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DESENVOLVIMENTO, CRESCIMENTO E QUALIDADE DE HASTES FLORAIS DE DÁLIAS CULTIVADAS A CAMPO

Santa Maria, RS
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Dissertação apresentada ao Programa de Pós-Graduação em Engenharia Agrícola, da Universidade Federal de Santa Maria (UFSM-RS), como requisito parcial para obtenção do título de **Mestre em Engenharia Agrícola.**

Orientador: Prof. PhD. Nereu Augusto Streck

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Dedico aos meus filhos amados.

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A cada novo progresso que alcances, descobrirás que teu horizonte se amplia.

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RESUMO

DESENVOLVIMENTO, CRESCIMENTO E QUALIDADE DE HASTES FLORAIS DE DÁLIAS CULTIVADAS A CAMPO

AUTORA: Moara Eliza Siqueira Fernandes
ORIENTADOR: Prof. PhD. Nereu Augusto Streck

A dália (*Dahlia* spp) é uma planta ornamental amplamente apreciada no mundo da jardinagem e paisagismo. Pertencente à família *Asteraceace*, ela se propaga por meio de várias técnicas, incluindo sementes, estacas, caules e tubérculos. No Rio Grande do Sul, a Equipe PhenoGlad da Universidade Federal de Santa Maria lidera um importante experimento dedicado a entender a ecofisiologia e a adaptação de diferentes cultivares de dália nas condições subtropicais do Brasil. Este estudo, realizado em colaboração com a Academia Brasileira de Artistas Florais e um produtor de bulbos em Holambra, São Paulo, é parte integrante do Projeto Flores para Todos, uma iniciativa liderada pela Equipe PhenoGlad. Desde seu início, em 2018, o projeto alcançou notáveis conquistas até junho de 2023, incluindo o envolvimento de 313 famílias rurais e 53 escolas do campo em 16 estados brasileiros e no Distrito Federal. Seu propósito é multifacetado, visando transformar a floricultura em uma alternativa de renda para os agricultores familiares, fomentar a produção e o consumo local de flores, criar empregos na comunidade, resgatar espécies de flores de baixo custo de produção e incentivar a permanência da juventude no campo para garantir a continuidade das famílias rurais. O estudo tem como objetivo geral compreender e caracterizar o crescimento e desenvolvimento das dálias cultivadas em campo no Sul do Brasil. Isso se torna ainda mais relevante devido às mudanças climáticas que estão causando aumento das temperaturas e ondas de calor extremo. O primeiro artigo concentrou-se na determinação da temperatura letal superior que causa danos irreversíveis nas dálias, concluindo que lesões térmicas irreversíveis ocorrem a partir de 35°C. Isso tem implicações importantes para os agricultores, que podem adotar práticas como sombreamento artificial e a escolha adequada das datas de plantio para mitigar o estresse térmico. O segundo artigo analisou o desenvolvimento das folhas durante a fase vegetativa das dálias, identificando variações no filocrono e no número final de pares de folhas em diferentes cultivares. Esses resultados fornecem informações valiosas para os produtores, permitindo a otimização do crescimento de suas culturas. O terceiro artigo explorou o crescimento e desenvolvimento de onze cultivares de dália em condições subtropicais no Brasil, levando em consideração as condições climáticas específicas da região. Os resultados destacaram a influência significativa da temperatura do ar no desenvolvimento das plantas, com diferenças notáveis entre cultivares e locais. Isso oferece orientações cruciais para o planejamento agrícola e a seleção adequada de cultivares em diferentes condições. Ao longo do estudo, algumas cultivares se destacaram por sua adaptabilidade e interesse comercial, como Rebecca's World e Sibéria, que também apresentaram características de rusticidade. Essa pesquisa fornece uma compreensão abrangente da cultura da dália, desde sua resposta ao estresse térmico até a seleção de cultivares ideais em diversas condições climáticas. Essas descobertas são fundamentais para capacitar os agricultores a enfrentar os desafios das mudanças climáticas e promover uma produção sustentável de dálias no Brasil.

Palavras-chave: Dhalia. Desenvolvimento foliar. Estresse térmico. Produção de Flores.

ABSTRACT

DEVELOPMENT, GROWTH AND QUALITY OF FIELD CULTIVATED DAHLIA FLORAL STEM

AUTHOR: MOARA ELIZA SIQUEIRA FERNANDES
SUPERVISOR: Profº PhD. NEREU AUGUSTO STRECK

The dahlia (*Dahlia* spp) is a widely cherished ornamental plant in the world of gardening and landscaping. Belonging to the Asteraceae family, it propagates through various techniques, including seeds, cuttings, stems, and tubers. In Rio Grande do Sul, the PhenoGlad Team at the Federal University of Santa Maria leads an important experiment dedicated to understanding the ecophysiology and adaptation of different dahlia cultivars in the subtropical conditions of Brazil. This study, conducted in collaboration with the Brazilian Academy of Floral Artists and a bulb producer in Holambra, São Paulo, is an integral part of the "Flowers for All" Project, an initiative led by the PhenoGlad Team. Since its inception in 2018, the project has achieved remarkable milestones until June 2023, including the involvement of 313 rural families and 53 rural schools in 16 Brazilian states and the Federal District. Its purpose is multifaceted, aiming to transform floriculture into an income alternative for family farmers, promote local production and consumption of flowers, create jobs in the community, rescue low-cost flower species, and encourage youth to stay in rural areas to ensure the continuity of rural families. The overarching goal of the study is to understand and characterize the growth and development of dahlias cultivated in the southern region of Brazil. This becomes even more relevant due to climate change, which is causing rising temperatures and extreme heatwaves. The first article focused on determining the upper lethal temperature that causes irreversible damage to dahlias, concluding that irreversible thermal injuries occur at temperatures above 35°C. This has important implications for farmers, who can adopt practices such as artificial shading and selecting appropriate planting dates to mitigate heat stress. The second article analyzed leaf development during the vegetative phase of dahlias, identifying variations in phyllochron and the final number of leaf pairs in different cultivars. These results provide valuable information for growers, allowing for the optimization of crop growth. The third article explored the growth and development of eleven dahlia cultivars in subtropical conditions in Brazil, taking into account the specific climatic conditions of the region. The results highlighted the significant influence of air temperature on plant development, with notable differences between cultivars and locations. This offers crucial guidance for agricultural planning and the proper selection of cultivars under different conditions. Throughout the study, some cultivars stood out for their adaptability and commercial interest, such as Rebecca's World and Siberia, which also exhibited hardiness characteristics. This research provides a comprehensive understanding of dahlia cultivation, from its response to thermal stress to the selection of ideal cultivars under diverse climatic conditions. These findings are essential to empower farmers to tackle the challenges of climate change and promote sustainable dahlia production in Brazil.

Key-words: Dhalia. Leaf development. Thermal stress. Flower production.

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LISTA DE ABREVIATURAS E SIGLAS

Ascar	Associação Sulina de Crédito e Assistência Rural
CS	Cachoeira do Sul
Emater	Empresa de Assistência Técnica e Extensão Rural
FLPN	Número final de pares de folhas
JA	Jaguari
JC	Júlio de Castilhos
INMET	Instituto Nacional de Meteorologia
IPCC	Intergovernmental Panel on Climate Change
LA	Lajeado
NC	Novo Cabrais
NFP	Número de folhas desdobradas
NLP	Número final de pares
PR	Paraná
RS	Rio Grande do Sul
SEAPDR	Secretaria da Agricultura, Pecuária e Desenvolvimento Rural
SM	Santa Maria
Tb	Temperatura Basal Inferior
TB	Temperatura Basal Superior
TLb	Temperatura Letal Irreversível
TLup	
Topt	Temperatura Ideal
TT	Tempo Térmico
TTd	
UFSM	Universidade Federal de Santa Maria

SUMÁRIO

1 INTRODUÇÃO

Anualmente, o comércio internacional de flores e plantas ornamentais movimenta bilhões de dólares. Somente no ano de 2018, por exemplo, somadas as exportações feitas por 102 países, o valor comercializado ultrapassou 20 bilhões. A Holanda é o país responsável pela maior parte dos valores movimentados (51,2%), representando grande influência no mercado de flores e plantas ornamentais, destacando-se também como a segunda maior importadora mundial. No mesmo período, no Brasil, o valor atingido pela comercialização de flores e plantas ornamentais chegou a marca dos 1,75 bilhões de reais (BRAINER, 2019).

O mercado de flores e plantas ornamentais, em âmbito geral, classifica-se em três grandes grupos: flores e folhagens de corte, flores e plantas em vasos (plantadas) e plantas para paisagismo e jardinagem. As flores e folhagens de corte são hastes de flores ou folhagens colhidas (cortadas) das plantas que as originaram e representam 30% do mercado florícola brasileiro (HUMMEL; SILVA, 2020).

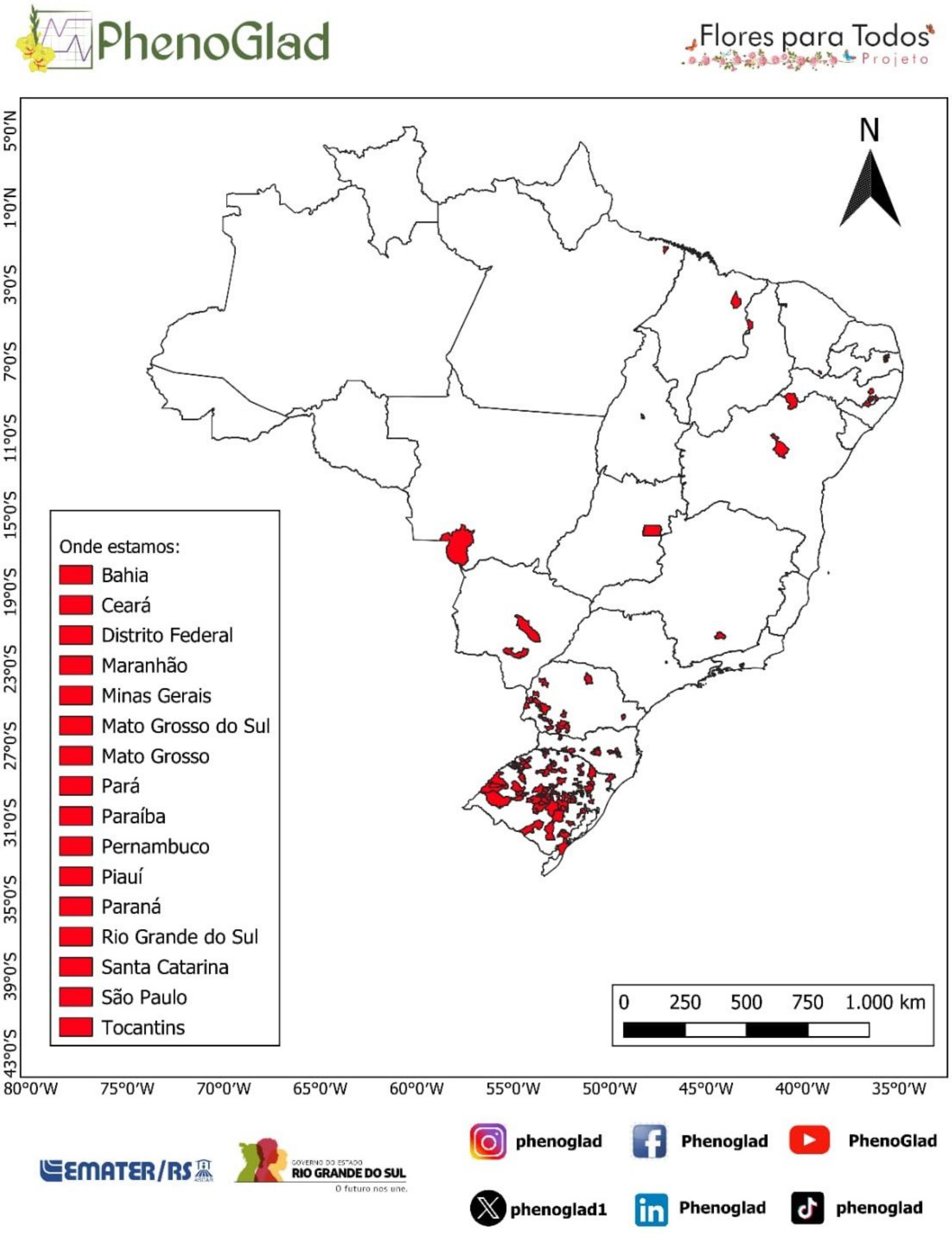
As flores de corte, dentre as quais a dália se classifica, somam em torno da metade do mercado de horticultura mundial. A Holanda lidera a produção de tubérculos de dália, seguida da França e do Chile. A produção e a comercialização de flores e plantas como a dália, para fins decorativos, vêm atingindo um crescimento significativo, isso porque o cultivo dessa planta, além da variedade de cores e da beleza, é caracterizado pela fácil propagação (MARINA, 2015).

Logo, cultivar a dália para flor de corte em regiões com condições climáticas favoráveis pode representar um considerável potencial econômico para as famílias da região, pois estas, ao se beneficiarem dessas condições, podem cultivar essa planta para comercialização. As oportunidades dos produtores locais de agregarem valor à produção são provenientes não só do conhecimento empírico, mas também conquistadas por meio da experimentação para implementar e manter esse cultivo (HEREDIA-HERNANDEZ; BALTAZAR-BERNAL, 2017).

Diante desse contexto, a Equipe PhenoGlad da Universidade Federal de Santa Maria (UFSM) iniciou um experimento inédito com dálias no Rio Grande do Sul, com objetivo de compreender, além da ecofisiologia, a adaptação de cultivares de dália nos subtrópicos brasileiros. O estudo ocorre em parceria com a Academia Brasileira de Artistas Florais e com um produtor de bulbos de Holambra/São Paulo-SP, com o intuito de incluir esta flor no Projeto Flores para Todos.

O Projeto Flores para Todos é conduzido pela Equipe PhenoGlad, composta por diversas universidades e institutos federais no Rio Grande do Sul-RS, em colaboração com a Empresa de Assistência Técnica e Extensão Rural (Emater) e a Associação Sulina de Crédito e Assistência Rural (Ascar) do Rio Grande do Sul (RS) e do Paraná (PR). O objetivo do projeto é promover a floricultura como fonte de renda para agricultores familiares, estimulando a produção e consumo locais de flores, gerando empregos na comunidade, resgatando espécies de flores de baixo custo de produção com potencial de consumo, além de incentivar a permanência dos jovens no campo para garantir a sucessão das famílias rurais (ULHMANN *et al.*, 2019). Desde seu início, no primeiro semestre de 2018 (primeira fase), até junho de 2023 (11ª fase), o projeto Flores para Todos já alcançou 313 famílias rurais e 53 escolas do campo em 16 estados brasileiros e Distrito Federal (Figura 1). Os números atuais da 11ª fase do Projeto em andamento em todo Brasil são: Girassol: 12 produtores e 2 escolas do campo em 14 municípios de 3 estados brasileiros. Com as culturas do gladíolo são 17 produtores, 1 escola do campo e 1 universidade em 12 municípios. Já com a statice, são 22 produtores e 2 escolas em 21 municípios, com o ornithogalum, 3 produtores em 3 municípios. Por fim, a Dália, cultura objeto de estudo da presente pesquisa, conta com 6 produtores em 6 municípios.

Figura 1 - A geografia do Projeto Flores para Todos no Brasil de 2018 a 2023.



Fonte: Redes sociais da equipe PhenoGlad (2023).

A metodologia do projeto Flores para Todos consiste em acompanhar e assessorar os produtores e escolas por meio de visitas técnicas das Equipes PhenoGlad e dos extensionistas da Emater, desde o plantio até a colheita da flor, de maneira a proporcionar que tanto os alunos quanto os produtores aprendam as técnicas de cultivo e assim consigam prosseguir sozinhos nos cultivos seguintes. Além do gladíolo e da statice, há uma demanda por outras espécies de flores de corte para aumentar o portfólio de espécies para os agricultores familiares e as escolas. A dália é uma destas espécies, pois atende aos requisitos para sucesso no projeto, como cultivo a campo, fácil manejo e boa aceitação do consumidor. Estudos ainda estão sendo realizados pela equipe para determinar a durabilidade pôs colheita, e desenvolver técnicas que propiciem a uma maior durabilidade em vaso.

Um estudo desenvolvido na cidade de Veracruz, no México, dedicou-se a descrever as etapas do cultivo, desde a germinação até a comercialização da dália, considerando as principais variáveis observadas, como fotoperíodo, manejo integrado de pragas, manejo ambiental e umidade do substrato (HEREDIA-HERNANDEZ; BALTAZAR-BERNAL, 2017). Outras pesquisas tem objetivado conhecer as características e a qualidade da flor de corte, abordando parâmetros relacionados à sua origem, importância econômica, descrição botânica, tratos culturais, propagação, entre outros. Assim, observa-se que a dália é uma cultura com grande potencial na floricultura, disseminando-se facilmente por estacas, com hábito perene e crescimento arbustivo (MARINA, 2015).

Nesse sentido, o cultivo dessa planta tem se tornado uma opção para a diversificação de propriedades rurais. Por ser uma planta rústica que pode ser produzida a campo, sem estufa, de fácil propagação por tubérculos e não demanda muito investimento, é uma cultura que atrai o seu cultivo. Dessa forma, o intuito do projeto Flores para Todos é levar a cultura da dália para as pequenas propriedades familiares, e a Equipe PhenoGlad, em conjunto com a Equipe da Emater/RS-Ascar transmitem conhecimentos a esses produtores quanto aos principais manejos dessa cultura. Como flor de corte, no entanto, a dália tem uma vida de vaso curta, comparada a outras flores, como gladíolo, girassol de corte, zinia, ornithogalum e agapanto. Para melhor entender possíveis variações da vida de vaso entre cultivares e épocas de cultivo, estudos básicos sobre o crescimento, desenvolvimento e adaptação de cultivares de dálias são fundamentais, mas não foram encontrados na literatura trabalhos com este foco na região subtropical do Brasil.

Dessa forma, com base nos objetivos do projeto Flores para Todos e seguindo as técnicas de manejo conduzidas pela equipe PhenoGlad, esta pesquisa tem como problema: como se dá o crescimento e o desenvolvimento de cultivares de dália cultivadas a campo no Sul do Brasil? Como objetivo geral, buscou compreender e caracterizar o crescimento e desenvolvimento das dálias cultivadas em campo no Sul do Brasil.

Esta dissertação está organizada em 3 capítulos: Artigo I - Dano e temperatura letal devido ao estresse por calor em dália cultivada a campo, que teve como objetivo determinar a temperatura letal superior que causa danos irreversíveis em botões e flores de dália cultivada a campo. Artigo II - Determinação do filocrono e número final de pares de folhas em cultivares de dálias cortadas na propriedade, cujo objetivo foi determinar o filocrono e o número final de pares de folhas em cultivares de dálias de corte em diferentes localidades. Artigo III - Desenvolvimento vegetativo e reprodutivo em dálias, que teve como objetivo avaliar várias variações fenológicas, incluindo a emergência, o número de folhas por planta, o desenvolvimento dos botões florais e o ponto de colheita das flores. Este estudo foi realizado com onze cultivares de dália, em oito locais do Estado do Rio Grande do Sul, Sul do Brasil, ao longo de três anos, estudando o crescimento e desenvolvimento de dálias em condições subtropicais.

2 ARTIGO I - Damage and lethal temperature due to heat stress in field grown dahlia*

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Abstract

Dahlia is an ornamental plant well adapted to open field cultivation and is one of the crops in the “Flowers for All” Project, a nation-wide extension project. High temperatures and the duration of extreme heat waves are expected to be more frequent in the next decades. Therefore, understanding and determining the high temperature that causes irreversible damage in dahlia flowers is of high interest for preparing farmers to mitigate and adapt their crop to climate change. The objective of this study was to determine the upper lethal temperature that causes irreversible damage on buds and flowers on open field grown dahlia.

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Commercial open field dahlia crops in five locations in Rio Grande do Sul (RS) State, Southern Brazil, during two growing seasons (2021/22 and 2022/23) were used in this study. During the period from 20 December 2021 to 30 January 2022 and from 14 January 2023 to 20 January 2023, daily observations were made in the dahlias in the five locations in order to identify symptoms of heat stress on leaves, buds and flowers such as leaf rolling, wilting, dry leaf edges, sunscald, burning and rotting. The appearance of those symptoms was correlated with maximum daily air temperature in order to estimate the lethal temperature. Irreversible heat injury in buds and flowers of open field grown dahlia start when air temperature reaches 35 ºC. Artificial shading, irrigation and planting date are management practices that can help farmers to protect dahlia flowers from heat stress.

Keywords: climate change, cut flowers, *Dahlia sp,* heat stress, heat injury, high temperatures.

Resumo

Dano e temperatura letal devido ao estresse por calor em dália cultivada a campo

A dália é uma planta ornamental bem adaptada ao cultivo a campo e é uma das culturas do Projeto “Flores para Todos”, um projeto de extensão nacional. Estima-se que as altas temperaturas e a duração de ondas de calor extremo sejam mais frequentes nas próximas décadas. Portanto, entender e determinar a alta temperatura que causa danos irreversíveis nas flores da dália é de grande interesse para preparar os agricultores para mitigar e adaptar sua cultura às mudanças climáticas. O objetivo deste estudo foi determinar a temperatura letal superior que causa danos irreversíveis em botões e flores de dália cultivada a campo. Culturas comerciais de dálias cultivadas a campo em cinco locais no estado do Rio Grande do Sul (RS), sul do Brasil, durante duas temporadas de cultivo (2021/22 e 2022/23) foram utilizadas neste estudo. Durante o período de 20 de dezembro de 2021 a 30 de janeiro de 2022 e de 14 de janeiro de 2023 a 20 de janeiro de 2023, foram feitas observações diárias nas dálias nas cinco localidades, a fim de identificar sintomas de estresse térmico em folhas, brotos e flores, como enrolamento de folhas, murchamento, bordas secas das folhas, queimaduras solares, queimaduras e apodrecimento. O aparecimento desses sintomas foi correlacionado com a temperatura máxima diária do ar para estimar a temperatura letal. Lesões térmicas irreversíveis em botões e flores de dálias cultivadas a campo começam quando a temperatura do ar atinge 35 °C. Sombreamento artificial, irrigação e data de plantio são práticas de manejo que podem ajudar os agricultores a proteger as dálias do estresse térmico.

Palavras-Chave: mudanças climáticas, flores de corte, *Dahlia sp.*, estresse por calor, lesões por calor, altas temperaturas.

Introduction

In Brazil, the consumption of flowers and ornamental plants reproduces the scenario of developing countries and other countries in Latin America, Asia and Africa, that is, the demand concentrated on special dates and occasions of the calendar, such as International Women's Day, Mother's Day, Valentine's Day, The All Souls' Day, among others. The professional activity of production, commercialization and distribution of cut flowers and ornamental plants has been one of the most promising in Brazilian agribusiness (Menegaes *et al.*, 2015; Junqueira and Peetz, 2017; Streck and Uhlmann, 2021).

Flower and ornamental crops is a promising sector for small landhoders, since it does not require an extensive area of land for cultivation and the production cycle of a large part of the species is short (Spier *et al.*, 2020). However, to be successful with a flower crop, it is necessary to know the recommended planting time to have the flowers ready for commercialization at the recommended harvest time, mainly with open field crops (Uhlmann *et al.*, 2017). Studies have been conducted on the cultivation of gladiolus in open field in Brazil, seeking to understand the influence of environmental factors, such as temperature, on the duration of the development cycle and on the quality of the selected cultivar (Schwab *et al.*, 2018), but not for dahlias.

Dahlia sp is an ornamental plant well adapted to open field cultivation, with colorful flowers, and widely used as a garden plant and as a cut flower. Belonging to the Asteraceae family, dahlia is native to the mountainous region of Mexico. It is an herbaceous, shrubby, perennial plant, with tuberous root system and upright growth. Its inflorescence is a capitulum of different types or shapes, such as orchid, anemone, pompom, waterlily, cactus and decorative, rounded in shape, with various colors of flowers and there are species of a flower of two colors. The propagation of this plant is by seeds, stem cuttings and tubers (Kashif *et al.*, 2014). Because of these agronomic and ornamental traits, dahlia is one of the crops of the “Flowers for All” Project, a nation-wide extension project that began in 2018 in order to promote the cultivation of flowers as an source of income and diversification for small landholders through species and genotypes of flowers that have rusticity, are ease of production and promote rapid financial return to farmers (Uhlmann *et al.*, 2019; Streck and Uhlmann, 2021).

Air temperature has a direct influence on plant growth and development (Bergamaschi, 2007). The lowest/highest temperature below to/above which there is no plant development or development takes place at very low rates than can be negligible are called lower base temperature (Tb) and upper base temperature (TB) while the temperature at which plant development is at the maximum rate is called the optimal temperature (Topt) (Erpen *et al.*, 2013). When temperature drops to below Tb freezing temperature or when temperature exceeds TB, then irreversible lethal temperatures (TLb and TLup, respectively) can be achieved and some organs of the plant or the whole plant die (Munns, 2018).

Cardinal temperatures for the development of dahlia are 5.5 ºC, 24.6 ºC and 34.9 ºC (minimum, optimal and maximum temperatures, respectively) during the vegetative phase, 2.4 ºC, 22.4 ºC and 31.3 ºC during the development phase of the floral bud and 5.2 ºC, 24.4ºC and 33.1 ºC from the appearance of the bud to flowering phase (Brondum and Heins, 1993). Although there are cardinal temperatures in the literature for different developmental phases of dahlia, values of TLup for floral development that cause irreversible damage by heat stress in open field cultivation were not found. High temperatures are common during the summer months in the tropics and subtropics of Southern Brazil, such as the heat wave that occurred during the month of January 2022 in Rio Grande do Sul State. This heat wave was characterized by a record of several consecutive days with extremely high maximum air temperatures (exceeding 40 ºC). In some meteorological stations of the National Institute of Meteorology (INMET) and the Secretary of Agriculture, Livestock and Rural Development (SEAPDR), 15 consecutive days were recorded with maximum daily temperatures higher than 39 ºC (Cardoso *et al.*, 2022). According to research carried out (Tazzo *et al.*, 2022). The meteorological results corroborate the INMET bulletin, which indicated that the heat wave (12 to 23 January), covered all regions of the State (INMET, 2022). Such high temperatures and the duration of extreme heat waves are expected to be more frequent in the next decades (Intergovernmental Panel on Climate Change - IPCC, 2021). Therefore, understanding and determining the high temperature that causes irreversible damage in dahlia flowers is of high interest for preparing farmers to mitigate and adapt their crop to climate change. The objective of this study was to determine the upper lethal temperature that causes irreversible damage on buds and flowers in open field grown dahlia.

Material and Methods

Commercial open field dahlia crops in Rio Grande do Sul (RS) State, Southern Brazil, during two growing seasons (2021/22 and 2022/23) were used in this study. During the 2021/22, the farms were located in Santa Maria/RS and Cachoeira do Sul/RS whereas during the 2022/23 the farms were located in Novo Cabrais/RS, Lajeado/RS and Júlio de Castilhos/RS. Details on the dahlia crops in each farm are in Table 1.

Table 1. Dahlia farms during two growing seasons (2021/22 and 2022/23) in Rio Grande do Sul State, Brazil, used in the study.

Location	Cultivars	Planting Date (dd/mm/yyyy)	Date of first flowering (dd/mm/yyyy)
Santa Maria	Rebecca´s World, Siberia, Promisse, Dark Spirit, Pompom	21/09/2021	01/12/2022
Cachoeira do Sul	Rebecca´s World, Siberia, Promisse, Dark Spirit, Pompom	14/10/2021	08/12/2022
Novo Cabrais	Rebecca´s World, Sibéria	18/11/2022	08/01/2023
Lajeado	Rebecca´s World, Sibéria	21/11/2022	15/01/2023
Júlio de Castilhos	Rebecca’s World, Sibéria	18/11/2022	06/01/2023

Tubers from a private company were used by farmers. Tubers were 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. All farmers used irrigation in their dahlia crops, except the crop in Santa Maria where no irrigation was used after 15 December 2021. In all farms, pre-planting fertilization was performed using 50g/m² of NPK, in formulation 5-20-20. When the first flower was harvest, a dressing fertilization was performed using 50g/m^2 of urea and 50g/m^2 of potassium chlorate.

Daily minimum and maximum air temperatures were collected from automatic meteorological stations of the INMET (2022), located in Santa Maria, Cruz Alta, Teutônia, and Rio Pardo. The weather station in Santa Maria represented the climate of the farm in Santa Maria and Novo Cabrais, the weather station in Cruz Alta represented the climate of the farm in Julio de Castilhos, the weather station in Teutônia represented the climate in Lajeado and the wather station in Rio Pardo represented the climate in Cachoeira do Sul.

Ten plants per cultivar were tagged in each farm at the time of the appearance of the floral bud, a moment that marks the beginning of the reproductive phase of the crop. During the period from 20 December 2021 to 30 January 2022, and from 14 January 2023 to 20 January 2023, daily observations were made in the dahlias in the five locations in order to identify symptoms of heat stress on leaves, buds, and flowers such as leaf rolling, wilting, dry leaf edges, sunscald, burning and rotting. The appearance of those symptoms were correlated with maximum daily air temperature measured at the meteorological stations in order to estimate the lethal temperature. The maximum temperature achieved the day before the symptom of heat stress was assumed to be the upper lethal temperature.

Results and discussion

Dahlia plants were exposed to a large variation in temperatures during the growing season in the two locations in 2021/22 growing season (Figure 1).

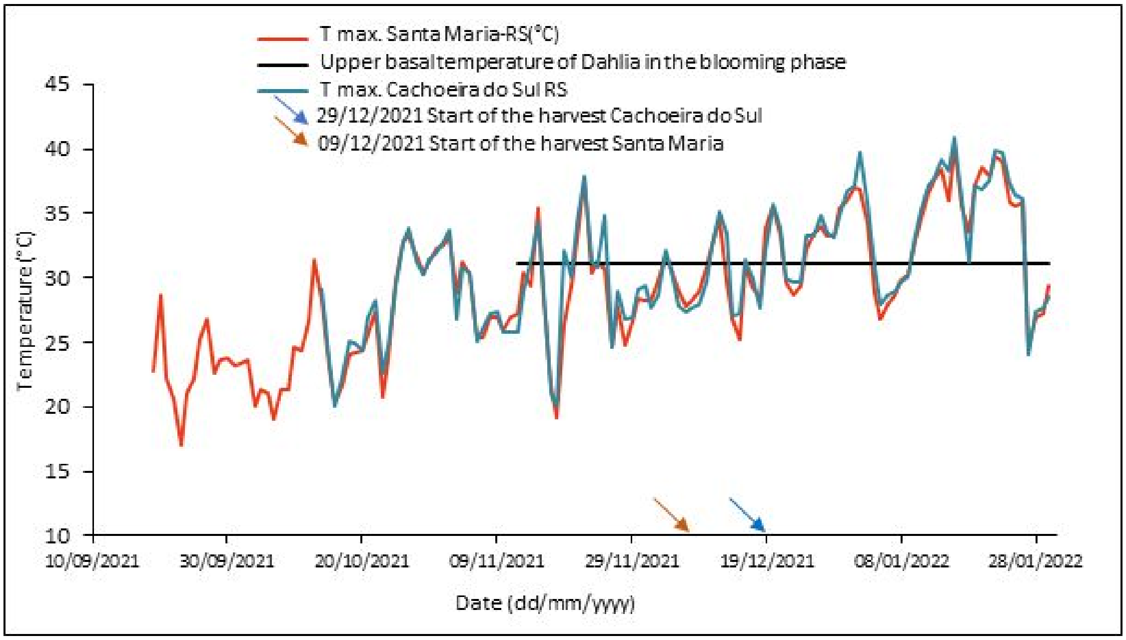

Figure 1. Maximum temperatures in Santa Maria and in Cachoeira do Sul-RS, Brazil, during the 2021/22 dahlia growing season.

During the period from 10 to 26 January 2022, an intense heat wave took place in the Rio Grande do Sul State as a result of an atmospheric blockage (SEAPDR, 2022) leading to an absolute maximum temperature of 39.6 °C and 40.8 °C in Santa Maria and in Cachoeira do Sul, respectively, and a16 days in a row of temperature above 33.1ºC, the upper base temperature (TB) for dahlia during the reproductive phase (Brondum and Heins, 1993), in both locations.

During the 2021/2022 growing season, in Santa Maria the injury by heat stress (burning) on dahlia buds and flowers in all cultivars was first observed in Santa Maria on 12 January 2022 and the maximum temperature on the day before was 35.2 ºC (Figure 2). In Cachoeira do Sul, the burning of buds and flowers was first observed on 20 January 2022 and the maximum temperature on the day before was 37.2 ºC (Figure 2).

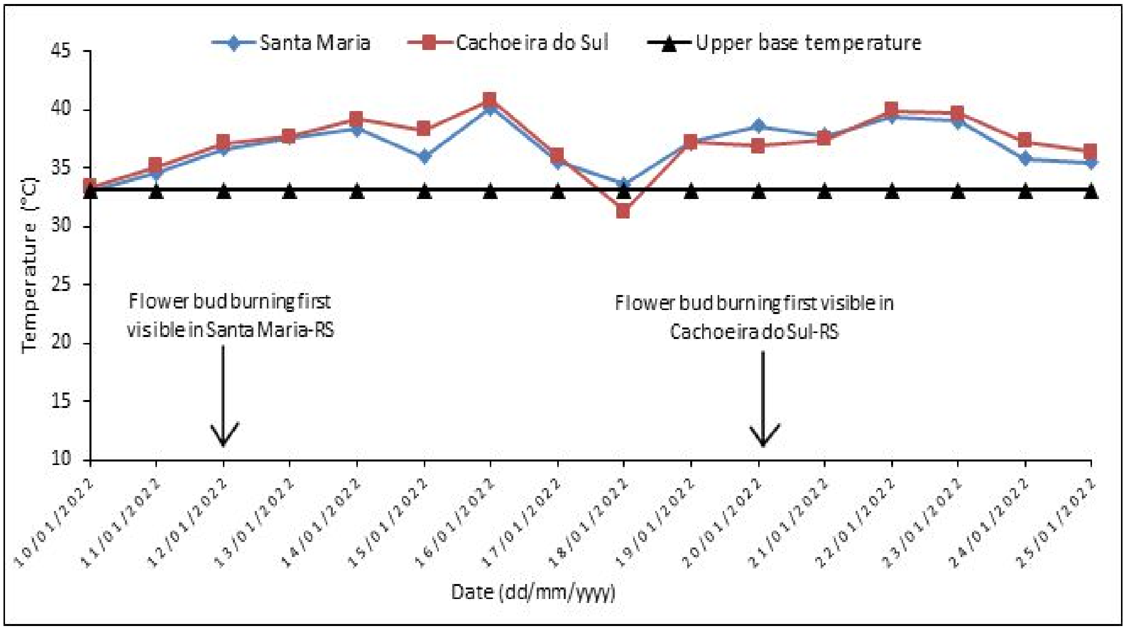

Figure 2. Maximum air temperature during the period that the first symptoms of heat damage (burning) on dahlia buds and flowers occurred in Santa Maria and in Cachoeira do Sul, RS/Brazil. The dotted line corresponds to the upper base temperature (TB) for dahlia during the reproductive phase (Brondum and Heins, 1993).

Observations of heat stress symptoms during the 2022/2023 growing season were also well related with high temperatures in Novo Cabrais and Lajeado (Figure 3a), and in Júlio de Castilhos (Figure 3b). Until 16/01/2023, no symptoms were observed in the dahlia plants in Novo Cabrais and Lajeado. Then on 17/01/2023 the maximum temperature was 35.3 ºC in Novo Cabrais and 34.9 ºC in Lajeado and the first symptoms of burning on buds were observed on 18/01/2023 in both locations and cultivars, indicating that the lethal temperature was achieved on 17/01/2023. Similarly, but one week later, in Julio de Castilhos the first symptoms of burning on buds were observed on 24/01/2023 and the maximum temperature the day before was 34.8 ºC.

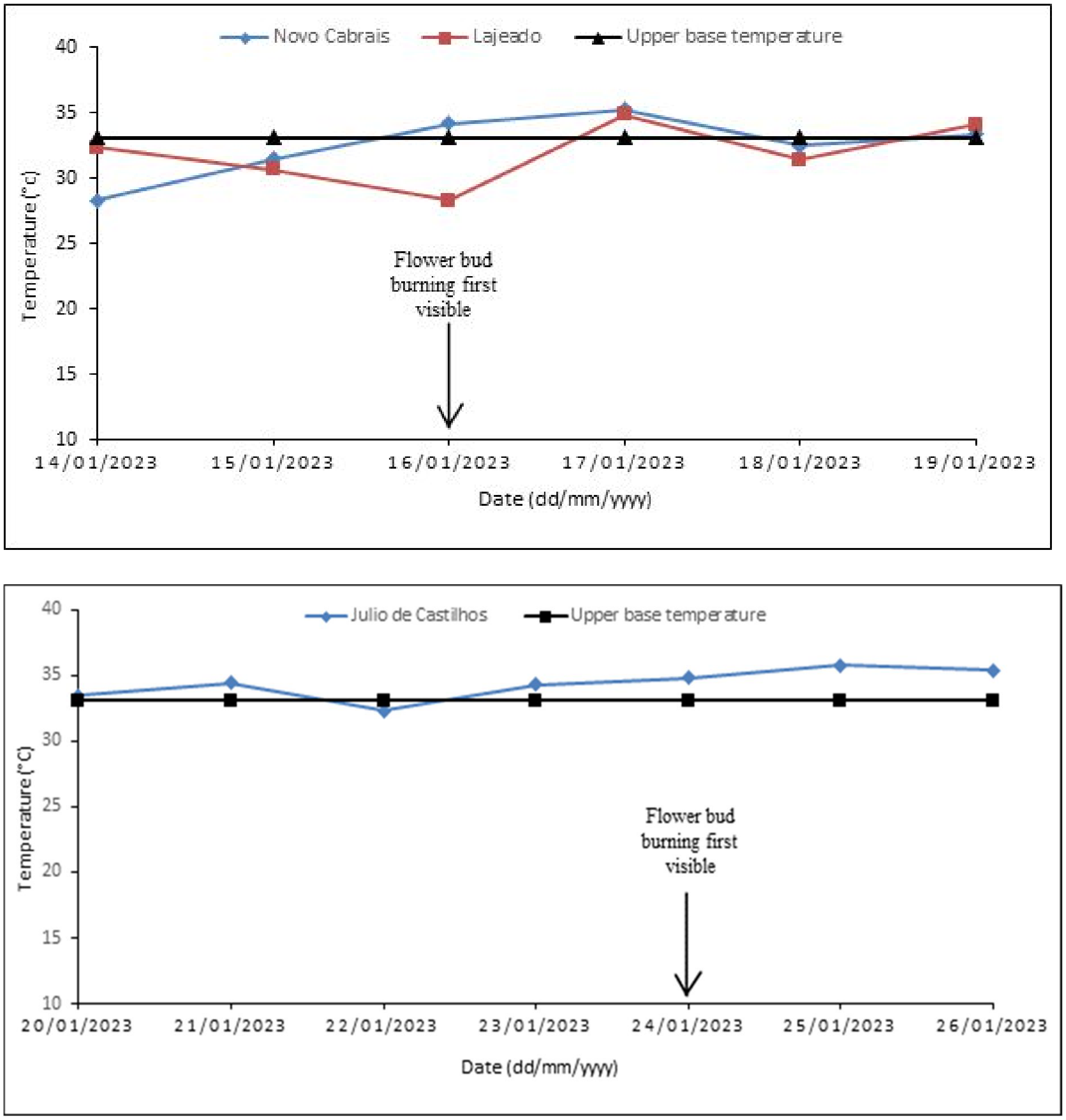

Figure 3. Maximum daily air temperature from 01/14/2023 to 01/19/2023 in Novo Cabrais/RS and Lajeado/RS (A), and Julio de Castilhos/RS from 01/20/2023 to 01/26/2023 (B). The dotted line corresponds to the upper basal temperature (TLup) of dahlia during the reproductive phase (Brondum and Heins, 1993).

From the results of the five locations, in four of them (Santa Maria, Novo Cabrais, Lajeado, and Julio de Castilhos) the temperature was close to 35 ºC the day before the symptom of burning on buds and flowers was observed. Only in Cachoeira do Sul the temperature that led to bud and flower burning was higher (37.2 ºC, Figure 2). Being conservative and for a more safe recommendation for farmers, taking the average of the maximum temperature values the day before the first symptoms of burning at the four locations (Santa Maria, Novo Cabrais, Lajeado and Júlio de Castilhos), 35 °C (± 0.2 °C) is an indication of the lethal temperature that cause irreversible damage by heat stress in buds and petals of open field grown dahlias.

Symptoms of injury due to heat stress in the five locations during the two growing seasons were characterized as burning of sepals and petals (Figure 4) and were irreversible both on buds (Figures 4A, 4B, 4E, 4F, 4G, 4J) or on semi open and open flowers (Figures 4C, 4D, 4H, 4I, 4K, 4L). Flower development stopped in injured dahlia buds and flowers, with a typical "mummification" of the burned parts (Figures 4A to 4L).

Figure 4. Damage caused by high temperatures in dahlia bud and flowers cultivated in the field in Santa Maria (A, B, C and D), in Cachoeira do Sul (E, F, G and H), and in Júlio de Castilhos (I, J, K and L), Rio Grande do Sul State, Brazil.

A heat wave is a climatic phenomenon characterized by the rise of maximum or minimum air temperature above than expected for the same region and the same time of year for a period of at least three consecutive days, providing the formation of an uncomfortable environment and harmful to health and agriculture (Lopes and Fioravanti, 2017). According to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), evidence of observed changes in extremes in weather events such as heat waves and droughts increased since the previous AR5 and they are projected to increase in their frequency and intensity during the next decades (IPCC, 2021). The Summer 2021/2022 was remarkable hot and dry in Southern Brazil (Figure 2) (Cardoso *et al.*, 2022), breaking records of high temperature in many locations across the Rio Grande do Sul State.

Cut flower crops are especially sensible to heat stress mainly because the marketable part of the plant (flower) is composed by petals and sepals whose tissue is very sensible to heat stress. In a recent study, Becker *et al.* (2021) demonstrated that temperatures above 34ºC that cause burning of sepals and petals in gladiola flowers can be remarkable increased by climate change scenarios projected for the next decades in the state of Rio Grande do Sul State, Brazil. Results presented in this study show that heat waves with temperatures above 35ºC cause irreversible injury to bud and flowers of cut dahlias.

In all locations, growing seasons and cultivars, injury due to heat was only observed in the reproductive parts (buds and flowers) of dahlia plants with no injury on leaves, stems and peduncles (Figure 4), i.e the vegetative parts of a dahlia plant are very resistant to heat stress (temperatures up to 40.8 ºC did not cause injury in leaves). Similar results were reported for gladiolus, were heat injury caused by temperatures above 34 ºC were not observed in vegetative parts (leaves), but were very remarkable on sepals and petals of the florets, and the last florets of the spike may not open if the crop is exposed to temperatures above 35 °C, even when under irrigation (Uhlmann *et al.*, 2017; Schwab *et al.*, 2018).

From the results of this study, a management practice that dahlia farmers can use to protect buds and flowers from heat injury is to use artificial shading with nets when dahlia are grown in regions that high temperature can achieve the threshold of 35 ºC. Another important management practice that farmers can take is to maintain dahlia plants well-watered. A water-stressed canopy can have up to 3 ºC greater temperature compared to a well-water canopy (Bockhold *et al.*, 2011). Therefore, based on our results we hypothesize that in a dahlia crop that is under water stress, heat injury in buds and flowers can start when temperature reaches 32 ºC.

Another important management factor that can help dahlia farmers to minimize heat injury is planting date. In the Subtropics such as in Rio Grande do Sul State, planting dahlia early in Spring will provide harvesting stating when temperatures still are not very high, thus avoiding injury by heat. A second planting can be performed in late Summer, so that reproductive phase starts when temperatures are dropping in early Fall, thus also avoiding high temperatures.

Conclusions

Irreversible heat injury in buds and flowers of open field grown dahlia start when air temperature reaches 35ºC. Artificial shading, irrigation, and planting date are management practices that can help farmers to protect dahlia flowers from heat stress.

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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. **MHLS**: 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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ARTIGO II - 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

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(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 (ºC day leaf pair^{-1}) was calculated as the slope of the linear regression. The results indicated that the phyllochron of dahlia cultivars varied between 46.5°C 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°C to 97.4°C pair of leaves^{-1} and 6 to 15 of final leaf pair number in the second experiment and 46.8°C 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 emission, 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 46.5 °C a 95.6 °C par de folhas^{-1} e 8 a 14 de número finais de par de folhas no primeiro experimento, 27.2 °C a 97.4°C par de folhas^{-1} e 6 a 15 de número final de par de folhas no segundo experimento e 46.8 °C 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.

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 (ºC day) or photothermal time (ºC 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.

(To be continued…).

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

(Conclusion)

Location	Cultivars	Planting date (dd/mm/yyyy)	Mean temperature (°C)
Experiment 3			
Júlio de Castilhos *29°25’58”S* *53°32’91”W*	C1-Siberia C2-Rebecca’s World	18/11/2022	24.3
Novo Cabrais *29°44’09”S* *52°57’48”W*	C1-Siberia C2-Rebecca’s World	18/11/2022	29.9

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):

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

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

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

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 ºC, 24.6 ºC, and 34.9 ºC respectively, Brondum and Heins (1993).

Accumulated thermal time (TT, ºC 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 ºC day^{-1}) and the phyllochron (ºC 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 (ºC 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.

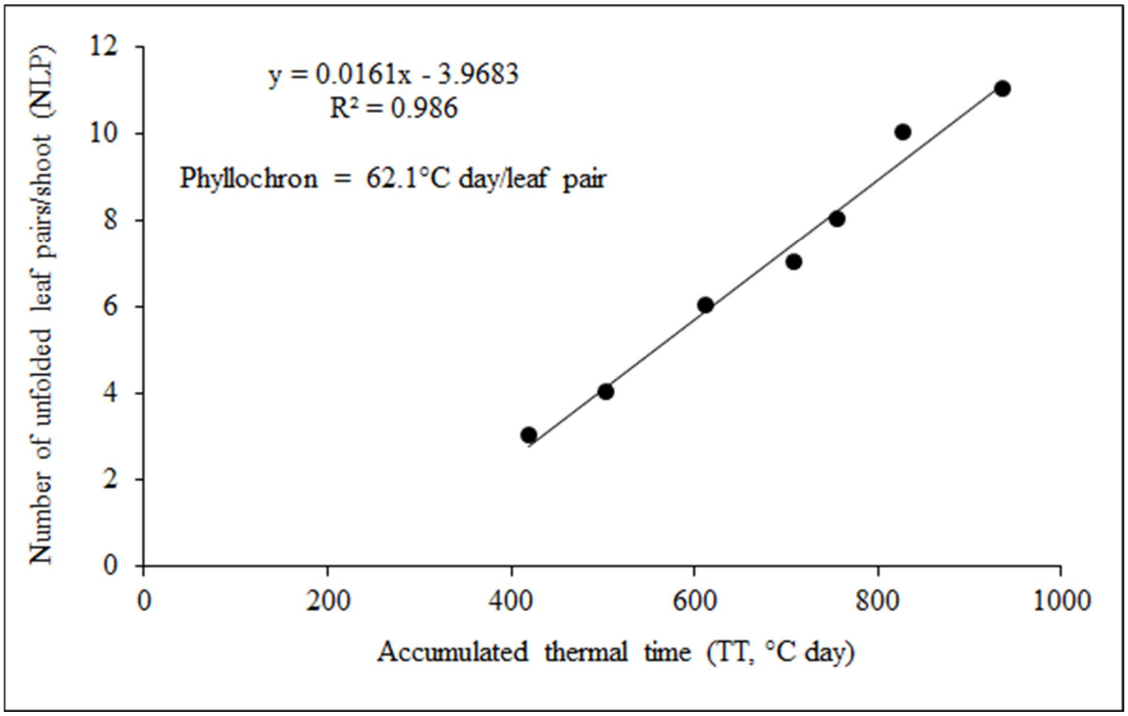

Figure 1. Number of accumulated unfolded leaf pairs (NLP) as a function of accumulated thermal time from emergence (TT) in one plant of dahlia cultivar “Rebecca’s World” in Experiment 3 in Júlio de Castilhos, Rio Grande do Sul State, Brazil, 2022. The equation is the linear regression with its coefficient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

The variable phyllochron (ºC 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 ºC day leaf pair^{-1}), E2 (experiment 2) had a median = 70.4 (58.0 to 79.1 ºC day leaf pair^{-1}), and E3 (experiment 3) had a median = 63.9 (57.0 to 72.9 ºC 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.

Table 2. Comparison for the variables phyllochron (ºC 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)		

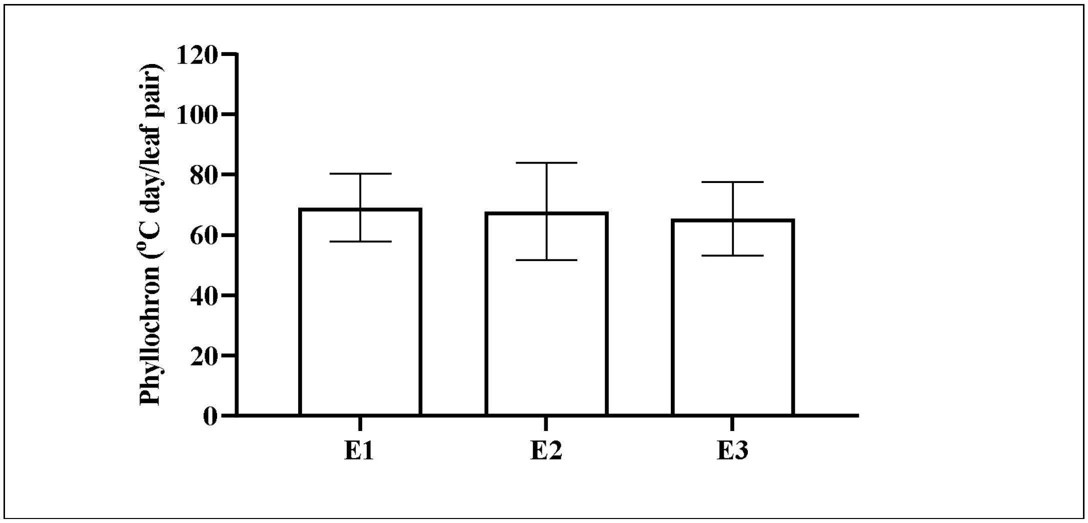

Figure 2. Phyllochron in dahlia, median of cultivars and locations in three on farm experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Error bars are one standard deviation of the median.

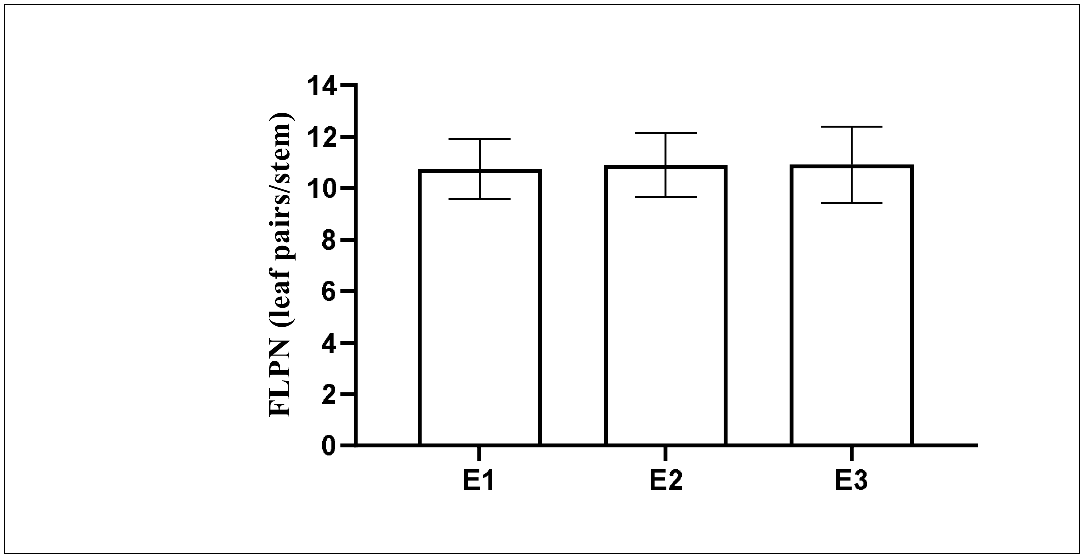

Figure 3. Final leaf pair number (FLPN) in dahlia, median of cultivars and locations in three on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Error bars are one standard deviation of the median.

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

Table 3. Comparison of locations (JA, SM, CS, JC, LA, NC) for the variable phyllochron (ºC 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 ºC day leaf pair^{-1}), significantly higher than the median in Lajeado 64.2 (58.4 to 69.2 ºC 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.

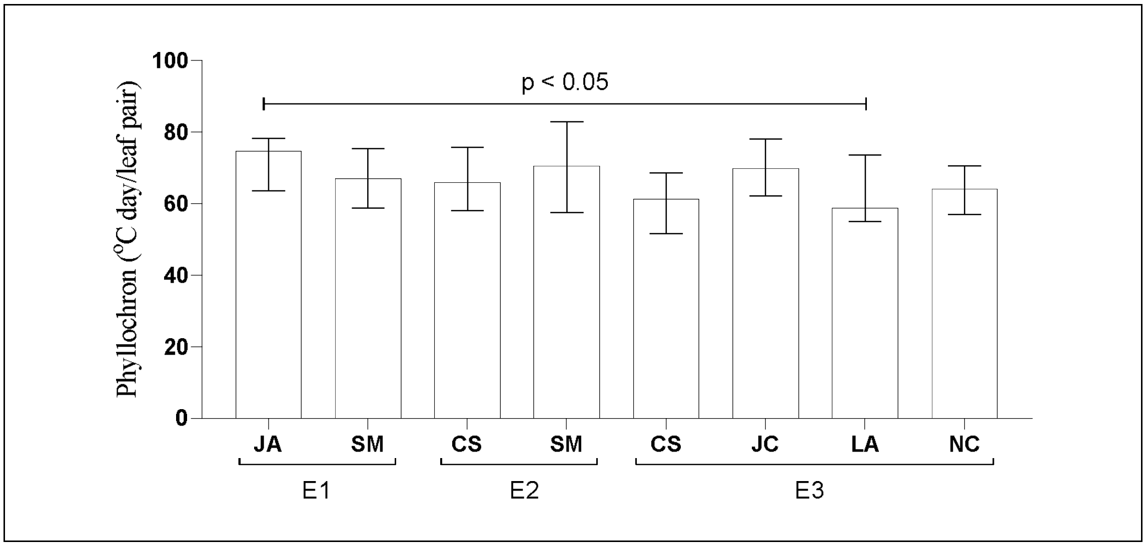

Figure 4. Median and interquartile range of the variable phyllochron in dahlias for comparison of locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio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

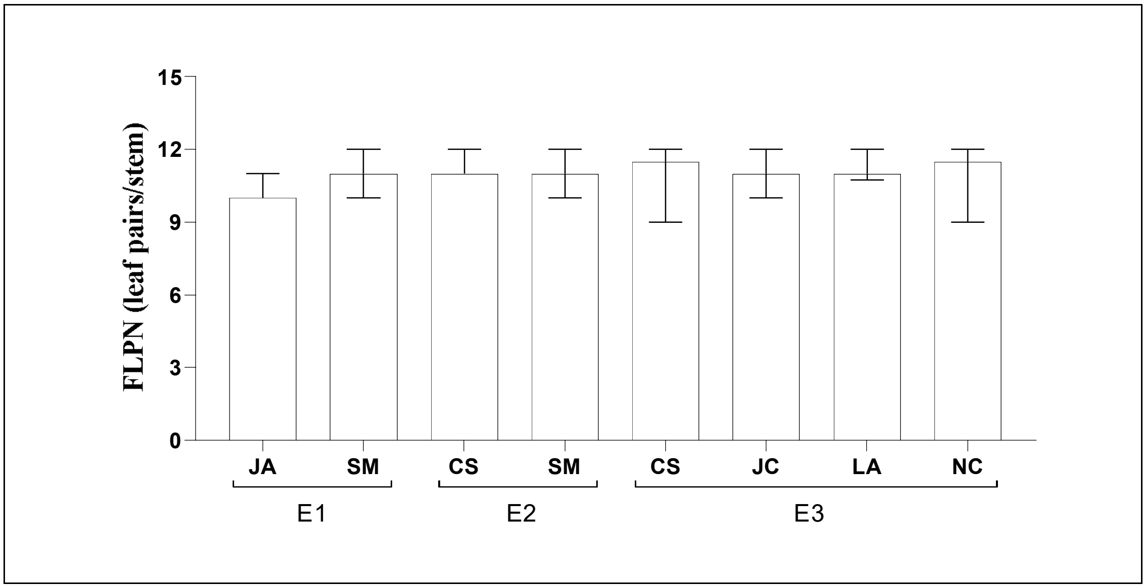

Figure 5. Median and interquartile range of the variable final leaf pair number on the main shoot (FLPN, leaf pairs stem^{-1}) in dahlias for comparison of locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA =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

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.

Table 5. Comparison of cultivars for the variable phyllochron (ºC 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.

(To be continued…)

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

(Conclusion)

LOC	Cv.	Min	Max	MD	1st Q	3rd Q	Mean	SD
Experiment 1								
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.

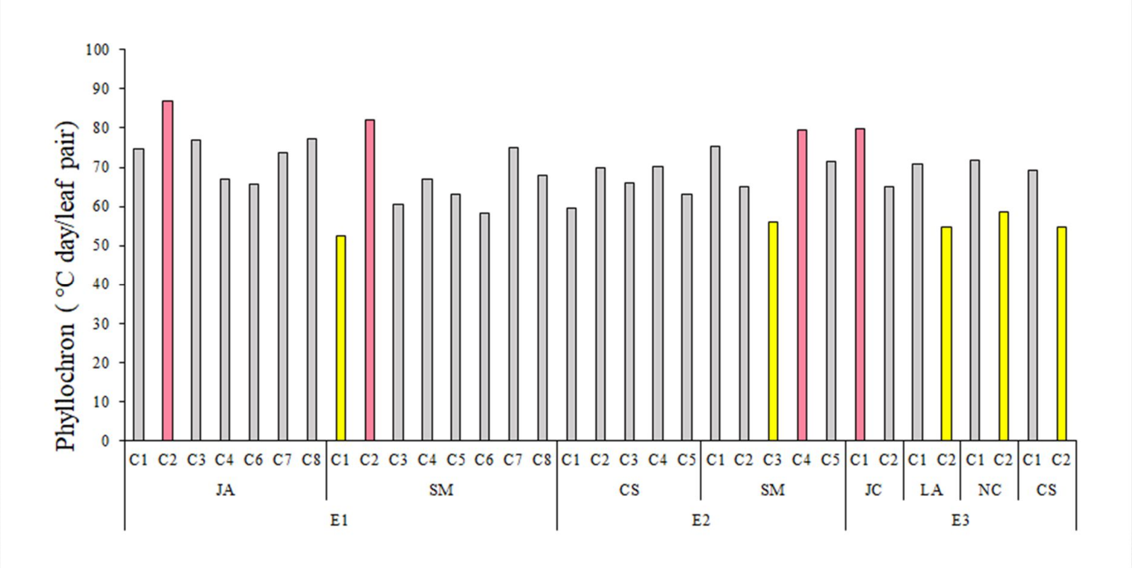

Figure 6. Median of the variable phyllochron in dahlias for comparison of cultivars in different locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = Jaguari, SM = Santa Maria, CS = Cachoeira do Sul, JC = Júlio 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								
JÁ	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).

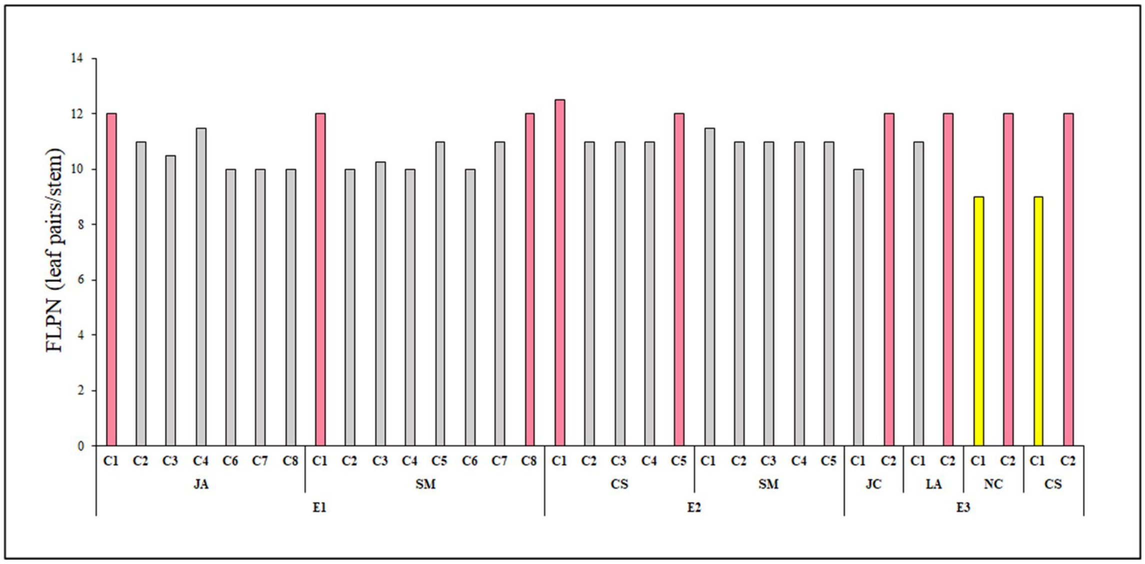

Figure 7. Median of the variable final leaf pair number on the main shoot (FLPN) (leaf pairs stem^{-1}) in dahlias for comparison of cultivars in different locations (JA, SM, CS, JC, LA, NC) in on farm Experiments (E1, E2, E3) in Rio Grande do Sul State, Brazil, described in Table 1. Locations: JA = 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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ARTIGO III – Vegetative and reproductive development in Dahlia*

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Abstract

This study analyzed the growth and development of ten Dahlia cultivars in the subtropical region of Brazil, taking into account the specific soil and climatic conditions of the area. It was conducted over three years at eight locations in the state of Rio Grande do Sul, southern Brazil. The study assessed various phenological variables, including emergence, the number of leaves per plant, development of floral buds, and the point of flower harvesting. The results highlight the significant influence of air temperature on plant development, with noticeable variations among cultivars and locations. The analysis of the vegetative and reproductive phases of the plants revealed differences in the duration of these phases for each cultivar, providing valuable information for agricultural planning and the selection of cultivars suitable for different conditions. The relationship between the total duration of the plant's cycle and the vegetative and reproductive phases was also explored, emphasizing how these factors are interconnected. These findings can guide the selection of cultivars

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based on the growing environment, available time, and other relevant factors for effective agricultural management.

Keywords: Dahlia, phenological variables, phenology, reproductive development, vegetative development.

Resumo

Desenvolvimento vegetativo e reprodutivo em dálias

Este estudo analisou o crescimento e desenvolvimento de dez cultivares de Dahlia no subtropico brasileiro, considerando as condições edafoclimáticas específicas da região. Foi realizado em oito locais no estado do Rio Grande do Sul, sul do Brasil, ao longo de três anos. O estudo avaliou várias variações fenológicas, incluindo a emergência, o número de folhas por planta, o desenvolvimento dos botões florais e o ponto de colheita das flores. Os resultados destacam a influência significativa da temperatura do ar no desenvolvimento das plantas, com variações notáveis entre as cultivares e os locais. A análise das fases vegetativas e reprodutivas das plantas revelou diferenças na duração dessas fases para cada cultivar, fornecendo informações importantes para o planejamento agrícola e a seleção de cultivares adequadas para diferentes condições. A relação entre a duração do ciclo total das plantas e as fases vegetativas e reprodutivas também foi explorada, destacando como esses fatores estão interligados. Esses resultados orientam a escolha de cultivares com base no ambiente de cultivo, tempo disponível e outros fatores relevantes para uma gestão agrícola eficaz.

Palavras-chave: Dahlia, variáveis fenológicas, fenologia, desenvolvimento reprodutivo, desenvolvimento vegetativo.

Introduction

A Dahlia (*Dahlia spp*.), native to Mexico and belonging to the Asteraceae family, is widely appreciated as an ornamental plant due to its diversity of colors and flower forms, which include varieties such as orchid, anemone, plate, cactus, pompom, among others. The Dahlia is a herbaceous, shrubby, and perennial plant with a tuberous root system and an upright growth habit (National Dahlia Society, 2021).

The versatility of the Dahlia is evident in its ability to be grown outdoors, eliminating the need for greenhouses, making its cultivation accessible and relatively low in production cost. However, its development requires a substantial amount of water, and high summer temperatures play a crucial role in its proper growth (Uhlmann, 2022).

Although several studies have been conducted on the post-harvest durability of Dahlia flowers in different countries, with a primary focus on prolonging vase life (Shimizu-yoto and Ichimura, 2013; Alkaç *et al.*, 2020; Azuma *et al.*, 2020; Shimizu-Yoto *et al.*, 2020), there is a notable lack of attention directed towards characterizing the growth and development of varieties in natural environments in Brazil. This gap is largely due to significant differences in edaphoclimatic conditions between the tropical and subtropical regions of the country. In this context, it is crucial to assess phenological variables to understand the ideal development of the Dahlia.

Phenology, a branch of botany, studies the various phases of plant growth and development, dividing them into vegetative and reproductive phases. This detailed analysis allows us to identify the physiological stage the plant is in and its needs for healthy growth, contributing to significant yield in the crop (Câmara, 2006).

Given the crucial role of temperature and sunlight exposure in the development of subtropical plants, these abiotic factors play a fundamental role in vegetative and reproductive phenology (Oliveira *et al.*, 2021). Therefore, this research was conducted with the purpose of identifying the phenological phases of ten Dahlia varieties in the subtropical environment of Brazil, aiming to highlight the influence of these environmental factors on the characteristics of each stage of plant development.

In this context, it is important to note that the emergence of leaves in Dahlia varieties is mainly influenced by temperature, as indicated by Fernandes *et al.* (2023a). Thus, the central objective of this study was to determine the phenological phases of ten Dahlia varieties in the Brazilian subtropics, highlighting the intrinsic relationship between these phases and environmental factors.

Therefore, this study gains relevance by contributing to the understanding of phenological variables, allowing for the identification of environmental characteristics that affect different growth phases and enabling the determination of the ideal moment for flower harvesting. It is important to emphasize that the development of Dahlia cultivars is closely linked to the prevailing conditions in the environment, with temperature playing a significant role.

The germination process of these plants, influenced by a variety of abiotic factors such as humidity and wind speed, is essential for reproductive growth and development. These effects, which tend to be more pronounced during the reproductive phase, especially during flowering, play a critical role throughout the plant's life cycle (Silva *et al.*, 2021). Given the above. This article aims to examine the growth and development of ten Dahlia cultivars in the subtropical region of Brazil, taking into account the specific edaphoclimatic conditions of this location.

Materials and methods

In this study, five agricultural experiments were conducted using two to eight cut dahlia cultivars, carried out over three years (2021 to 2023) at eight locations in the state of

Rio Grande do Sul, southern Brazil. Details of the cultivation locations and Dahlia cultivars are listed in Table 1.

Table 1. Dahlia farms during two growing seasons (2021/22 and 2022/23) in Rio Grande do Sul State, Brazil, used in the study.

Location	Cultivars	Planting Date (dd/mm/yyyy)
Santa Maria	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom, Vera, Frantonio	25/02/2021
Jaguari	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom, Vera, Frantonio	27/02/2021
Pelotas	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom, Vera, Frantonio	27/08/2021
Santa Maria	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom	21/09/2021
Cachoeira do Sul	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom	14/10/2021
Novo Cabrais	Rebecca´s World, Sibéria	18/11/2022
Lajeado	Rebecca´s World, Sibéria	21/11/2022
Júlio de Castilhos	Rebecca’s World, Sibéria	18/11/2022
Alegrete	Rebecca´s World, Siberia, Promise, Dark Spirit, Pompom, Vera	06/02/2023
Júlio de Castilhos	Vicent Van, Marina, Carla	01/05/2023

The varying number of cultivars used at each location was based on the availability of tubers provided by the farmers. The climate in all these locations, according to the Köppen system, is Cfa, which corresponds to a humid subtropical climate with hot summers and no dry season (Kuinchtner and Buriol, 2001; Kottek *et al.*, 2006). Soil chemical analyses conducted at the Santa Maria and Cachoeira do Sul farms indicated soil organic matter content of 2.1% and 3.3%, soil pH of 4.55 and 6.13, phosphorus (P) content of 88.3 mg dm-^{3} and 56.1 mg dm-^{3}, potassium (K) content of 206.5 mg dm-^{3} and 366.7 mg dm-^{3}, and calcium (Ca) + magnesium (Mg) content of 5.4 cmolc dm-^{3} and 11.1 cmolc dm-^{3}, respectively. Soil tests were not conducted at the other farms, but the areas were used for flower and vegetable cultivation and therefore represented local conditions. Tubers from a private company were used by the farmers and planted in beds with a width of 1.0 m and a height of 0.2 m, spaced at 0.40 m x 0.40 m and at a depth of 0.05 cm in all properties. Fertilization included pre-planting application of lime to achieve a pH of 6.0 and 50g m^2 of NPK (5-20-20), as indicated by Brondum and Heins (1993) and Kumar *et al.* (2019). All farmers used irrigation to prevent water stress in their dahlia crops at all locations. The number of emerged plantas was couted daily until reaching the final plant stand, with the emergence was considered to have occurred when 50% of the plants had emerged. After complete emergence, the main above-ground part of 10 plants per cultivar was marked on each farm. The number of pairs of unfolded leaves (NPL - one leaflet was considered unfolded when the edges of the leaflets were no longer touching) on each plant was counted once a week in Cachoeira do Sul, Lajeado, Júlio de Castilhos, Novo Cabrais, and Alegrete, and twice a week in Santa Maria, Jaguari, and Pelotas until the unfolding of the last pair of leaves, which is the final leaf pair number (FLPN, measured in pairs of leaves per main stem). These findings were in line with the FLPN data reported by Fernandes *et al.* (2023b).

Daily minimum and maximum air temperatures were collected from automatic weather stations of the National Institute of Meteorology (INMET), located in Santa Maria, Pelotas, São Vicente do Sul, Cruz Alta, Teutônia, and Rio Pardo. The Santa Maria weather station represented the climate at the Santa Maria farm and Novo Cabrais, while Pelotas represented the Pelotas farm. São Vicente do Sul represented the climate at the Jaguari farm, Cruz Alta represented the climate at the Júlio de Castilhos farm, Teutônia represented the climate in Lajeado, and Rio Pardo represented the climate in Cachoeira do Sul. The Alegrete weather station represented the farm in the same location.

From crop emergence until the appearance of the final pair of leaves on the main above-ground part, daily thermal time, defined as the thermal sum during a day (TTd, °C day), was calculated following the methods of Gilmore and Rogers (1958) and Arnold (1960):

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

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

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

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

The accumulated thermal time (TT, °C day) from crop emergence until the appearance of the final pair of leaves was calculated as follows:

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

The experimental design was factorial, with location and cultivars as factors in each experiment, with 10 plants per cultivar serving as repetitions. The following data were observed:

(I) Emergence: The timing when 50% of the plants had emerged.

(II) Number of leaves per plant on the main stem starting from the emergence of sprouting.

(III) Floral bud: The first visible floral bud on the plant.

(IV) Floral bud showing color: The stage at which the floral bud begins to display its color.

(V) Harvest point: The stage when the first flower on the marked plant is ready for harvest.

Results end discussion

The development of plants at different phenological stages is significantly influenced by air temperature. Therefore, it is preferred to estimate these stages through the accumulation of thermal units (or degree-days) rather than using calendar days (Steinmetz *et al.*, 2017). The thermal unit method is commonly used to represent the effect of temperature on plant development because it is a simple and more biologically relevant measure of time than calendar days or days after sowing (Trentin *et al.*, 2008).

It's important to highlight that air temperature is a critical factor in guiding the phenology and planting date of a crop (Uhlmann *et al.*, 2017; Tomiozzo *et al.*, 2018), whereas photoperiod doesn't have as significant an impact on plant growth and development (Silva *et al.*, 2022). Plant growth also depends on the duration of the vegetative phase, as this stage affects the overall crop cycle, with relationships to leaf emergence rate (phyllochron), radiation interception, and canopy evapotranspiration (Streck *et al.*, 2012).

Regarding the variation among cultivars, the data clearly indicate that different cultivars have different durations of vegetative and reproductive phases. Some cultivars may spend more time in the vegetative phase, while others may enter the reproductive phase earlier. For example, the Dark Spirit cultivar in Pelotas (Figure 1A).

The results also suggest that the location where plants are cultivated can influence the duration of growth phases. There may be noticeable variations between locations, indicating that environmental conditions play a significant role in regulating plant development. When comparing differences between phases, such as the vegetative and reproductive phases, it becomes evident if one phase is longer or shorter than the other for a specific cultivar. This information can be crucial for agricultural planning, especially for determining the timing of harvest or other management processes.

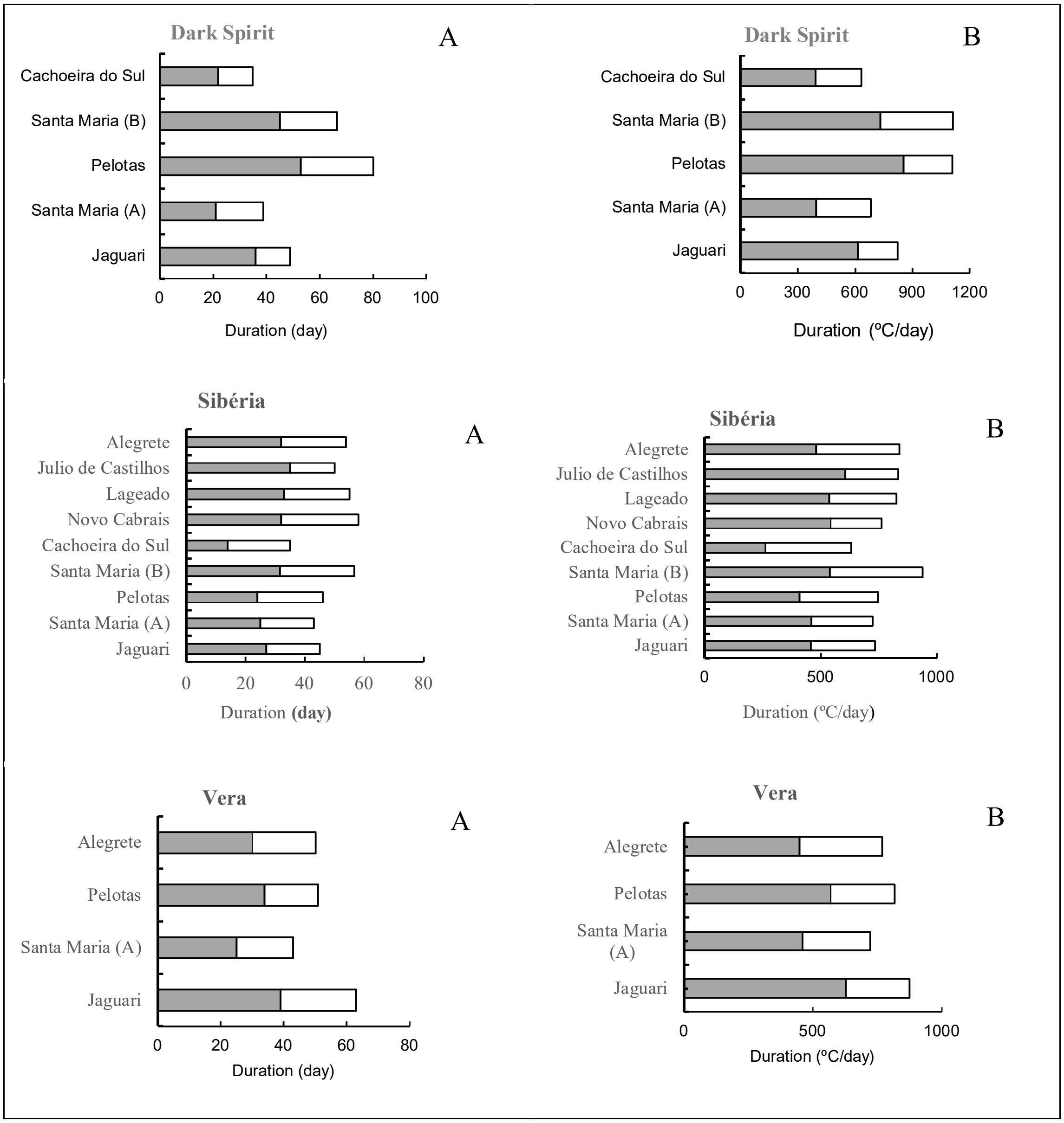


Figure 1. Duration of phases per cultivar in their respective locations, in days (A) and in °C days (B) for the vegetative phase (from emergence to the first visible floral bud) and the reproductive phase (from the first visible floral bud to the first flower with the first layer of petals fully open).

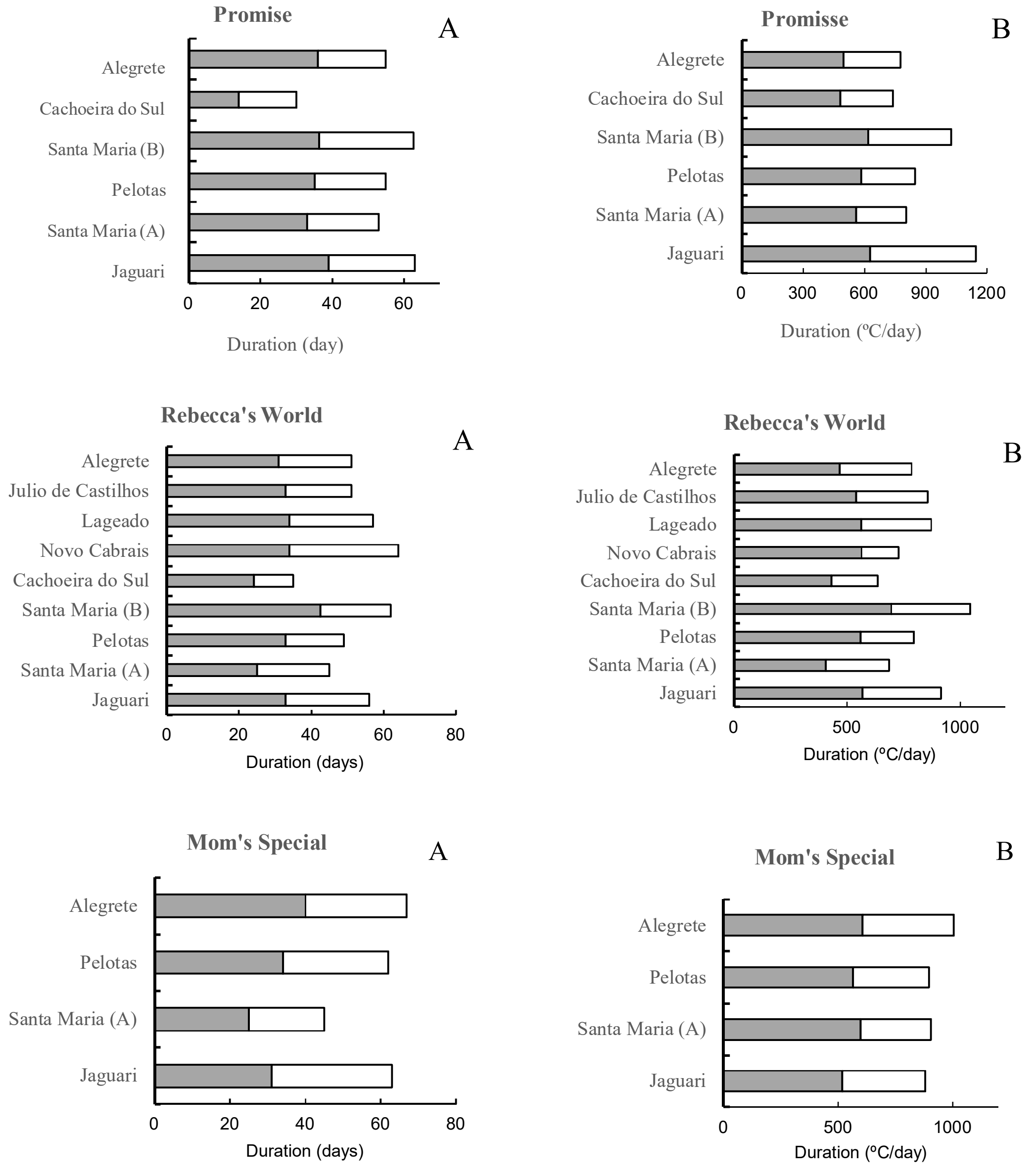
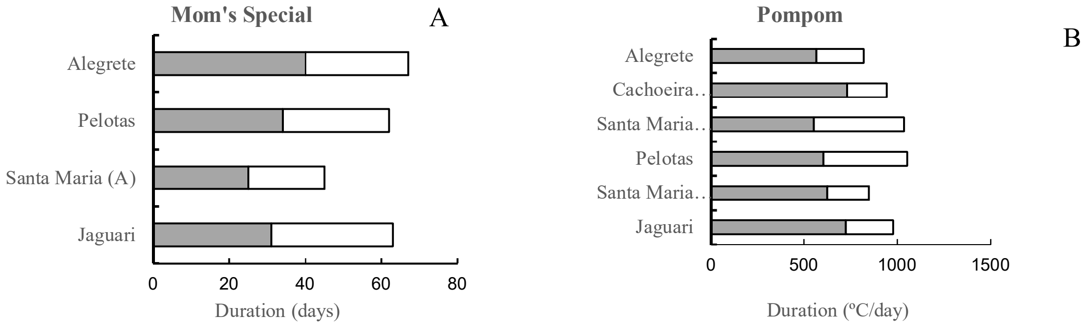


Figure 2 – Duration of phases per cultivar in their respective locations, in days (A) and in °C days (B) for the vegetative phase (from emergence to the first visible floral bud) and the reproductive phase (from the first visible floral bud to the first flower with the first layer of petals fully open).



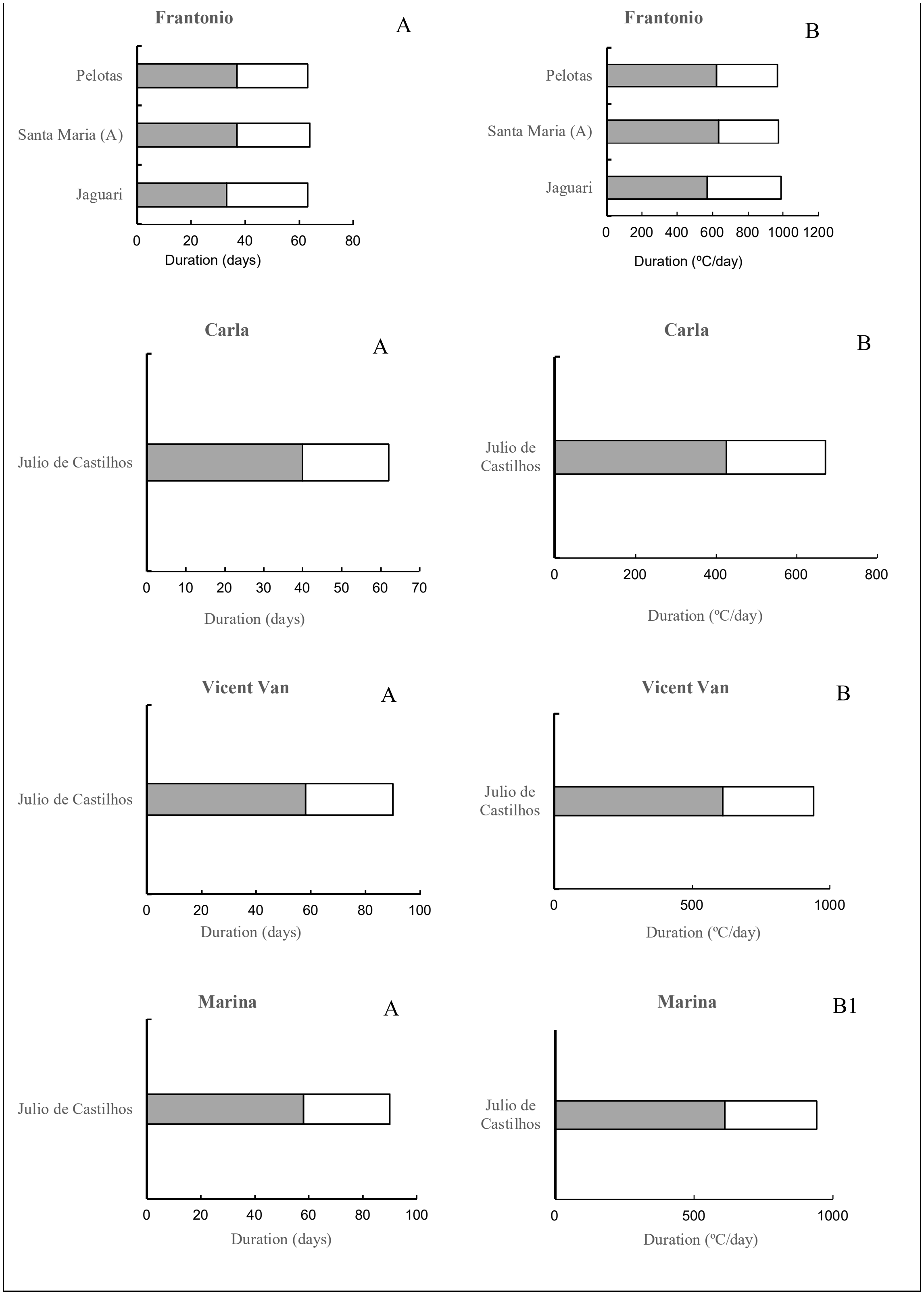


Figure 3 - Duration of phases per cultivar in their respective locations, in days (A) and in °C days (B) for the vegetative phase (from emergence to the first visible floral bud) and the reproductive phase (from the first visible floral bud to the first flower with the first layer of petals fully open).

The presentation of results in Celsius-days (B) is valuable because it takes temperature variations into account. This is particularly relevant for understanding how temperatures affect plant development, as different temperatures can either accelerate or slow down growth (Fernandes *et al.*, 2023b).

These data can be highly valuable for farmers, researchers, and agronomists. They can be used to select cultivars that are better suited for specific regions, optimize planting and harvesting schedules, and improve crop management for more consistent and efficient yields.

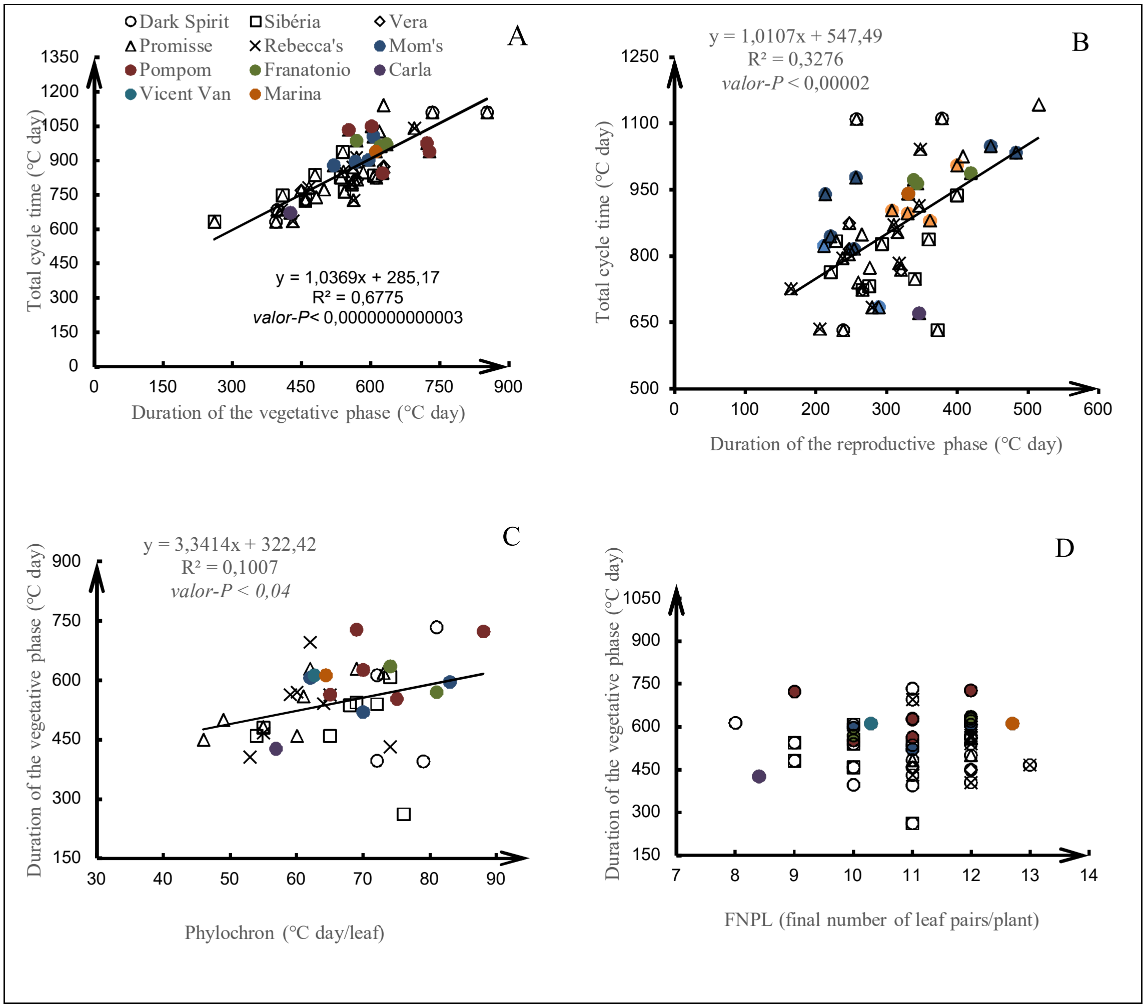


Figure 4 – Relationship between (A) duration of the total cycle (planting – flowering) and duration of the vegetative phase (emergence until the first visible floral bud). (B) duration of the total cycle and reproductive phase (from the first visible flower bud to the first flower with the first layer of petals fully opened). (C) duration of the vegetative phase and phyllochron. (D) duration of the vegetative phase and the (FNPL) Final number of pairs of leaves, in 11 cultivars of Dahlias, Dark Spirit, Pompom, Frantonio, Vera, Rebecca's World, Promise, Carla, Vicent Van, Mom's Special and Marina in 8 cities in RS.

Figure 4A - Duration of the Total Cycle vs. Vegetative Phase displays a significant positive linear relationship between the total cycle duration (from planting to flowering) and the duration of the vegetative phase (from emergence to the first visible floral bud). It's noticeable that some cultivars may have shorter cycles, indicating that they reach flowering earlier after planting, while others may have longer cycles, possibly due to an extended vegetative phase. Figure 4B explores the relationship between the total cycle duration and the duration of the reproductive phase (from the first visible floral bud to the first flower with the first layer of petals fully open). It's interesting to observe how the duration of the reproductive phase affects the total cycle.

Some cultivars may spend more time in the reproductive phase, while others may enter the reproductive phase later. Figure 4C investigates the relationship between the duration of the vegetative phase and the phyllochron, which is the time interval between the emergence of successive leaves at the same node. The connection between the vegetative phase and the phyllochron can provide insights into the rate of leaf growth and development during the vegetative phase. Duration of the Vegetative Phase vs. Final Number of Leaf Pairs (FLPN) in Figure 4D shows the relationship between the duration of the vegetative phase and the Final Number of Leaf Pairs (FLPN). FLPN is an important indicator of the plant's developmental stage, and this relationship can help understand how the duration of the vegetative phase affects leaf development and, by extension, overall plant growth.

Collectively, these analyses in Figure 4 provide valuable information on how different factors are interconnected in the growth cycle of Dahlia cultivars. This information can be used to guide the selection of cultivars based on the growing environment, available time, and other relevant factors for effective agricultural management. Furthermore, this analysis can contribute to a deeper understanding of plant growth and development mechanisms (Fernandes *et al.*, 2023b).

Conclusion

This study provides valuable tools for understanding the development of different Dahlia cultivars under various environmental conditions. The information obtained is essential for decision-making in agriculture, including the selection of suitable cultivars for each region and the optimization of planting and harvesting schedules. Furthermore, the analysis of the vegetative and reproductive phases and their relationship with the total plant cycle contributes to a deeper understanding of Dahlia growth and development mechanisms, benefiting farmers, researchers, and agronomists. This research plays a crucial role in improving Dahlia cultivation in Brazil, enabling more consistent and efficient production.

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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. **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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CONCLUSÃO

Os resultados obtidos nos experimentos apresentados por meio dos três artigos que compuseram o presente estudo sobre o cultivo de dálias revelam que as lesões irreversíveis por calor começam a ocorrer a partir de 35ºC de temperatura do ar. No entanto, práticas de manejo como sombreamento artificial, irrigação, supervisão e dados de planejamento, como data de plantio, podem ajudar a mitigar o estresse térmico nas flores dália. Além disso, o estudo, ao investigar a relação entre temperatura e aparecimento de folhas em cultivares de dália, encontrou uma forte correlação entre os dois, conforme indicado por um R2 superior a 0,9 em todos os locais e experimentos. Isto sugere que a temperatura desempenha um papel crucial no desenvolvimento das folhas das dálias.

Além disso, o estudo examinou a variabilidade no filocrono e no número final de pares de folhas em diferentes cultivares e locais, revelando diferenças significativas nos cultivares, mas não nos locais para FLPN. O filocrono variou de 27,2 ºC a 106,4 ºC dia par de folhas^{-1} nas cultivares Rebecca's World e Sibéria respectivamente, e FLPN de 6 a 15 pares de folhas/caule dependendo da cultivar. Como o FLPN é uma característica genética pouco afetada pelo ambiente nas cultivares de dália utilizadas no estudo, a implicação prática deste resultado é que as observações de campo do FLPN podem facilmente ajudar os agricultores no planejamento da época de colheita.

Durante os estudos, cultivares mais adaptadas e com maior interesse comercial foram sendo selecionadas. Das 11 cultivares utilizadas na realização da presente pesquisa, as que obtiveram maior procura foram as cultivares Rebecca's World e Sibéria, além de apresentarem características de rusticidade e adaptabilidade. Estas descobertas fornecem informações valiosas para produtores e pesquisadores de dálias para compreenderem o desenvolvimento de diferentes cultivares de dália sob diversas condições ambientais, ajudando-os a identificarem os fatores que influenciam o desenvolvimento das plantas nesta cultura ornamental.

Logo, as informações obtidas são essenciais para a tomada de decisões na agricultura, incluindo a seleção de cultivares adequadas para cada região e a otimização dos cronogramas de plantio e colheita. Além disso, a análise das fases vegetativa e reprodutiva e sua relação com o ciclo total da planta contribui para uma compreensão mais profunda dos mecanismos de crescimento e desenvolvimento das plantas, beneficiando agricultores, pesquisadores e agrônomos. Em conjunto, essas descobertas fornecem ferramentas avançadas para melhorar o cultivo de diferentes cultivares de dália, contribuindo para uma produção mais consistente e eficiente, com implicações práticas significativas para a agricultura no Brasil.

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