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Scientific Article

Determining the phyllochron and final leaf pair number in on-farm cut dahlia cultivars

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Abstract

Dahlia is an important ornamental crop and widely used as a garden plant in beds and mixed borders as well as a cut flower in bouquets and flower arrangements. Understanding the factors that support sustainable flower production is essential for dahlia growers to increase their profits. Two key variables that define leaf development during the vegetative phase of a crop are the rate of appearance of leaves on the main stem and the final number of leaves. The objective in this study was to determine the phyllochron and the final leaf pair number (FLPN) in cut dahlias cultivars grown in different locations. Three on farm experiments varying from two to eight cut dahlia cultivars were conducted during two years (2021/2022) in six locations in Rio Grande do Sul State, Southern Brazil. The number of unfolded leaf pairs (NLP - an unfolded leaf was assumed when the foliolates edges were not touching anymore) on each plant was counted once or twice a week, depending on the farm, until the last leaf pair was unfolded. The NLP was linearly regressed against TT (thermal time °C day^{-1}) and the phyllochron (°C day leaf pair^{-1}) was calculated as the slope of the linear regression. The results indicated that the phyllochron of dahlia cultivars varied between 45.7 to 95.6 °C pair of leaves^{-1} and 8 to 14 of final number of pair of leaves in the first experiment, 27.2 to 97.4 °C pair of leaves^{-1} and 6 to 15 of final leaf pair number in the second experiment and 46.8 at 106.4 °C leaf pair^{-1} and 6 to 13 the final leaf pair number in the third. Thus, there was no significant difference between the sites in the phyllochron and NFP variables.

Keywords: cut flower, *Dahlia* spp., leaf appearance, thermal time.

Resumo

Determinação do filocrono e número final de pares de folhas em cultivares de dálias cortadas na propriedade

A dália é uma importante cultura ornamental e amplamente utilizada como planta de jardim em canteiros e bordaduras mistas, bem como flor de corte em buquês e arranjos florais. O entendimento dos fatores que propiciam uma produção sustentável de flores é essencial para que os produtores de dálias aumentem seus lucros. Duas variáveis-chave que definem o desenvolvimento da folha durante a fase vegetativa de uma cultura são a taxa de aparecimento de folhas na haste principal e o número final de folhas. O objetivo deste trabalho foi determinar o filocrono e o número final de pares de folhas em cultivares de dálias de corte em diferentes localidades. Três experimentos em fazendas variando de dois a oito cultivares de dália de corte foram conduzidos durante dois anos (2021/2022) em seis localidades do estado do Rio Grande do Sul, sul do Brasil. O número de pares de folhas desdobradas (NLP - uma folha desdobrada foi assumida quando as bordas folioladas não se tocavam mais) em cada planta foi contado uma ou duas vezes por semana, dependendo da fazenda, até que o último par de folhas fosse desdobrado. O NLP foi regredido linearmente contra TT (tempo termal °C dia^{-1}) e o filocrono (ºC dia par folha^{-1}) foi calculado como a inclinação da regressão linear. Os resultados indicaram que o filocrono de cultivares de dálias variou entre 45.7 a 95.6°C par de folhas^{-1} e 8 a 14 de número finais de par de folhas no primeiro experimento, 27.2 a 97.4 °C par de folhas^{-1} e 6 a 15 de número finais de par de folhas no segundo experimento e 46.8 a 106.4 °C par de folhas^{-1} e 6 a 13 o número final de par de folhas no terceiro. Desta forma não apresentou diferença significativa entre os locais nas variáveis filocrono e NFP.

Palavras-Chave: *Dahlia* spp., emissão foliar, flor de corte, tempo termal.

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Introduction

Dahlia (*Dahlia* spp.) is an important ornamental crop native of Mexico, *Asteraceace* family, and worldwide used as a garden plant in beds and mixed borders as well as a cut flower in bouquets and flower arrangements. It is an herbaceous shrub, perennial in tropical and subtropical climates but tender in cold climates, propagated by seeds, stem cuttings, and tubers. The inflorescence is a capitulum of several shapes such as anemone, decorative, pompom, cactus, and orchid among others (The National Dahlia Society, 2021). Dahlia can be easily grown and is well adapted to open field cultivation with high yields, and is one of the cut flowers of the "Flowers to All Project", a nation-wide project led by The PhenoGlad Teams in several regions of Brazil (Uhlmann et al., 2019; Streck and Uhlmann, 2021).

Understanding basic processes that lead to high and sustainable production of flower is essential for dahlia growers increase their profits. Leaf development is an important process because during the vegetative phase dahlia plants build their leaf area index that intercepts solar radiation and create the structure (stems) to support flowers. Two key variables that define the dynamics of leaf development during the vegetative phase of a crop are the rate that leaves appear on a stem and the final leaf number on the stem (Hodges, 1991; Uhlmann et al., 2017). The rate that leaves appear is frequently represented by the phyllochron, defined as the time interval between the appearance of two successive leaves, with unit of time leaf^{-1} (Frank and Bauer, 1995; Wilhelm and McMaster, 1995; Hermes et al., 2001). In dahlia, leaves appear as a pair of leaves from each node (Brondum and Heins, 1993) and therefore the phyllochron can be defined as the time between the appearance of two successive leaf pairs (with unit of time/leaf pair), and the final leaf number as the final leaf pair number (FLPN).

Temperature, photoperiod, planting date, location, and cultivar are the major factors than can affect the phyllochron whereas solar radiation, soil moisture, soil compaction, and soil fertility are among minor factors that can affect the phyllochron in different crops (Kirby, 1995). Therefore, units of time in the phyllochron concept can be in days, thermal time (°C day) or photothermal time (°C day h). There are several cultivars of cut dahlias grown in Brazil, and quantifying how those cultivars respond to different environments is important for understanding the genotype x environment interaction as well as for the fine tuning of management practices by farmers (Shukla et al., 2018; Bajaraya et al., 2019). While there are reports on the phyllochron and final leaf number on flower crops like lily (Streck et al., 2004), safflower (Streck et al., 2005), gladiolus (Streck et al., 2012) and Statice (Buffon et al., 2020), no reports on phyllochron and final leaf number in dahlia were found in the literature, which constituted the rationale for this study. The objective in this study was to determine the phyllochron and the final leaf pair number (FLPN) in cut dahlias cultivars grown in different locations.

Materials and Methods

Three on farm experiments varying from two to eight cut dahlia cultivars were conducted during two years (2021 and 2022) in six locations in Rio Grande do Sul State, Southern Brazil were used in this study (Table 1).

Table 1. On farm experiments with cut dahlias used in the study, Rio Grande do Sul State, Brazil.

Location	**Cultivars**	**Planting date (dd/mm/yyyy)**	**Mean temperature (°C)**
Experiment 1			
Santa Maria 29°40’42”S 53°41’14”W	C1-Promise	25/02/2021	21.5
	C2-Siberia		
	C3-Rebecca’s World		
	C4-Dark Spirit		
	C5-Pompom		
	C6-Frantonio		
	C7-Vera		
	C8-Mom’s Special		
Jaguari 29°29’25”S 54°41’40”W	C1-Promise	27/02/2021	22
	C2-Siberia		
	C3-Rebecca´s World		
	C4-Dark Spirit		
	C5-Pompom		
	C6-Frantonio		
	C7-Vera		
	C8-Mom’s Special		
Experiment 2			
Santa Maria 29°40’42”S 53°41’14”W	C1-Promise	21/09/2021	21.7
	C2-Siberia		
	C3-Rebecca’s World		
	C4-Dark Spirit		
	C5-Pompom		
Cachoeira do Sul 29°58’58”S 52°56’13”W	C1-Promise	14/10/2021	23.4
	C2-Siberia		
	C3-Rebecca’s World		
	C4-Dark Spirit		
	C5-Pompom		
Experiment 3			
Lajeado 29°28’22”S 51°59’22”W	C1-Siberia	21/11//2022	25.2
	C2-Rebecca’s World		
Cachoeira do Sul 29°58’58”S 52°56’13”W	C1-Siberia	18/11/2022	25.3
	C2-Rebecca’s World		
Júlio de Castilhos 29°25’58”S 53°32’91”W	C1-Siberia	18/11/2022	24.3
	C2-Rebecca’s World		
Novo Cabrais 29°44’09”S 52°57’48”W	C1-Siberia	18/11/2022	29.9
	C2-Rebecca’s World		

The different number of cultivars used in each location was based on farmers availability of tubers. Climate in all locations according to the Köppen system is Cfa, humid subtropical with hot summer and no dry season (Kuinchtner and Buriol, 2001; Kottek et al., 2006). Chemical soil tests taken in the farms at Santa Maria and Cachoeira do Sul indicated soil Organic Matter content of 2.1% and 3,3%, soil pH of 4.55 and 6.13, P content of 88.3 mg dm^{-3} and 56.1 mg dm^{-3}, K content of 206.5 mg dm^{-3} and 366.7mg dm^{-3}, and Ca+Mg content of 5.4 $cmol_c$ dm^{-3} and 11.1 $cmol_c$ dm^{-3}, respectively. No soil tests were taken from the other farms, but the areas had been used for flower and vegetable crops and therefore representing local conditions. Tubers from a private company were used by farmers and planted in beds 1.0 m wide and 0.2 m height spaced 0.40 m x 0.40 m at 0.05 cm depth in all farms. Fertilization included pre-planting lime application for a pH of 6.0 and 50g m^{-2} of NPK (5-20-20), as indicated Brondum and Heins (1993) and Kumar et al. (2019). All farmers used irrigation in order to avoid water stress in their dahlia crops in all locations.

The number of emerged plants was counted daily until the final stand of plants was achieved, and the emergence date was considered when 50% of the plants were emerged. After emergence was completed, the main shoot of 10 plants per cultivar was tagged in each farm. The number of unfolded leaf pairs (NLP - an unfolded leaf was assumed when the foliolates edges were not touching anymore) on each plant was counted once a week in Cachoeira do Sul, Lajeado, Julio de Castilhos, and Novo Cabrais, and twice a week in Santa Maria, until the last leaf pair was unfolded, which is the final leaf pair number (FLPN, with unit of leaf pairs/stem on the main shoot).

Daily minimum and maximum air temperatures were collected from automatic meteorological stations of the Brazilian National Weather Service (INMET), located in Santa Maria, São Vicente do Sul, Cruz Alta, Teutônia, and Rio Pardo. The weather station in Santa Maria represented the climate of the farm in Santa Maria and in Novo Cabrais, São Vicente do Sul represented the climate of the farm in Jaguari, Cruz Alta represented the climate of the farm in Júlio de Castilhos, Teutônia represented the climate in Lajeado, and Rio Pardo represented the climate in Cachoeira do Sul.

From crop emergence to the appearance of the final leaf pair on the main shoot, daily thermal time, defined as the thermal sum during one day (TTd, °C day), was calculated as (Gilmore and Rogers, 1958; Arnold, 1960):

$TTd = (T_{mean} - Tb).\ 1\ day$, when T_{mean} is between Tb and Topt (1)

$TTd = \{(Topt - Tb).\ [TB - T_{mean})/(TB-Topt)]\}$, when $Topt < T_{mean} < TB$ (2)

$TTd = 0$, when $T_{mean} < Tb$ or $T_{mean} > TB$ (3)

where T_{mean} is the mean air temperature calculated as the average of daily minimum and maximum air temperatures, and Tb, Topt and TB are the lower base, the optimum and the upper base temperature for leaf pair unfolding in dahlia (5.5 °C, 24.6 °C, and 34.9 °C respectively, Brondum and Heins (1993).

Accumulated thermal time (TT, °C day) from crop emergence to the appearance of the final leaf pair was calculated as:

$$TT = \sum TTd \quad (4)$$

The NLP was linearly regressed against TT for each tagged plant. The slope of the linear regression is the leaf pair unfolding rate LPUR (leaf pairs °C day^{-1}) and the phyllochron (°C day leaf $pair^{-1}$) was estimated by the inverse of the slope of the linear regression, i.e. 1/LPUR (Klepper et al., 1982; Kirby, 1995).

The experimental design was a factorial with location and cultivars as factors in each Experiment, with 10 plants per cultivar as replications. The variables phyllochron and FLPN were tested for Normality and Homoscedasticity, and the *p*-value was not significant for both variables, indicating that ANOVA is not appropriate. Therefore, to analyse the dependent variables phyllochron (°C day leaf $pair^{-1}$) and FLPN (leaf pairs $stem^{-1}$) in data from the 3 experiments, according to the location and cultivars, descriptive and inferential statistical approaches were applied. Quantitative variables were analysed by statistics of central tendency and variation, and their normality was tested with the Shapiro-Wilk and D'Agostino-Pearson tests. In the inferential part, the following approach were applied: to compare the dependent variables in the context of Experiment, Locations, and Cultivars, the Kruskal-Wallis test with Dunn's post-test was used. A significance level of 5% was used for rejecting the null hypothesis, and statistical processing was performed using BioEstat version 5.3 and SPSS version 28 software.

Results

A linear regression between NLP and TT with an R2 greater than 0.9 was observed in all locations and experiments, indicating that leaf appearance in dahlia cultivars is mainly driven by temperature. An example of this relationship and how the phyllochron was calculated is in Figure 1.

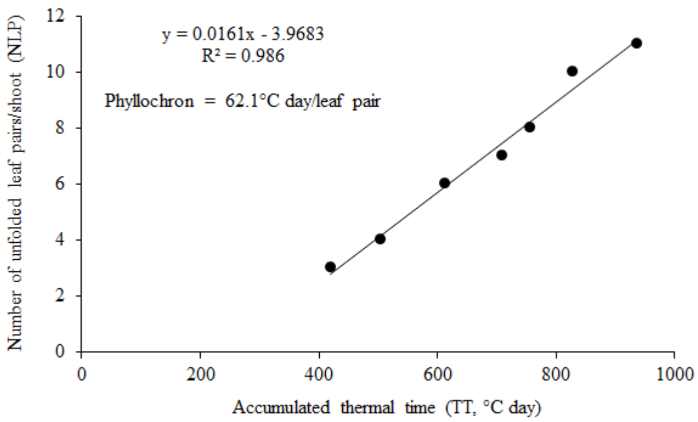

Figure 1. Number of accumulated unfolded leaf pairs (NLP) as a function of accumulated thermal time from emergence (TT) in one plant of dahlia cultivar "Rebecca's World" in Experiment 3 in Júlio de Castilhos, Rio Grande do Sul State, Brazil, 2022. The equation is the linear regression with its coefficient of determination (R^2) and the phyllochron is the inverse of the slope of the linear regression (1/0.0161).

The variable phyllochron (°C day leaf pair^{-1}) did not has homogeneity between the variances of the three experiments, and therefore the evaluation was performed using the Kruskal-Wallis test. The test of hypothesis resulted in a *p*-value = 0.0871, which is not significant, indicating that there was no difference in phyllochron among the experiments. Then, the variable phyllochron was evaluated by the median and the interval between the quartiles. The E1 (experiment 1) had a median = 69.9 (60.0 to 77.0 °C day leaf pair^{-1}), E2 (experiment 2) had a median = 70.4 (58.0 to 79.0 °C day leaf pair^{-1}), and E3 (experiment 3) had a median = 63.9 (57.0 to 72.9 °C day leaf pair^{-1}).

The variable FLPN (leaf pairs/stem) did not present a normal distribution in experiments E2 and E3, and therefore the statistical analysis was performed using the Kruskal-Wallis test. The test of hypothesis resulted in a *p*-value = 0.1690, which is not significant, indicating that there was no difference in FLPN among the experiments. Because of that, the variable FLPN was also evaluated by the median and the interval between the quartiles. The FLPN in E1 had a median = 11.0 (10.0 to 12.0 leaf pairs stem^{-1}), in E2 had a median = 11.0 (10.0 to 12.0 leaf pairs stem^{-1}), and E3 had a median = 11.0 (10.0 to 12.0 leaf pairs stem^{-1}). Statistics for the comparison of the variables phyllochron and FLPN in the experiments are in Table 2, and a graphical representation of no effect of Experiments E1, E2, and E3 on phyllochron and FLPN is in Figures 2 and 3, respectively.

Analysis of central tendency and variability of the phyllochron within each location was performed using the Kruskal-Wallis test (Table 3).

Table 2. Comparison for the variables phyllochron (°C day leaf pair^{-1}) and final leaf pair number on the main shoot (FLPN, leaf pairs stem^{-1}) in dahlia for on farm experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1.

Statistics	**Variables**					
	Phyllochron			FLPN		
	E1	E2	E3	E1	E2	E3
Sample size	15	10	8	15	10	8
Minimum	46.5	27.2	46.8	8.0	6.0	6.0
Maximum	95.6	97.4	106.4	14.0	15.0	13.0
Median	69.6	70.4	63.9	11.0	11.0	11.0
1st Quartile	60.0	58.0	57.0	10.0	10.0	10.0
3rd Quartile	77.0	79.1	72.9	12.0	12.0	12.0
Arithmetic Mean	69.1	67.8	65.4	10.7	10.9	10.9
Standard Deviation	11.3	16.1	12.3	1.2	1.2	1.5
Coefficient of Variation	16.39%	23.77%	18.76%	10.90%	11.39%	13.58%
Normality (p-value)	0.4819	0.1036	0.0145	0.4299	< 0.0001	0.004
Homoscedasticity (p-value)	0.0343 (heterocedasticity)			0.4544 (homocedasticity)		
Kruskal-Wallis (p-value)	0.0871(ns)			0.1690(ns)		

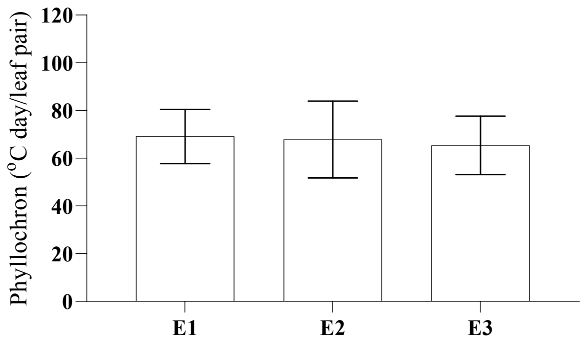

Figure 2. Phyllochron in dahlia, median of cultivars and locations in three on farm experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Error bars are one standard deviation of the median.

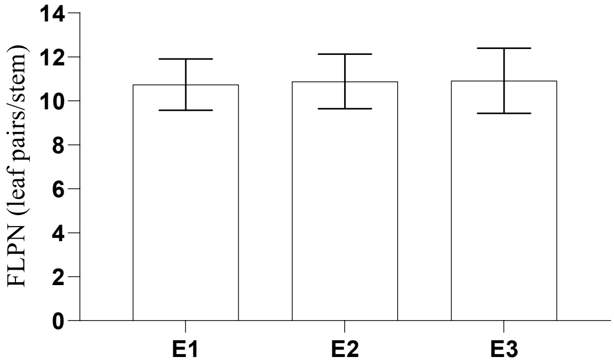

Figure 3. Final leaf pair number (FLPN) in dahlia, median of cultivars and locations in three on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Error bars are one standard deviation of the median.

Table 3. Comparison of locations (JA, SM, CS, JC, LA, NC) for the variable phyllochron (°C day leaf pair^{-1}) in dahlia in on farm experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1.

Statistics	Experiments							
	E1		E2		E3			
	JA	SM	CS	SM	CS	JC	LA	NC
Sample size	7	8	5	5	2	2	2	2
Minimum	57.6	46.5	45.7	27.2	48.0	56.8	46.8	49.1
Maximum	94.9	95.6	83.6	97.4	87.1	106.4	92.9	88.2
Median	74.7	67.1	66.0	70.6	61.3	69.9	58.8	64.2
1st Quartile	65.6	59.0	58.0	58.3	53.4	63.5	55.5	58.4
3rd Quartile	77.6	75.3	75.5	81.6	67.5	76.9	70.8	69.2
Arithmetic Mean	73.4	67.6	66.2	68.1	62.0	71.7	64.4	64.3
Standard Deviation	9.8	11.5	10.7	17.0	10.9	12.7	14.0	10.7
Coeff. Variation	13.4%	17.0%	16.1%	25.0%	17.6%	17.8%	21.7%	16.7%

**p*-value = 0.0417, Kruskal-Wallis. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul.

The test of hypothesis resulted in a *p*-value = 0.0417, which indicates that there was a statistically significant difference. This difference was evaluated using Dunn's post-test, which indicated that there was a difference between Jaguari (E1) and Lajeado (E3). Jaguari has a median of 74.7 (56.6 to 77.6 °C day leaf pair^{-1}), significantly higher than the median in Lajeado 64.2 (58.4 to 69.2 °C day leaf pair^{-1}). A graphical representation of the location effect on the phyllochron, with the median and interquartile range, shows the differences between Jaguari and Lajeado (Figure 4).

For the variable final leaf pair number on the main shoot, the locations effect was not significant, (*p*-value = 0.4491, Table 4) and a graphical representation of no effect of location on FLPN is in Figure 5.

The cultivar effect on the phyllochron using the Kruskal-Wallis test was highly significant (*p*-value < 0.0001*), as shown in Table 5. Considering this difference, we divided the cultivars in two groups according to the phyllochron.

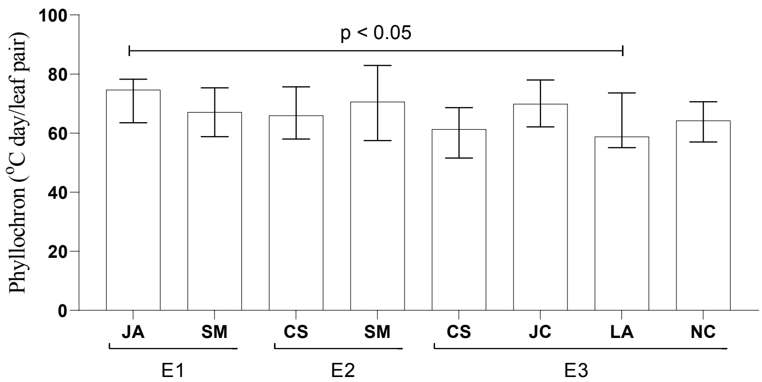

Figure 4. Median and interquartile range of the variable phyllochron in dahlias for comparison of locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul. The p-value indicates difference between JA in E1 and LA in E3.

Table 4. Comparison of locations (JA, SM, CS, JC, LA, NC) for the variable final leaf pair number on the main shoot (leaf pairs stem^{-1}) in dahlia in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1.

Statistics	Experiments							
	E1		E2		E3			
	JA	SM	CS	SM	CS	JC	LA	NC
Sample size	7	8	5	5	2	2	2	2
Minimum	9.0	8.0	6.0	7.0	6.0	10.0	10.0	8.0
Maximum	14.0	13.0	15.0	13.0	13.0	12.0	12.0	13.0
Median	10.0	11.0	11.0	11.0	11.5	11.0	11.0	11.5
1st Quartile	10.0	10.0	11.0	10.0	9.0	10.5	11.0	9.0
3rd Quartile	11.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Arithmetic Mean	10.7	10.8	11.2	10.8	10.6	11.2	11.2	10.8
Std. Deviation	1.1	1.2	1.9	1.1	1.9	0.9	0.8	1.8
Coeff. Variation	10.1%	11.2%	17.1%	9.8%	18.4%	7.7%	7.2%	16.4%

*p-value = 0.4491, Kruskal-Wallis. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul.

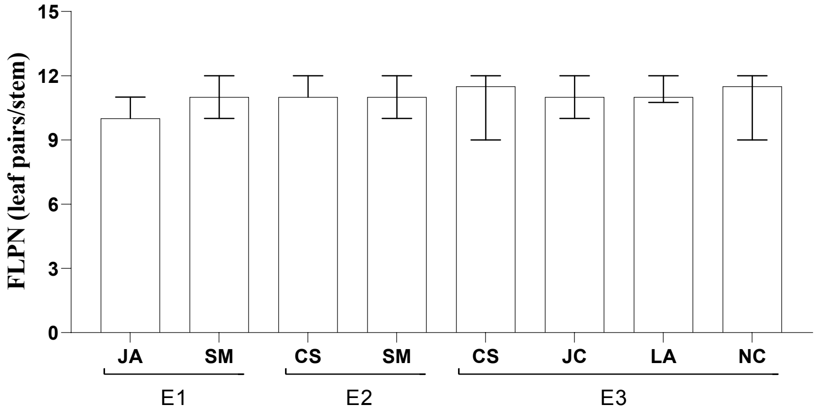

Figure 5. Median and interquartile range of the variable final leaf pair number on the main shoot (FLPN, leaf pairs stem^{-1}) in dahlias for comparison of locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul.

Table 5. Comparison of cultivars for the variable phyllochron (°C day leaf pair^{-1}) in dahlia in different locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1.

LOC	Cv.	Min	Max	MD	1st Q	3rd Q	Mean	SD
Experiment 1								
JA	Promise	60.0	78.6	74.8	70.4	76.4	72.0	8.3
	Siberia	58.7	94.9	86.8	78.1	90.4	81.8	16.0
	Rebecca's World	66.6	82.0	77.0	74.4	78.3	75.7	6.5
	Dark Spirit	61.8	82.2	66.8	62.3	73.9	69.4	9.5
	Frantonio	57.6	77.0	65.7	59.6	72.5	66.5	9.1
	Vera	73.7	73.7	73.7	73.7	73.7	73.7	---
	Mom's Special	72.3	77.2	77.2	74.8	77.2	75.6	2.8
SM	Promise	46.5	67.9	52.6	48.9	58.5	54.2	7.3
	Siberia	75.3	94.9	82.2	79.5	85.7	83.1	6.7
	Rebecca´s World	54.3	72.2	60.6	59.5	66.3	62.5	5.8
	Dark Spirit	55.2	86.4	67.1	63.4	81.1	71.5	11.5
	Pompom	56.7	74.8	63.1	59.4	71.1	64.7	6.7
	Frantonio	46.5	73.3	58.1	54.6	65.2	59.5	8.2
	Vera	71.6	81.5	75.1	73.7	78.7	75.9	3.2
	Mom's Special	60.9	95.6	68.0	63.8	73.6	71.0	11.2
Experiment 2								
CS	Promise	52.4	78.3	59.7	56.6	65.6	62.5	11.1
	Siberia	55.5	83.6	69.9	63.2	79.2	70.3	11.5
	Rebecca's World	45.7	76.6	66.0	58.0	75.9	64.4	13.0
	Dark Spirit	48.3	75.5	70.2	65.2	74.8	67.3	10.3
	Pompom	63.2	63.2	63.2	63.2	63.2	63.2	---
SM	Promise	53.2	90.2	75.3	71.4	77.2	73.9	7.7
	Siberia	38.1	97.4	65.1	57.5	75.6	66.2	15.5
	Rebecca's World	27.2	86.0	56.0	38.1	68.0	55.3	18.4
	Dark Spirit	28.8	97.2	79.6	70.0	83.6	75.2	14.2
	Pompom	38.1	97.2	71.3	63.5	88.3	73.4	17.4
Experiment 3								
JC	Siberia	73.1	106.4	79.8	76.4	83.7	83.2	12.0
	Rebecca's World	56.8	72.9	64.9	60.8	65.3	64.0	5.2
LA	Siberia	55.4	92.9	70.8	56.7	81.7	70.8	14.1
	Rebecca's World	46.8	70.7	54.8	49.1	59.3	55.9	8.9
NC	Siberia	64.6	88.2	71.7	66.1	76.3	72.8	8.3
	Rebecca's World	49.1	69.3	58.6	50.7	61.8	57.5	6.9
CS	Siberia	63.9	87.1	69.2	65.3	75.9	71.5	8.1
	Rebecca's World	48.0	61.3	54.6	49.4	58.1	54.4	5.4

* *p*-value <0.0001, Kruskal-Wallis, post hoc Dunn test. LOC (Locations), Cv. (Cultivar) Min. (Minimun), Ma.x (Maximum), MD (Median),1st Q (Fist quartile), 3rd Q (Third quartile), Mean (Arithmetic mean), SD (Standard Deviation). Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul.

The first group, considered the cultivars with the higher phyllochron values, which includes Siberia (Experiment 1 in Jaguari and Santa Maria plus Experiment 3 in Júlio de Castilhos) and Dark Spirit (Experiment 2 in Santa Maria). The second group consider the cultivars with lower phyllochron values: Promise (Experiment 1 in Santa Maria), and Rebecca's World (Experiment 2 in Santa Maria and Experiment 3 in Lajeado, Novo Cabrais and Cachoeira do Sul. A graphical representation of the effect of cultivar on the phyllochron is in Figure 6.

When compared the final leaf pair number on the main shoot (FLPN) using the Kruskal-Wallis test, a statistically significant difference (*p*-value < 0.05*) was identified to the cultivar effect (Table 6).

Then two groups were formed: a group included the cultivars with higher FLPN values: Promise (Experiment 1in Jaguari and Experiment 2 in Cachoeira do Sul), Mom's Special (Experiment 1 in Santa Maria), Pompom (Experiment 2 in Cachoeira do Sul) and Rebecca's World (Experiment 3 in Júlio de Castilhos, Lajeado, Cachoeira do Sul). The other group included the cultivars with lower FLPN, that are: Siberia (Experiment 3 in Novo Cabrais and Cachoeira do Sul), and Rebecca's World, cultivated in Novo Cabrais. A graphical representation of the cultivar effect on the FLPN is in Figure 7.

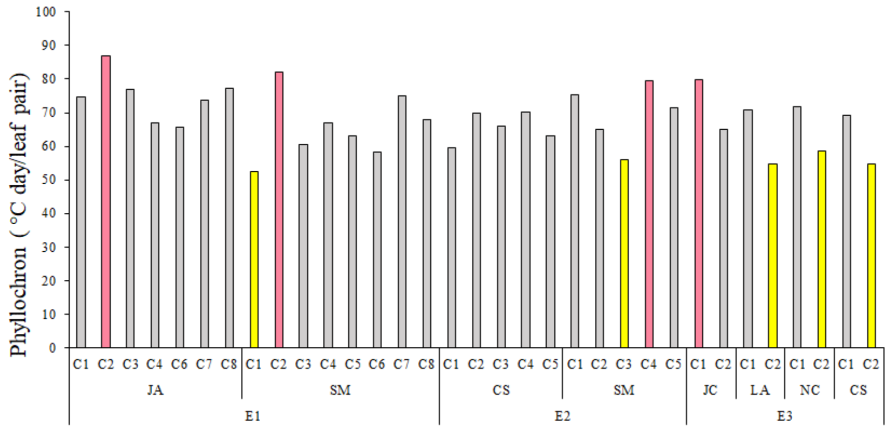

Figure 6. Median of the variable phyllochron in dahlias for comparison of cultivars in different locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio de Castilhos, LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul. Cultivars: in Experiment 1 C1 = Promise, C2 = Siberia, C3 =Rebecca's World, C4 =Dark Spirit, C5 = Pompom, C6 = Frantonio, C7 = Vera, C8 = Mom's Special; in Experiment 2 C1 = Promise, C2 = Siberia, C3 =Rebecca's World, C4 =Dark Spirit, C5 = Pompom; in Experiment 3 C1 =Siberia C2 =Rebecca's World. Red bars are different from yellow bars according to the Kruskal-Wallis test at 5% probability.

Table 6. Comparison of cultivars for the variable final leaf pair number on the main shoot (leaf pairs stem^{-1}) in dahlia in different locations (JA, SM, CS, JC, LA, NC) in on farm experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1.

LOC	Cv.	Min	Max	MD	1st Q	3rd Q	Mean	SD
Experiment 1								
JA	Promise	10.0	14.0	12.0	11.5	12.5	12.0	1.6
	Siberia	10.0	11.0	11.0	10.8	11.0	10.8	0.5
	Rebecca's World	10.0	11.0	10.5	10.0	11.0	10.5	0.6
	Dark Spirit	9.0	12.0	11.5	10.5	12.0	11.0	1.4
	Frantonio	10.0	10.0	10.0	10.0	10.0	10.0	0.0
	Vera	9.9	10.0	10.0	10.0	10.0	10.0	0.1
	Mom's Special	10.0	10.0	10.0	10.0	10.0	10.0	0.0
SM	Promise	10.0	12.0	12.0	11.0	12.0	11.5	0.8
	Siberia	9.0	10.0	10.0	9.0	10.0	9.6	0.5
	Rebecca´s World	10.0	12.5	10.3	10.0	11.3	10.8	1.0
	Dark Spirit	8.0	11.0	10.0	9.0	11.0	9.9	1.1
	Pompom	11.0	13.0	11.0	11.0	12.0	11.6	0.8
	Frantonio	9.0	10.0	10.0	9.0	10.0	9.6	0.5
	Vera	10.0	12.0	11.0	11.0	12.0	11.2	0.8
	Mom's Special	9.0	13.0	12.0	12.0	12.3	11.9	1.2
Experiment 2								
CS	Promise	6.0	14.0	12.5	10.5	13.3	11.3	3.6
	Siberia	11.0	12.0	11.0	11.0	12.0	11.4	0.5
	Rebecca's World	10.0	15.0	11.0	11.0	11.0	11.6	1.9
	Dark Spirit	8.0	12.0	11.0	9.5	11.8	10.5	1.6
	Pompom	11.9	12.0	12.0	12.0	12.0	12.0	0.1
SM	Promise	9.0	12.0	11.5	11.0	12.0	11.3	0.9
	Siberia	8.0	12.0	11.0	10.0	12.0	10.6	1.3
	Rebecca's World	9.0	13.0	11.0	10.0	12.0	11.0	1.0
	Dark Spirit	7.0	12.0	11.0	11.0	11.0	10.8	1.1
	Pompom	8.0	12.0	11.0	10.0	11.0	10.6	1.0
Experiment 3								
JC	Siberia	10.0	11.0	10.0	10.0	10.8	10.3	0.5
	Rebecca's World	11.0	12.0	12.0	12.0	12.0	11.8	0.4
LA	Siberia	10.0	11.0	11.0	10.0	11.0	10.6	0.5
	Rebecca's World	12.0	12.0	12.0	12.0	12.0	12.0	0.0
NC	Siberia	8.0	10.5	9.0	8.4	9.3	9.0	0.9
	Rebecca's World	11.0	13.0	12.0	12.0	12.4	12.2	0.6
CS	Siberia	6.0	10.5	9.0	8.4	9.3	8.8	1.4
	Rebecca's World	11.0	13.0	12.0	12.0	12.2	12.1	0.5

* *p*-value <0.0001, Kruskal-Wallis, post hoc Dunn test. LOC (Locations), Cv. (Cultivar), Min (Minimun), Max (Maximum), MD (Median),1st Q (Fist quartile), 3rd Q (Third quartile), Mean (Arithmetic mean), SD (Standard Deviation). Locations: JA (Jaguari), SM (Santa Maria), CS (Cachoeira do Sul), JC (Júlio de Castilhos), LA (Lajeado), NC (Novo Cabrais) and CS (Cachoeira do Sul).

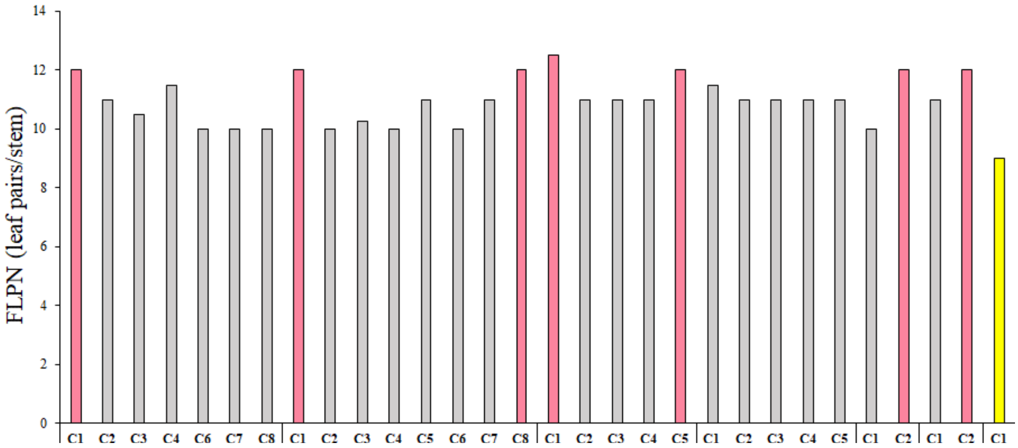

Figure 7. Median of the variable final leaf pair number on the main shoot (FLPN) (leaf pairs stem^{-1}) in dahlias for comparison of cultivars in different locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria), CS = Cachoeira do Sul, JC = Júlio de Castilhos , LA = Lajeado, NC = Novo Cabrais, and CS = Cachoeira do Sul. Cultivars: in Cultivars: in Experiment 1 C1 = Promise, C2 = Siberia, C3 =Rebecca's World, C4 =Dark Spirit, C5 = Pompom, C6 = Frantonio, C7 = Vera, C8 = Mom's Special; in Experiment 2 C1 = Promise, C2 = Siberia, C3 =Rebecca's World, C4 =Dark Spirit, C5 = Pompom; in Experiment 3 C1 =Siberia C2 =Rebecca's World. Red bars are different from yellow bars according to the Kruskal-Wallis test at 5% probability.

Discussion

Ecophysiological studies use different variables and factors to understand the dynamics of plant development. Brondun and Heins (1993) demonstrated the effect of temperature and photoperiod on the growth and development of dahlias plants. Temperatures during the three on farm experiments varied from an average of 21.6 to 29.9 °C (Table 1), which are high temperatures for dahlias and therefore challenging environments for adaptation of cut dahlias. No previous studies that investigated the dynamics of development during the vegetative phase in dahlias were found. To our knowledge, this study is the first that quantifies the phyllochron and the final leaf pair number considering different locations, cultivars and planting dates, thus providing a strong robust data set and results.

The effect of planting date on the phyllochron already was widely studied for the other ornamentals as *Lilium longiflorum* Thunb. (Streck et al., 2004), *Calendula Officinalis* L. (Koefender et al., 2008) and *Gladiolus* x *grandiflorus* Hort. (Streck et al., 2012). Similarly, for these studies, the reason for differences in the dahlia phyllochron between locations can be explained by the environmental. The Experiment 1, in Jaguari, occurred during the end Summer and Autumn, a period when temperatures are decreasing conferring a higher phyllochron than in Lajeado, where the experiment started in the end Spring and Summer. Studies demonstrating how the phyllochron may vary among different growing seasons were also identified in other species, like *Salvia hispanica* L. (Goergen et al., 2022), *Sorghum bicolor* (L.) Moench (Camera et al., 2023), and *Oryza sativa* L. (Streck et al., 2007). In wheat (*Triticum aestivum*), the phyllochron varied with the cultivar and sowing date, demonstrating a higher phyllochron in autumn or winter sowings than in spring or summer sowings (Rosa et al., 2009). The phyllochron in oats (*Avena sativa* L.*)* varies according to the cultivars, with early cultivars having a lower phyllochron compared to later cultivars. This variation may have practical implications for crop cultivation, such as predicting the flowering date and fertilization recommendations. This demonstrates that although there is little variation in the number of leaves between cultivars, there is a phyllochron difference for the evaluated genotypes. In addition, the different stimuli verified at different planting times (photoperiod and temperature) have a strong influence on plant development (Oliveira et al., 2018). Furthermore, the results showed differences not only among locations, but also among cultivars, indicating that besides the environmental, genetic also plays an import role in defining the phyllochron and therefore the dynamics of plant development during the vegetative phase.

The FLPN is an important variable for defining the end the vegetative phase in dahlia. After the FLPN is defined, the development of flower bud starts indicating the onset of the reproductive phase of a dahlia crop. In this study, the FLPN was affected by cultivar and not by location, indicating that FLPN is a genetic trait that is little affected by environment in the dahlia cultivars used in the study. The practical implication of this result is that field observations of FNPN can easily help farmers in planning harvesting time. In calendula, final number of leaves was influenced by sowing date, with final number of leaves on the main stem of the April sowing (26.6 leaves main stem^{-1}) higher compared to June and October sowings (22.8 leaves main stem-1) (Koefender et al., 2008). In gladiolus, the duration of the vegetative phase until heading has a positive linear relationship with the duration of the total cycle and, determined by the rate of appearancd of leaves and the final number of leaves. Early cultivars have a higher rate of leaf appearance (lower phyllochron) and lower final number of leaves than late cultivars (Streck et al., 2012).

Conclusions

In dahlia, the phyllochron ranged from 27.2 to 106.4 ºC day pair of leaves^{-1}, in cultivars Rebecca's World and Siberia respectively and FLPN from 6 to 15 pairs of leaves/stem depending on the cultivar, with no significant difference between locations. As FLPN is a genetic trait little affected by environment in the dahlia cultivars used in the study, the practical implication of this result is that FLPN field observations can easily help farmers in planning the harvest time.

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Author Contribution

MESF: conception of the work, collection, analysis and interpretation of the data, writing and critical review of the article. **RT:** conception of the work, collection, analysis and interpretation of the data, writing and critical review of the article. **CPOF:** conception of the work, collection, analysis and interpretation of the data, writing and critical review of the article. **TPR:** conception of the work, collection, analysis and interpretation of the data, writing and critical review of the article. **LF:** conception of the work, collection, analysis and interpretation of the data, writing and critical review of the article. **LOU:** work advisor, work conception, data collection, analysis and interpretation, writing and critical review of the article. **AZJ:** work advisor, work conception, data collection, analysis and interpretation, writing and critical review of the article. **NAS:** work advisor, work conception, data collection, analysis and interpretation, writing and critical review of the article.

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