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Research Article

Artificial defoliation and its impact on the agronomic performance of sunflower in a non-preferential season

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Abstract

The objective of this work was to evaluate the partitioning of photoassimilates in sunflower plants sown in a non-preferential season coincident with the occurrence of fallow areas in the region, submitted to artificial defoliation with 100% intensity, in different phenological stages of the reproductive period. The experimental design used was randomized blocks with six treatments and three replications, consisting of 18 experimental units and all plants were defoliated. The treatments performed were artificial defoliation, I: No defoliation (control); II: Defoliation at the R1 phenological stage; III: Defoliation at the R3 phenological stage; IV: Defoliation at the R5 phenological stage; V: Defoliation at the R7 phenological stage and VI: Defoliation at the R8 phenological stage. Artificial defoliation performed at 100% intensity at different phenological stages influences the morphological attributes and yield components of sunflower in a distinct way. Defoliations performed at R1 phenological stage have a negative effect on most of the variables analyzed, which provided lower plant height, stem diameter, capitulum diameter, number of rows of achenes, number of achenes per row, achene length, achene width, thousand achene mass and, consequently, in grain yield. This phenological stage was marked by the beginning of the reproductive period, which has a high demand for photoassimilates to maintain plant metabolism and yield. Defoliation performed at R8 phenological stage had better performance for plant height, capitulum diameter, capitulum mass, number of rows of achenes, number of achenes per row, number of plants per hectare and grain yield (>1000 kg ha^{-1}). The plants of experimental units without defoliation had results similar to those defoliated in the R8 phenological stage, however, they still had better performance for thousand achene mass, achene length, achene width, volume index and even a smaller diameter of missing seeds.

Keywords: *Helianthus annuus*; assimilate partition; remobilization; biotic stresses; correlation; organoleptic quality oil.

Introduction

Sunflower (*Helianthus annuus*) was originally an ornamental plant whose genetic improvement worked with a focus on maximizing the production of capitulums and achenes (Carvalho, Silva, Magano, Hutra, & Loro, 2021). Its cultivation is strongly linked to oil production, which is one of the best nutritional and organoleptic quality oils. In addition to being a raw material for the production of fuels such as biodiesel, it is used for animal feed in the form of grains or plant biomass in the form of silage, high-protein cake or sunflower bran and reuse of by-products from the industry (Carvalho et al., 2021). Its first commercial cultivations in Rio Grande do Sul were reported in the 1940s, without much success due to the low adaptability of the cultivars available at the time, with low productivity and susceptibility to diseases (Dall'Agnol, Vieira, & Leite, 2008).

As it has an aggressive pivoting root system, it is an alternative for use as a cover plant, as it introduces roots into the system and performs natural subsoiling, it allows for soil structuring, increased porosity and less impediment to root growth (Bertollo & Levien, 2019) which improves infiltration, soil water storage and gas flow. As it is considered a rustic and highly adaptable crop in different edaphoclimatic conditions, it fits perfectly into a crop rotation system, allows its cultivation in non-traditional times, has an advantage over invasive plants for having fast initial growth and allelopathic effect for some species and has a low implementation cost (Cavasin, 2001).

Winter cover crops used for rotation or cultural succession bring ecological benefits such as protection against soil erosion and ion leaching, in addition to the structuring and aggregation of particles, they promote the recycling of nutrients, with the only restriction being no immediate economic return. Sunflower has the potential to be used as a crop rotation species for productive diversification (Cavasin, 2001) with the ability to generate income on the property through the harvesting and commercialization of grains.

Stress from an agronomic point of view is characterized as a condition of disturbance caused by the environment and causes a reduction in productivity (Carvalho et al., 2021). Agricultural activities are often exposed to biotic and abiotic stresses such as the occurrence of hail or severe attack by defoliating pests which are often controlled with the use of insecticides indiscriminately, to carry out photosynthetically maintenance of the active leaf area. After the adoption of appropriate criteria for diagnosing the damages and losses in productivity caused by the loss of leaf area, it can facilitate decision-making to solve the problem by the grower or technician (Lucas, Heldwein, Maldner, Dalcin, & Loose, 2012). Some studies were carried out in maize, where Carvalho et al. (2021) showed that defoliation after the flowering stage reduces, on average, 79.6% in grain yield.

Thus, the identification of the most critical phase for the loss of leaves becomes substantial, for this it is necessary to evaluate the affected yield components, the climatological data for the elaboration of predictive models of grain yield. In this sense, the objective of this work was to evaluate the partitioning of photoassimilates in sunflower plants sown in a non-preferential season coincident with the occurrence of fallow areas in the region, submitted to artificial defoliation with 100% intensity, in different phenological stages of the reproductive period.

Material and Methods

The experiment was carried out at the Regional Institute of Rural Development – IRDeR, under the responsibility of the Department of Agrarian Studies – DEAg, of the Regional University of Northwestern Rio Grande do Sul – UNIJUÍ, located at coordinates 28º25'55" S, 54º00'24" W, in the county of Augusto Pestana - RS. The soil in the area is classified as a Typical Dystroferric Red Latosol (Oxisol) at an approximate altitude of 288 meters.

The experimental design used was randomized blocks with six treatments and three replications, consisting of 18 experimental units and all plants were defoliated. Sunflower sowing was carried out on February 11, 2020, using the cultivar Nusol 4510 CLAO, a simple hybrid with ClearField® technology from Atlântica Sementes. The sowing density was six seeds per linear meter, with the use of a tractored fertilizer seeder with seven lines, spaced 50 centimeters apart, with a density of 120,000 seeds per hectare. The base fertilization applied in the sowing line was a dose of 170 kg ha^{-1} of chemical fertilizer formulated N.P.K. in formulation 12-31-18, in a total experimental area of 35m x 40m (1,400 m²). Each experimental unit had 3.5m x 10m, with 35 m², with a total useful area of 630 m². The rest of the sown area was discarded which was considered border.

The treatments performed were artificial defoliation, which consisted of manual removal of leaves with 100% intensity at different phenological stages of the reproductive phase. They were carried out as follows: Treatment I: No defoliation (control); Treatment II: Defoliation at the R1 phenological stage; Treatment III: Defoliation at the R3 phenological stage; Treatment IV: Defoliation at the R5 phenological stage; Treatment V: Defoliation at the R7 phenological stage and Treatment VI: Defoliation at the R8 phenological stage.

Before harvesting, the measurement of the plant stand in each experimental unit was carried out, then, for the evaluation of the characteristics, 15 plants were collected per experimental unit. The variables measured were:

- the number of plants per hectare (NPH, unit), by counting the plants in the experimental unit (35 square meters) and converted to 10,000 square meters;
- plant height (PH, m) obtained by measuring the stem from ground level to the insertion of the capitulum, using a measuring tape;
- stem diameter (SD, cm) obtained by measuring the stem at five centimeters above ground level;
- number of leaves (NL, unit), through the leaf count of the measured plants;
- capitulum mass (CM, g) obtained by weighing the capitulum;
- capitulum diameter (CD, cm) obtained using a measuring tape; number of rows of achenes in the capitulum (NRA, unit) by counting 15 capitulums per experimental unit;
- number of achenes in the last row (NAR, unit), obtained by counting the achenes per row of 15 capitulums per experimental unit;
- diameter of missing achenes (DMA, cm) obtained by measuring the diameter of missing achenes in the center of the capitulum;
- thousand achenes mass (TAM, g), obtained by measuring six replicates per experimental unit;
- achenes length (AL, cm), by measuring one hundred achenes per experimental unit;
- achenes width (AW, cm), obtained by measuring one hundred achenes per experimental unit;
- length-width ratio (LWR, %);
- volume index (VI, %); and
- grain yield (GY, kg ha^{-1}), obtained by quantifying the mass of achenes per capitulum clean and dry at 13% moisture, with population adjustment of the experimental unit, through conversion to yield in kg ha^{-1}.

The data obtained were subjected to the assumptions of the statistical model, normality and homogeneity of residual variances, as well as the additivity of the model, then, the analysis of variance at 5% probability was performed in order to verify the variability and significance of defoliation treatments. The variables that showed significance were submitted to the method of grouping of means by Scott Knott at 5% probability. In order to understand the degree of contribution of the defoliation levels to the responses of the characters, the Deviance analysis at 5% probability was carried out using the x^2 test, which, when shown to be significant, expressed reliability of the variance components and genetic parameters extracted via Restricted Maximum Likelihood methodology, namely: genetic variance (σ^2G), contribution of genetic variance in phenotypic manifestation (σ^2G %), residual variance (σ^2E), contribution of residual variance to treatment (σ^2E %), phenotypic variance (σ^2P), broad-sense heritability ($\hat{H}^2$), broad sense heritability of the character mean ($\hat{H}^2mg$), accuracy (Accuracy), genetic variation coefficient (Cvg%), residual variation coefficient (Cvr%) and ratio between genetic and residual variation coefficients (Cvg/Cvr).

Subsequently, with the phenotypic hopes of each treatment and variables, the mean Euclidean method was used to calculate the distances and make the classification dendrogram of the treatments based on the mean grouping between pairs (UPGMA). In the same way, in order to identify the trend of association between the characters, linear correlation was performed with significance based on the t test at 5% probability. Stepwise multiple regression was performed to determine which meteorological variables were essential for grain yield stratified by artificial defoliation effect. Analyzes were performed using the R software.

Results and Discussion

Average temperatures ranging from 9 to 29 °C, minimum temperatures from 2.4 to 21 °C, maximum temperatures from 12 to 38 °C, and temperature ranges from 2.1 to 22 °C were observed. Solar radiation values ranged from 13 to 466 W/m² and total rainfall was 343 mm during the crop cycle.

By analyzing the climate variables occurring in the different phenological stages and comparing with what Castro and Farias (2005) and Castiglioni, Bala, Castro and Silveira (1994) consider ideal for the vegetative period (VP), the consulted literature considers the ideal temperature to be from 20 to 27 °C. There were average temperatures of 25 °C, minimum of 16 °C and maximum of 30 °C. There were not outlying oscillations in relation to the optimal. For rainfall, the ideal water demand can vary from 0.7 to 6 mm per day, where there were 162 mm, with a daily average of 2.45 mm.

For the flowering stage, encompassed by the phenological stages R5 and R6, the climate preference for temperature is that they be lower than 35 ºC. However, the average maximum temperatures did not exceed 30 ºC, which was a positive point observed, as high temperatures associated with lack of precipitation that occurred, would have a potential for even greater reduction in productivity. According to Carvalho et al. (2021) the occurrence of a single day of temperature close to 40 ºC, can damage one to two floral circles, with a reduction in productivity of 10 to 15 %. However, there were very mild minimum temperatures, around 15 and 7 °C in the R5 and R6 stages, respectively, which can present pollination failures, due to the low reproductive capacity of pollen grains and low insect activity (Castro & Farias, 2005). For rainfall, there were 51.2mm in 16 days, with an average of 3.2 mm per day, approximately half of the minimum required for the period, which is 6.0 mm per day.

In the achene filling phase, encompassed by the phenological stages R7 and R8, the ideal temperature is in the range of 20 to 26 °C, where the occurrence of minimum temperatures in the average of 9 °C, average temperatures of 16 °C and maximum temperatures of 24 °C were recorded. Only the minimum temperature remained outside the ideal range. For rainfall, there were 129.8 mm in a 24-day period, with an average of 5.4 mm per day, according to demand. A reduction in the intensity of solar radiation was also noticed, where Thomaz, Zagonel, Colasante and Nogueira (2012) concluded that higher radiation intensities in achene filling have a positive correlation with productivity. The analysis of variance (Table 1) revealed significance at 5% for all analyzed variables.

Thus, the grouping of treatments was performed using the Scott Knott test at 5% probability. For plant height (PH) (Figure 1a), artificial defoliation performed at phenological stage R8 and plants without defoliation, presented superior results, with average heights of 1.14 and 1.10 meters, respectively, as defoliation occurred towards the end of the cycle, after definition of the maximum height, and the treatment without defoliation had its normal development. In group B, artificial defoliation performed in phenological stages R7, R5 and R3 were grouped, with average heights of 1.09, 1.07 and

1.06 meters, respectively. In group C, the artificial defoliation performed in the R1 phenological stage was classified, with the smallest heights, with an average of 0.95m.

The percentage variation between the highest value in group B to the highest in group A was 4.60%, and the percentage change from the highest value in group C to group A was 20%. The coefficient of variation was 10.07%, considered low and of high precision. Souza et al. (2015) achieved maximum height 60 days after emergence. Considering that the first defoliation was performed at 66 DAS, it can explain the fact that the height of the defoliated plants in R1 was more affected, as the injury was close to the height definition.

Table 1. Summary of analysis of variance for variables plant height (PH, m); number of sheets (NL); stem diameter (SD, cm); capitulum diameter (CD, cm); capitulum mass (CM, g); number of rows of achenes (NRA); number of achenes in the last row (NAR); grain yield (GY, kg ha^{-1}); number of plants per hectare (NPH); diameter of missing achenes (DMA, cm); thousand achene mass (TMA, g); achene length (AL, cm); achene width (AW, cm); length-to-width ratio (LWR, %); volume index (VI, %), measured in six defoliation treatments. IRDeR/DEAg/UNIJUÍ, Augusto Pestana, Rio Grande do Sul State, Brazil.

Sources of variation	DF	F-test probability at 5%							
		PH	NL	SD	CD	CM	NRA	NAR	GY
Defoliation	5	<0,001*	<0,001*	<0,001*	<0,001*	<0,001*	<0,001*	<0,001*	<0,001*
Blocks	2	1,07e-5	0,259	0,089	0,837	0,427	0,182	0,0005	0,592
CV (%)		10,07	42,78	20,89	14,36	41,52	36,5	19,78	31,7
Sources of variation	DF	F-test probability at 5%							
		NPH	DMA	TMA	AL	AW	LWR	VI	
Defoliation	5	<0,001*	<0,001*	0,001*	0,001*	0,001*	0,005*	0,001*	
Blocks	2	0,006	0,138	2,17e-16	0,686	0,207	0,231	0,017	
CV (%)		11,46	24,23	11,74	32,42%	32,39	32,38	9,36	

For the number of leaves (NL) (Figure 1b), the experimental units without defoliation showed plants with an average of 16.28 leaves, followed by artificial defoliation performed at the phenological stage R1, in group B, with an average of 5,40 leaves. In group C, artificial defoliation was performed at the R3 phenological stage, with an average of 0.75 leaves. Group D had zero leaves, with no emission of new leaves after artificial defoliation. The percentage change between the highest value in group B to the highest in group A was 201.48%, the percentage change in the mean from group C to group A was 2,070.66%. The coefficient of variation was 42.78%, considered high, with low data precision. In the first two defoliations, in stages R1 and R3, new leaf emissions close to the capitulum were observed.

Regarding the stem diameter (SD) (Figure 1c), the artificial defoliation performed at the R5 phenological stage was classified in group A, with the best performance, with an average of 1.87 centimeters. In group B, experimental units without defoliation were classified, artificial defoliation performed at phenological stages R3, R8 and R7, with averages of 1.61, 1.60, 1.55 and 1.50 centimeters, respectively. In group C, the worst treatment was artificial defoliation at the R1 phenological stage, with an average of 1.29 centimeters. The percentage change between the highest value in group B to the highest in group A was 16.87%, the percentage change from the highest value in group C to group A was 44.96%. The coefficient of variation was 20.89%, considered medium, with good data precision. Silva et al. (2012) found maximum stem diameter at 45 days after emergence. This morphological characteristic is important in increasing stem resistance, because with the filling of achenes, the mass of the upper part of the plant increases, stems of smaller diameter have a strong relationship with plant lodging and breakage (Ivanoff, Uchôa, Alves, Smiderle, & Sediyama, 2010).

For capitulum diameter (CD) (Figure 1d), plants without defoliation and artificial defoliation at phenological stage R8 had better performances, with averages of 14.90 and 14.74 centimeters, respectively. Artificial defoliations performed at phenological stages

R7 and R5 formed group B with averages of 13.86 and 13.16 centimeters, respectively. Group C was composed of artificial defoliation at R3 phenological stage, with an average of 11.10 centimeters and group D with the worst result, composed of artificial defoliation at R1 phenological stage with an average of 10.01 centimeters. The percentage variation between the highest value in group B to the highest in group A was 7.50%, the percentage change from the highest value in group C to group A was 34.23% and the variation from group D to the A was 48.85%. The coefficient of variation was 14.36%, considered low, with high data accuracy. According to Lima Junior, Bertoncello, Melo, Degrande and Kodama (2010) smaller capitulum diameters caused by loss of leaf area occurring during flowering and filling of achenes reduces yield, given the positive correlation between grain yield and capitulum diameter, being the yield component of greatest impact.

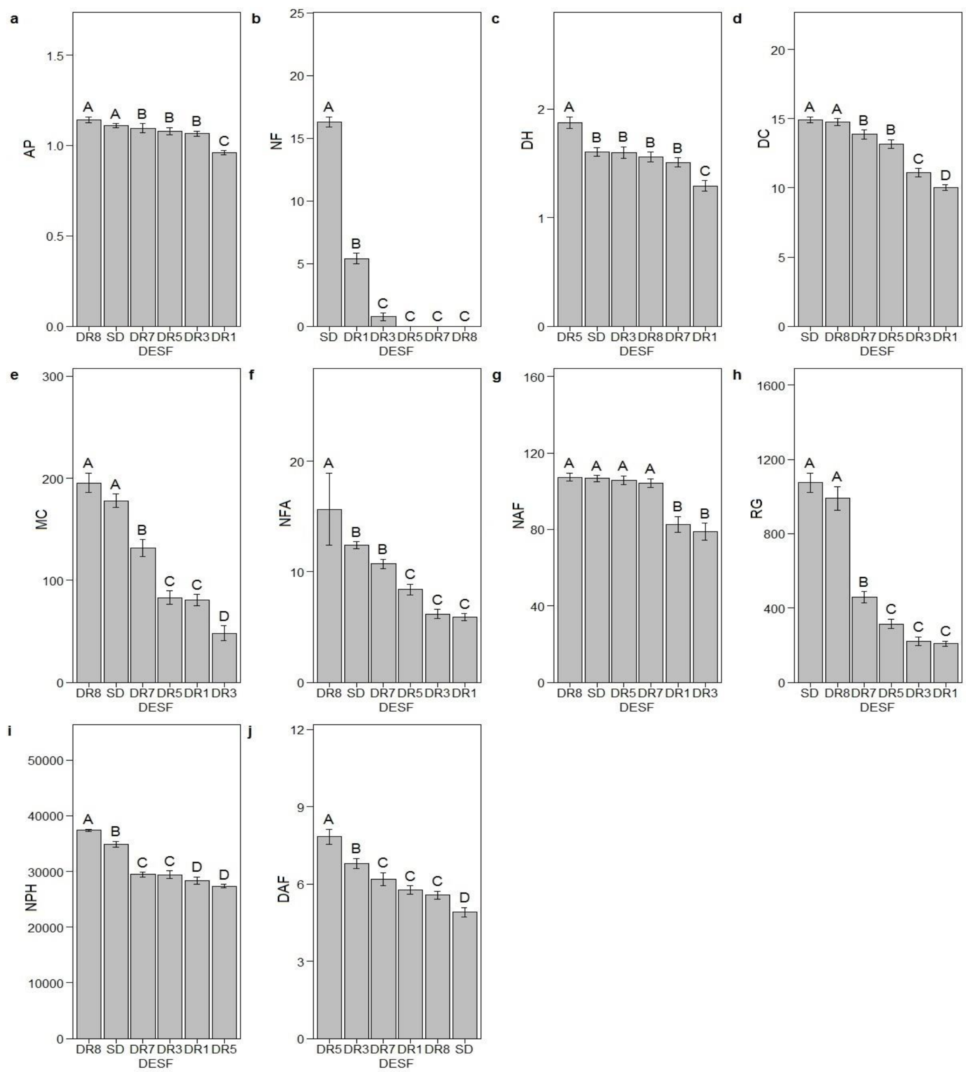

Figure 1. Graphics of plant morphological variables and data grouping by Scott Knott; a: plant height (cm); b: number of leaves; c: stem diameter (cm); d: capitulum diameter (cm); e: capitulum mass (g); f: number of rows of achenes; g: number of achenes in the last row; h: grain yield (kg ha^{-1}); i: number of plants per hectare; j: diameter of missing achenes (cm). ND: no defoliation; DR1: defoliation at the R1 phenological stage; DR3: defoliation at the R3 phenological stage; DR5: defoliation at the R5 phenological stage; DR7: defoliation at the R7 phenological stage; DR8: defoliation at the R8 phenological stage.

For capitulum mass (CM) (Figure 1e), defoliation performed at R8 phenological stage and without defoliation had the best performance, classified in group A, with averages of 195 and 177 grams, respectively. Artificial defoliation performed at R7 phenological stage formed group B with an average of 131 grams. Group C was composed of artificial defoliation performed at phenological stages R5 and R1, with averages of 83 and 80 grams, respectively. Group D with the worst result, composed of artificial defoliation performed at phenological stage R3 with an average of 48g. The percentage change between the highest value in group B to the highest in group A was 48.61%, the percentage change from the highest value in group C to group A was 135.14%. The coefficient of variation was 41.52%, considered high, with low data precision.

For the number of rows of achene (NRA) (Figure 1f), the defoliation performed in the R8 phenological stage, showed an average of 15.64 rows. The plots without defoliation and artificial defoliation at R7 phenological stage formed group B with means of 12.39 and 10.72 rows. Group C was composed of artificial defoliation carried out in the phenological stages R5, R3 and R1, with means of 8.38, 6.17 and 5.88 rows. The percentage change between the highest value in group B to the highest in group A was 26.23%, the percentage change from the highest value in group C to group A was 86.63%. The coefficient of variation was 36.50%, considered high, with low data precision.

As for the number of achenes in the last row (NAR) (Figure 1g), artificial defoliation performed in R8 phenological stage, experimental units without defoliation, artificial defoliation performed in phenological stages R5 and R7 had better results forming the group A, with means of 107.28, 106.63, 105.75 and 104.37 achenes, respectively. Artificial defoliations performed at phenological stages R1 and R3 formed group B with averages of 82.73 and 78.82 achenes, respectively. The percentage variation between the highest value in group B to the highest in group A was 29.67%. The coefficient of variation was 19.78%, considered medium, with good data accuracy.

For grain yield (GY) (Figure 1h), experimental units without defoliation and artificial defoliation performed at R8 phenological stage were classified in group A, with averages of 1,074 and 990 kg ha^{-1}. Group B consisted of the artificial defoliation treatment performed at the R7 phenological stage, with an average of 457 kg ha^{-1}. Group C consisted of artificial defoliation performed at R5 phenological stage, with an average of 314 kg ha^{-1}. And group D was composed of artificial defoliation carried out in phenological stages R3 and R1, with averages of 221 and 208 kg ha^{-1}, respectively. The percentage change between the value from group B to the highest value in group A was 135.01%, the percentage change from the highest value in group C to group A was 242.03% and the change in the highest value in group D for the highest value of group A it was 385.97%. The coefficient of variation was 31.7%, considered high, with low data precision. Aguiar, Oliveira, Amaral, Dalcim and Monteiro (2009) concluded that under favorable climate conditions, the average yield was 1,190 kg ha^{-1}, however, under water deficit conditions the average yield was 379 kg ha^{-1}, and the most productive genotype with 699 kg ha^{-1}.

For the number of plants per hectare (NPH) (Figure 1i), the best result was obtained in the artificial defoliation carried out in the R8 phenological stage, with an average of 37,380 plants. Group B consisted of experimental units without defoliation, with an average of 34,882 plants. Group C was composed of artificial defoliation carried out at phenological stages R5 and R3, with averages 29,438 and 29,442 plants, respectively. Group D, composed of artificial defoliation carried out in the phenological stages R1 and R5 with averages of 28,432 and 27,333 plants, respectively. The percentage change between the value from group B to the highest value in group A was 7.16%, the percentage change from the highest value in group C to group A was 26.97% and the change in the highest value in group D for the highest value of group A it was 31.47%. The coefficient of variation was 11.46%, considered low, with high data accuracy. There was no influence of defoliation, since the establishment of the stand took place in the first phenological stages and no plant death due to defoliation was observed.

For the diameter of missing achenes (DMA) (Figure 1j), the artificial defoliation performed at the R5 phenological stage, showed the largest failure diameter, with an average of 7.83 centimeters. In group B, the artificial defoliation performed at the R3 phenological stage had an average of 6.80 centimeters. In group C, the artificial defoliation performed in the R7 phenological stage had a failure diameter of 6.19 centimeters, the R1 and R8 phenological stages had an average failure diameter of 5.77 and 5.56 centimeters, respectively. Group D shows plants without artificial defoliation with the smallest fault diameter.

As a variable that must be analyzed inversely, larger failure diameters result in lower productivity. The percentage variation between the value of group B and group A was 15.14%, the percentage variation of the highest value of group C for the group A was 26.49%, the variation from D to the highest value in group A was 59.79%. The coefficient of variation was 24.23%, considered high, with low data precision. Plants defoliated at stage R5 showed failures in the production of achenes in an average of 59.49% of the total diameter, whereas those without defoliation showed only 32.88%.

For the thousand achenes mass (TAM) (Figure 2a) the experimental units without defoliation had the best result, with an average of 47.66 grams. In group B, artificial defoliation performed at phenological stage R8 was classified, with an average of 34.44 grams. In group C, artificial defoliations performed in phenological stages R5, R3 and R7 were classified, with means of 32.14, 31.30 and 30.20 grams, respectively. The percentage variation between the highest value in group B to the highest in group A was 38.38%. The variation from group C to group A was 48.28%, and the percentage variation from group D to group A was 135.35%. The coefficient of variation was 11.74%, considered low, with high data accuracy.

For the achenes length (AL) (Figure 2b), the experimental units without defoliation, had the best result, with an average of 1.03 centimeters. In group B, artificial defoliations performed at phenological stages R5, R8, R7 and R3 were classified, with means of 0.98, 0.97, 0.96 and 0.94 centimeters, respectively. In group C, artificial defoliation performed at the R1 phenological stage was classified, with an average of 0.83 centimeters. The percentage variation between the highest value in group B to the highest in group A was 5.10%. The variation from group C to group A was 24.09%. The coefficient of variation was 32.42%, considered high, with low data precision.

For the achene width (AW) (Figure 2c), the experimental units without defoliation and the artificial defoliation performed at the R7 phenological stage, had the best results, with averages of 0.61 and 0.59 centimeters, respectively. In group B, artificial defoliations performed at phenological stages R3, R8 and R5 were classified with averages of 0.59, 0.57 and 0.57 centimeters, respectively. In group C, artificial defoliation performed at the R1 phenological stage was classified, with an average of 0.47 centimeters. The percentage variation between the highest value in group B to the highest in group A was 3.39%. The variation from group C to group A was 29.78%. The coefficient of variation was 32.39%, considered high, with low data precision.

For the length-width ratio (LWR) (Figure 2d), in group A, the artificial defoliation performed at the R1 phenological stage was classified, with an average of 1.83. In group B, artificial defoliation performed in phenological stages R5, R3, R8 and experimental units without defoliation were classified, and plants defoliated in phenological stage R7, with averages of 1.74, 1.73, 1.70, 1 .70 and 1.64 respectively. The percentage variation between the highest value in group B to the highest in group A was 5.17%. The coefficient of variation was 32.38%, considered high, with low data precision.

For the volume index (VI) (Figure 2e), the experimental units without defoliation had the best result, with an average of 0.38. In group B, artificial defoliation performed at phenological stage R7 was classified, with an average of 0.36. In group C, artificial defoliations performed in phenological stages R8 and R5 were classified, with means of 0.36 and 0.35 respectively. In group D, artificial defoliation performed at the R3 phenological stage was classified, with an average of 0.34. In group E, artificial defoliation performed at the R1 phenological stage was classified, with an average of 0.29. The percentage variation between the highest value from group B to the highest value in group A was 5.55%, the variation from group C to group A was 5.55%, the variation from D to

A was 11.76 %, the variation from E to A was 31.03%. The coefficient of variation was 9.36%, considered low, with high data accuracy.

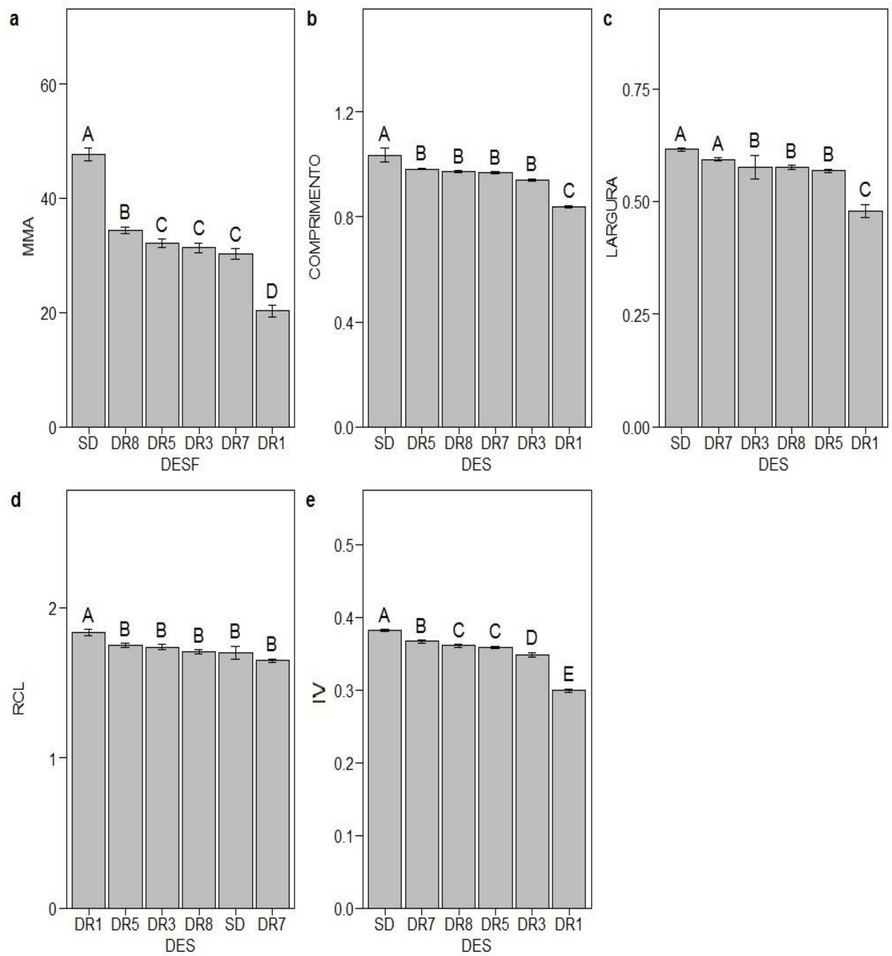

Figure 2. Graphics of morphological variables of achenes and data grouping by Scott Knott; a: thousand achene mass (g); b: achene length (cm); c: achene width (cm); d: length-to-width ratio (%); e: volume index (%). ND: no defoliation; DR1: defoliation at the R1 phenological stage; DR3: defoliation at the R3 phenological stage; DR5: defoliation at the R5 phenological stage; DR7: defoliation at the R7 phenological stage; DR8: defoliation at the R8 phenological stage.

Pearson's linear correlation (Figure 3) allows us to infer on the linear relationships between characters of interest (Carvalho et al., 2018). Thus, the correlation matrix revealed 78 associations between the 13 morphological characteristics evaluated, where 17 are significant. Plant height (PH) had a positive correlation coefficient for CD (r=0.9), NRA (r=0.83) and VI (r=0.91), and negative correlation for LWR (r= - 0.84).

For Nobre, Silva, Guimarães, Resende and Macedo (2018), plant height is the main phenotypic element that determines productivity, even if indirectly, by the number of leaves. Farhatullah and Khalil (2008) also found a highly significant correlation between plant height and achene production per plant. The head diameter (CD) showed a positive correlation for CM (r=0.85), NRA (r=0.9), NAR (r=0.93), GY (r=0.85) and VI (r=0.88), similar results were found by Amorin et al. (2008), mainly to the capitulum diameter directly linked to the grain yield, being a fundamental genetic characteristic for the selection of productive genotypes. Farhatullah and Khalil (2008) also concluded in their studies the positive correlation of capitulum diameter and grain yield.

The capitulum mass (CM) had a positive correlation with NRA (r=0.96), GY (r=0.95) and NPH (r=0.88). The number of rows of achenes (NRA) has a positive correlation with GY (r=0.91) and with NPH (r=0.88). The number of rows of capitulum achenes certainly influences the total number of capitulum achenes. Farhatullah and Khalil (2008) also found a positive correlation between number of capitulum achenes with grain yield. Grain yield (GY) has a positive correlation with NPH (r=0.93). The length-width ratio (LWR) has a negative correlation with the VI (r= - 0.87). The volume index (VI) has a positive correlation with the TAM (r=0.86).

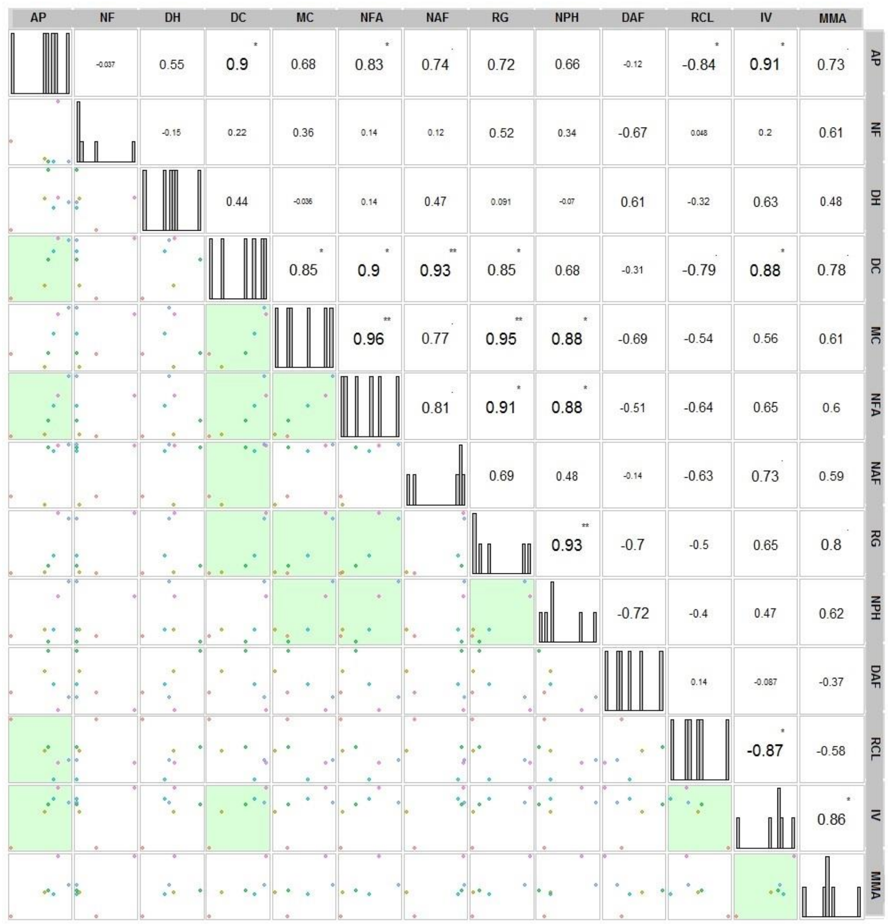

Figure 3. Estimates of Pearson's linear correlation for 13 morphological characters of sunflowers, defoliated at different phenological stages. IRDeR/DEAg/UNIJUÍ, Augusto Pestana, Rio Grande do Sul State, Brazil. * Pearson linear correlation coefficients, significant at 5.00% probability of error. PH: plant height (cm); NL: number of leaves; SD: stem diameter (cm); CD: capitulum diameter (cm); CM: capitulum mass (g); NRA: number of rows of capitulum achenes; NAR: number of achenes in the last row; GY: grain yield (kg ha^{-1}); NPH: number of plants per hectare; DMA: diameter of missing achenes (cm). TAM: thousand achene mass (g); LWR: length-to-width ratio (%); VI: volume index (%).

The correlations allow a better understanding of the formation of the final yield, considering the participation and each component of productivity, where in this work, the most significant interaction of the capitulum mass in the grain yield was observed. The predictive models created in this work allow to estimate yield in different defoliation situations, making a harvest forecast even before sowing in different defoliation scenarios (Table 2).

Deviance analysis revealed significance at 5% probability by the chi-square test (X^2) for the variables plant height (PH), number of leaves (NL), stem diameter (SD), capitulum diameter (CD), capitulum mass (CM), number of row of achenes (NRA), number of achenes in the last row (NAR), number of plants per hectare (NPH), diameter of missing achenes (DMA), achene length (AL), achene width (AW), length-width ratio (LWR), volume index (VI) and thousand achene mass (TAM). For sunflower defoliated at different phenological stages was revealed the accuracy of the predictions made in the study.

Table 2. Predictive model based on multiple linear regression (Stepwise) for grain yield (GY) for defoliation performed at different phenological stages. IRDeR/DEAg/UNIJUÍ, Augusto Pestana, Rio Grande do Sul State, Brazil.

PREDICTIVE MODELS	
Regardless of defoliation	GY= 114,512 + 22,693(TMin) +1,009(RAD)
No Defoliation	GY= 376,725 + 9,549(RAD)
Defoliation in R1	GY= 202,4179 + 5,2507(AT) – 0,5457(RAD)
Defoliation in R3	GY= 142,70 + 45,15(AT) – 46,41(TMin) + 15,75(URM) – 14,50(HRMax)
Defoliation in R5	Not significant
Defoliation in R7	GY= -712,80 – 0,50(RHA) + 7,27(URMin) + 25,46(URMax)
Defoliation in R8	GY=2154,29+81,439(RHA)–39,936(URMin) – 59,889(URMax) + 1,664(RAD)

*significant at 5% by t test. RAD: solar radiation; TMin: minimum temperature; AT: average temperature; RHA: average relative humidity; HRMax: maximum relative humidity; HRmin: minimum relative humidity.

Estimating the variance components allows dismembering the expression from the phenotype and identifying the contributions of artificial defoliation. Plant height (PH) was determined by 23.62% due to the effects of artificial defoliation and 73.38% were environmental effects (Table 3). The number of leaves (NL) was determined by 88.32% due to the effects of artificial defoliation and 5.57% were environmental effects. Stem diameter (SD) was determined by 23.17% due to the effects of artificial defoliation and 76.83% were environmental effects. The capitulum diameter (CD) was determined by 52.20% due to the effects of artificial defoliation and 47.80% were environmental effects. The capitulum mass (CM) was determined by 54.56% due to artificial defoliation effects and 45.44% were environmental effects.

The number of rows of achenes in the capitulum (NRA) was determined by 13.98% by artificial defoliation effect and 86.02% by environmental effects. The number of achenes per row (NAR) was determined 30.17% due to the effects of artificial defoliation and 69.83% were environmental effects. Grain yield (GY) was determined by 59.19% due to the effects of artificial defoliation and 40.81% were environmental effects. The number of plants per hectare (NPH) was determined by 54.72% due to the effects of artificial defoliation and 45.26% were environmental effects. The diameter of missing achenes (DMA) was determined by 32.64% due to genetic effects, where 67.36% were environmental effects.

The achene length (AL) was determined by 3.84% due to the effects of artificial defoliation and 96.16% were environmental effects. The achene width (AW) was determined by 5.64% due to the effects of artificial defoliation and 94.36% were environmental effects. The length-to-width ratio (LWR) was determined by 0.85% by the effects of artificial defoliation and 99.15% were environmental effects. The volume index (VI) was determined by 41.79% for the effects of artificial defoliation and 58.21% for environmental effects. The thousand achene mass (TAM) was determined by 83.41% due to the effects of artificial defoliation and 16.59% were environmental effects.

The number of leaves (NL), capitulum mass (CM), number of rows of achenes (NRA), grain yield (GY) and thousand achene mass (TAM) had a high coefficient of variation due to the treatment and effects of defoliation. On the other hand, the other variables had a low treatment coefficient of variation. Plant height (PH), stem diameter (SD), number of row of achenes (NRA), number of achenes in the last row (NAR), diameter of missing achenes (DMA), achene length (AL), achene width (AW), length width ratio (LWR) and volume index (VI) had a low relationship between treatment coefficients of variation and residual coefficient of variation. The number of leaves (NL), capitulum diameter (CD), capitulum mass (CM), grain yield (GY), number of plants per hectare (NPH) and thousand achene mass (TAM) had a high relationship between the treatment coefficient of variation and residual coefficient of variation. Only the number of rows of achenes (NRA), achene length (AL), achene width (AW) and length-to-width ratio (LWR) had low accuracy.

Table 3. Estimation of variance components and genetic parameters (REML) for plant height (PH, m); number of leaves (NL, no.); stem diameter (SD, cm); capitulum diameter (CD, cm); capitulum mass (CM, g); number of rows of capitulum achenes (NRA, no.); number of achenes in the last row (NAR, no.); grain yield (GY, kg ha^{-1}); number of plants per hectare (NPH, nº); diameter of missing achenes (DMA, cm); thousand achene mass (TMA, g); achene length (AL, cm); achene width (AW, cm); length-to-width ratio (LWR); volume index (VI), for sunflower defoliated at different phenological stages. IRDeR/DEAg/UNIJUÍ, Augusto Pestana, Rio Grande do Sul State, Brazil.

Variance component	Characters								
	PH	NL	SD	CD	CM	NRA	NAR	GY	NPH
σ^2G	0,003	42,17	0,032	3,925	3400	12,75	164,0	149770	16009577
σ^2G (%)	23,62	88,32	23,17	52,20	54,56	13,98	30,17	59,19	54,74
σ^2E	0,011	5,57	0,107	3,59	2832	78,44	379,6	103261	13239618
σ^2E (%)	76,38	11,68	76,83	47,8	45,44	86,02	69,83	40,81	45,26
σ^2P	0,015	47,75	0,139	7,51	6232	91,18	543,6	253032	29249195
$\hat{H}^2$	0,236	0,88	0,231	0,52	0,545	0,139	0,301	0,5919	0,5474
$\hat{H}^2mg$	0,481	0,95	0,047	0,76	0,782	0,327	0,564	0,8131	0,7839
Accuracy	0,693	0,97	0,689	0,87	0,884	0,572	0,751	0,9017	0,8854
Cvg (%)	5,600	117,6	11,47	15,00	45,50	34,87	13,00	62,26	12,60
Cvr (%)	10,07	42,78	20,89	14,36	41,52	86,50	19,78	51,70	11,46
Cvg/Cvr	0,556	2,75	0,549	1,04	1,096	0,403	0,657	1,204	1,100

Variance component	Characters					
	DMA	AL	AW	LWR	VI	TAM
σ^2G	1,012	0,0039	0,002	0,002	0,00007	83,95
σ^2G (%)	32,64	3,844	5,643	0,850	41,79	83,41
σ^2E	2,088	0,098	0,034	0,312	0,001	16,70
σ^2E (%)	67,36	96,16	96,36	99,15	58,21	16,59
σ^2P	3,099	0,102	0,036	0,314	0,001	100,7
$\hat{H}^2$	0,326	0,038	0,056	0,008	0,417	0,834
$\hat{H}^2mg$	0,592	0,107	0,152	0,025	0,682	0,967
Accuracy	0,769	0,327	0,390	0,158	0,826	0,983
Cvg (%)	16,87	6,482	7,920	2,999	7,928	26,32
Cvr (%)	24,23	32,42	32,39	32,38	9,357	11,74
Cvg/Cvr	0,696	0,199	0,244	0,092	0,847	2,242

σ^2G: genetic variance; σ^2G(%): contribution of genetic variance in the phenotypic manifestation; σ^2E: residual variance; σ^2E(%): contribution of residual variance to the treatment; σ^2P: phenotypic variance, $\hat{H}^2$: broad sense heritability; $\hat{H}^2mg$: broad sense heritability of the mean character; Accuracy: accuracy; Cvg%: coefficient of genetic variation; Cvr%: residual coefficient of variation; Cvg/Cvr: ratio between genetic and residual coefficients of variation.

The dendrogram (Figure 4) grouped the artificial defoliation treatments by similarity of behavior of the analyzed variables (Barbosa et al., 2016), where three groups were formed, the first consisting of defoliations in the phenological stages R1 and R5, the second group formed by the artificial defoliation performed in the phenological stage R3 and the parcels without defoliation, and the third group formed by defoliations carried out in stages R7 and R8.

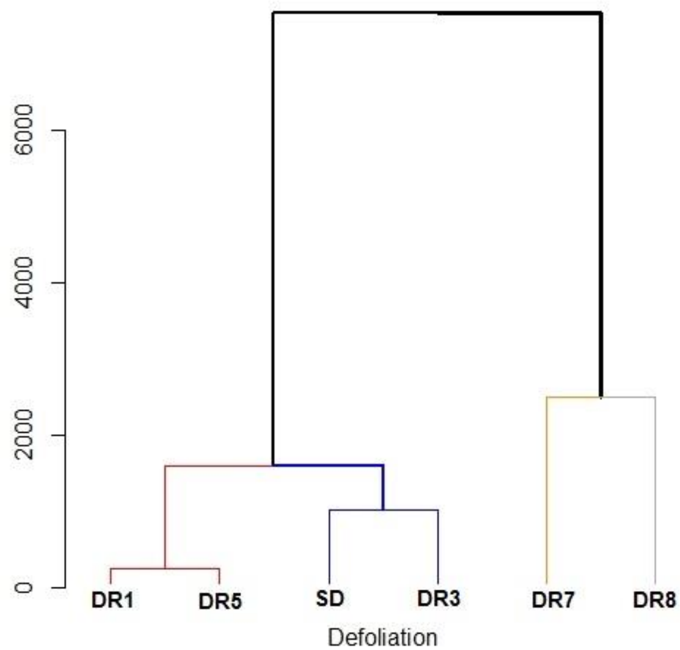

Figure 4. Dendrogram with dissimilarity obtained through the mean Euclidean distance of the variables plant height (PH, m); number of leaves (NL, no.); stem diameter (SD, cm); capitulum diameter (CD, cm); capitulum mass (CM, g); number of rows of capitulum achenes (NRA, no.); number of achenes in the last row (NAR, no.); grain yield (GY, kg ha^{-1}); number of plants per hectare (NPH, nº); diameter of missing achenes (DMA, cm); thousand achene mass (TMA, g); achene length (AL, cm); achene width (AW, cm); length-to-width ratio (LWR); volume index (VI), using the UPGMA grouping method, to group the defoliation treatments in the phenological stage. IRDeR/DEAg/UNIJUÍ, Augusto Pestana, Rio Grande do Sul State, Brazil. (DR1): artificial defoliation at the R1 phenological stage; (DR3): artificial defoliation at the R3 phenological stage; (DR5): artificial defoliation at the R5 phenological stage; (DR7): artificial defoliation at the R7 phenological stage; (DR8): artificial defoliation at phenological stage R8 and (ND): plots without artificial defoliation.

Conclusion

Artificial defoliation performed at 100% intensity at different phenological stages influences the morphological attributes and yield components of sunflower in a distinct way. Defoliations performed at R1 phenological stage have a negative effect on most of the variables analyzed, providing lower plant height, stem diameter, capitulum diameter, number of rows of achenes, number of achenes per row, achene length, achene width, thousand achene mass and, consequently, in grain yield. This is a phenological stage marked by the beginning of the reproductive period, which has a high demand for photoassimilates to maintain plant metabolism and yield.

Defoliation performed at R8 phenological stage had better performance for plant height, capitulum diameter, capitulum mass, number of rows of achenes, number of achenes per row, number of plants per hectare and grain yield (>1000 kg ha^{-1}). The plants of experimental units without defoliation had results similar to those defoliated in the R8 phenological stage, however, they still had better performance for thousand achene mass, achene length, achene width, volume index and even a smaller diameter of missing seeds.

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