Harvest	16	17	18	19	20	21	22	23	24	25	28	29	31	33	35	37	39	41	43	45	47	49	51
Variety	Maisy White	II	II		II	II	II			II			I	I	I	I	I	I	I	I	I	II	II	II
	Zembla Sunny	II		II	II	II	II		I	II	I			I	I	I	I	I	I	II	II	II	II	II
	Anastasia White	II	II	II	II	II	II	II	II	II				II	I	I		II	II	II	II	II	II	II
Calendar week	Planting	5	6	7	8	9	10	11	12	13	14	17	18	20	22	24	26	28	30	32	34	36	38	40
	Harvest	15	16	17	18	19	20	21	22	23	24	27	28	30	32	34	36	38	40	42	44	46	48	50
Variety	Atlantis White		II	II		II	II	II	II	I	II	I	I	I	I	I	I	I	I	I	I	II	II	II

Clustering I   Clustering II   Not advailable

Table 3: The behavior of the climatic and growth variables according to clusters

Variable	Unit	Variety	Group			
			I		II	
			Average	SD[(1)]	Average	SD
Weight	g planta^{-1}	AW	84.6	12.5	70.6	17.3
		MW	100.7	14.5	91.6	12.0
		ZS	98.4	16.2	88.9	15.4
		AN	82.1	7.0	76.8	13.5
Heigth	mm	AW	953.1	45.6	890.8	64.2
		MW	950.4	68.5	896.3	68.8
		ZS	879.7	54.1	829.3	73.0
		AN	1002.5	42.7	930.4	59.5
Flower	flowers stem^{-1}	AW	7.8	1.3	8.6	1.5
		MW	7.7	1.6	9.3	1.7
		ZS	6.9	2.6	7.7	2.4
Tmin[(2)]	°C		10.1	1.5	10.9	1.5
Tav[(3)]			17.1	0.5	16.7	0.5
Tmax[(4)]			25.7	0.7	25.2	0.8
RHmin[(5)]	%		40.4	3.5	42.9	6.6
RHav[(6)]			81.7	2.6	84.5	2.6
DLIav[(7)]	mol day^{-1}		46.2	2.6	35.4	2.6
DLIac[(8)]	mol cycle^{-1}		3380.9	310.2	2856.5	263.0
GDD[(9)]	degree-days cycle^{-1}		602.3	42.1	630.8	41.4

[(1)] Standard deviation. [(2)] Minimum temperature. [(3)] Average temperature. [(4)] Maximun temperature. [(5)] Minimum relative humidity. [(6)] Average relative humidity. [(7)] Average Daily Light Integrated. [(8)] Accumulated Daily Light Integrated. [(9)] Growth degree days.

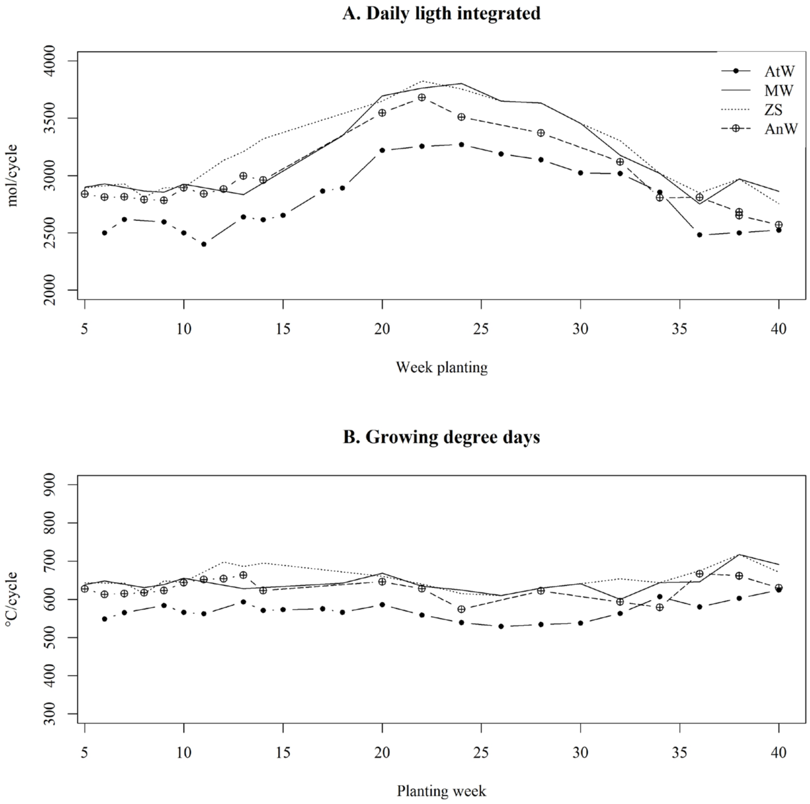
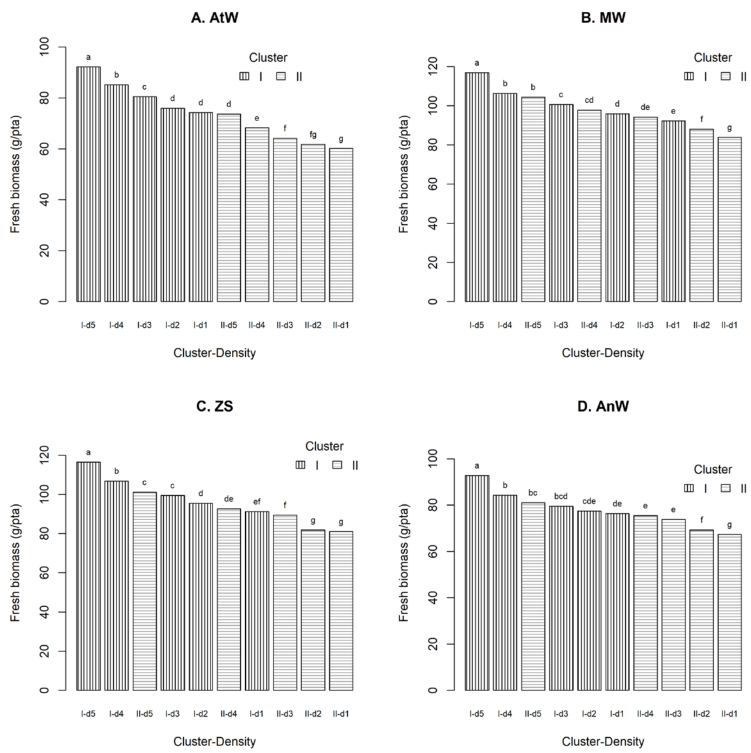


Figure 4: The behavior of the DLI (A) and GDD (B) accumulated during the different crop cycles established throughout the year.



Where: d1: 88.9, d2: 79, d3: 69.1, d4: 59.3, d5: 44.4 are plants m^{-1}

Figure 5: Effect of interaction season of crop cycle defined by the clustering and density of planting in the fresh biomass of different Chrysanthemum varieties. A: Atlantis White. B: Maisy White. C: Zembla Sunny. D: Anastasia White. Dissimilar letters on the bar mean significant differences ($p<0.05$) between interactions cluster-density.

mass, number of flowers per plant, and stem length were higher in summer than in winter. The feeling of flower growers in tropical regions is that they have favorable conditions throughout the year for flower production; however, our findings contradict this. Although there are no demarcated seasons in the tropics, it is possible to differentiate periods with better conditions for growing flowers, and the change between these is gradual (Table 2 and Figure 7 A). Our results agree with the Sharma & Singh (2021) and Nagdeve *et al*. (2021) reports, which investigated the effect of density on plant growth in cut flower *Chrysanthemum*. They suggest an effect of year date of transplanting, row spacing and orientation on the dry matter partitioning and flower size in *Chrysanthemum*. The density responses, are essentially mediated by the available light per plant with differences between cultivars.

CONCLUSIONS

The multivariate analysis allowed us to define two periods in the year between which the *chrysanthemum* varieties presented significant differences in the accumulation of fresh biomass, height, and the number of flowers. The DLI was the most limiting characteristic between these periods. The climatic conditions of period I were dryer with greater amplitude in the temperature behavior, an increased accumulation of DLI, and similar GDD accumulated and favored the growth reached of all varieties under all densities, allowing higher crop densities. In contrast, in period II, the densities must be adjusted in function of the stem quality.

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