UNIVERSIDADE FEDERAL DE SANTA MARIA
CENTRO DE CIÊNCIAS RURAIS
PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONOMIA

Regina Tomiozzo

ECOFISIOLOGIA, MODELAGEM E DESEMPENHO AGRONÔMICO DE *Helianthus annus* L. E L*imonium sinuatum* Mill. COMO FLORES DE CORTE

Santa Maria, RS
2024

Regina Tomiozzo

ECOFISIOLOGIA, MODELAGEM E DESEMPENHO AGRONÔMICO DE *Helianthus annus* L. E *Limonium sinuatum* Mill. COMO FLORES DE CORTE

Tese apresentada ao Programa de Pós-Graduação em Agronomia, Área de Concentração em Produção Vegetal, da Universidade Federal de Santa Maria (UFSM, RS), como requisito parcial para obtenção do título de **Doutora em Agronomia.**

Orientador: Prof. PhD. Nereu Augusto Streck

Santa Maria, RS
2024

This study was financied in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001

Tomiozzo, Regina
ECOFISIOLOGIA, MODELAGEM E DESEMPENHO AGRONÔMICO DE Helianthus annus L. E Limonium sinuatum Mill. COMO FLORES DE CORTE / Regina Tomiozzo.- 2024.
161 p.; 30 cm

Orientador: Nereu Augusto Streck
Coorientador: Alencar Junior Zanon
Tese (doutorado) - Universidade Federal de Santa Maria, Centro de Ciências Rurais, Programa de Pós Graduação em Agronomia, RS, 2024

1. Floricultura 2. Girassol de Corte 3. Statice 4. Ambiente 5. Cultivo a Campo I. Augusto Streck, Nereu II. Junior Zanon, Alencar III. Título.

Sistema de geração automática de ficha catalográfica da UFSM. Dados fornecidos pelo autor(a). Sob supervisão da Direção da Divisão de Processos Técnicos da Biblioteca Central. Bibliotecária responsável Paula Schoenfeldt Patta CRB 10/1728.

Declaro, REGINA TOMIOZZO, para os devidos fins e sob as penas da lei, que a pesquisa constante neste trabalho de conclusão de curso (Tese) foi por mim elaborada e que as informações necessárias objeto de consulta em literatura e outras fontes estão devidamente referenciadas. Declaro, ainda, que este trabalho ou parte dele não foi apresentado anteriormente para obtenção de qualquer outro grau acadêmico, estando ciente de que a inveracidade da presente declaração poderá resultar na anulação da titulação pela Universidade, entre outras consequências legais.

Regina Tomiozzo

ECOFISIOLOGIA, MODELAGEM E DESEMPENHO AGRONÔMICO DE *Helianthus annus* L. E *Limonium sinuatum* Mill. COMO FLORES DE CORTE

Tese apresentada ao Programa de Pós-Graduação em Agronomia, Área de Concentração em Produção Vegetal, da Universidade Federal de Santa Maria (UFSM, RS), como requisito parcial para obtenção do título de **Doutora em Agronomia.**

Aprovada em 24 de abril de 2024:

____
Nereu Augusto Streck, Ph.D. (UFSM)
(Presidente e orientador)

____
Beatrice Nesi, Dra. (CREA)

____
Lilian Osmari Uhllmann, Dra. (UFSM)

____
Petterson Baptista da Luz, Dr. (UNEMAT)

____
Márkilla Zunette Beckmann-Cavalcante, Dr. (UNIVASF)

Santa Maria, RS
2024

AGRADECIMENTOS

Agradeço a Deus, Pai, Filho e Espírito Santo e a Mãe Rainha e Vencedora Três Vezes Admirável de Schoenstatt por guiarem-me em cada passo dado e nunca me deixarem cair, permitindo que eu finalizasse essa etapa na minha jornada.

Aos meus pais e meus irmãos pela compreensão, apoio incondicional, carinho e cuidado nesses anos dedicados a vida acadêmica, que entenderam a minha ausência por acreditarem em mim e nos meus sonhos.

Ao meu orientador Professor Nereu Augusto Streck, incansável e visionário, que sempre acreditou no meu potencial e investiu em mim para que construíssemos um belo caminho de flores na história da floricultura brasileira, através do projeto “Flores para Todos”. Obrigada por nunca se contentar com o básico e por isso, me instigar a buscar mais e fazer melhor.

Ao meu comitê de orientação, Professora Leosane Cristina Bosco e Professor Alencar Junior Zanon e ao Programa de Pós-Graduação em Agronomia, colegas e professores.

À CAPES pela concessão da bolsa de doutorado e ao CNPq pela oportunidade de realizar doutorado sanduíche na Itália. Aos pesquisadores e colegas do CREA e da UniFi, agradeço a troca de experiências e amizade.

Às Equipes PhenoGlad de todo o Brasil pelo auxílio na coleta de dados e aos produtores rurais, extensionistas e escolas participantes do Projeto Flores Para Todos.

Aos funcionários do Setor de Campo do Departamento de Fitotecnia, por toda ajuda que recebi com as atividades de campo, amizade e conversas diárias.

À Equipe PhenoGlad Santa Maria e a professora Lilian Osmari Uhlmann, agradeço imensamente pelo apoio prestado, parceria e trabalho em equipe durante os anos de doutorado.

“Que a tua vida não seja uma vida estéril. - Sê útil. - Deixa rasto.”

São Josemaria Escrivá

RESUMO

ECOFISIOLOGIA, MODELAGEM E DESEMPENHO AGRONÔMICO DE *Helianthus annus* L. E *Limonium sinuatum* Mill. COMO FLORES DE CORTE

AUTORA: Regina Tomiozzo
ORIENTADOR: Nereu Augusto Streck

A floricultura brasileira é uma promissora e típica atividade da agricultura familiar, que entre 2012 e 2023 cresceu a uma taxa média de 12% ao ano. É uma atividade que está alinhada com as necessidades da produção agrícola global, que enfrenta o desafio de aumentar a produtividade sem expandir a área cultivada. A pandemia do Covid-19 trouxe inúmeras perdas para este setor, ocasionando um intenso período de vulnerabilidade. Uma questão chave é como fortalecer toda a cadeia produtiva brasileira de flores e plantas ornamentais em escala nacional para enfrentar futuros imprevistos. Seria realizando melhorias que acompanhem as tendências do mercado internacional, desde a produção até a comercialização? Neste sentido, existem dois caminhos possíveis. Um, é através da produção e comércio local, que permitem a redução de custos e fomentam o consumo interno de flores. Este moderno modelo de floricultura é popular em países da Europa e da América do Norte, e no Brasil é um caminho que já vem sendo seguido e tem se consolidado com o Projeto Flores para Todos, o maior projeto inclusivo de extensão em Floricultura do Brasil. O outro caminho é desenvolver inovação e gerar tecnologias de ponta para a floricultura, através da criação de modelos que simulem o desenvolvimento de espécies de flores. Juntos, estes caminhos têm potencial para consolidar um crescimento sustentável e de sucesso para a floricultura brasileira e aumentar a participação do Brasil no mercado internacional de flores e plantas ornamentais. Unindo esses caminhos estratégicos, foram conduzidos ensaios de campo em diversas regiões do Brasil e na região da Toscana, na Itália, com o objetivo de aprofundar o entendimento dos processos ecofisiológicos que regem o desenvolvimento de duas espécies cultivadas como flores de corte: o girassol e a statice, visando assim, a sua aplicação em modelos de simulação do desenvolvimento vegetal para área da floricultura. Desta forma, esta tese está dividida em três capítulos, com os seguintes objetivos: i) avaliar o crescimento, desenvolvimento e produção de girassol de corte em ambientes tropicais, subtropicais e temperados; ii) estimar o filocrono em genótipos de girassol de corte cultivado a campo considerando diversos locais e épocas de semeadura e, iii) descrever o padrão de florescimento da cultura da statice em ambiente subtropical, investigando fatores que influenciam seu ciclo reprodutivo. Os genótipos de girassol de corte utilizados para este estudo são bem adaptados nos ambientes tropical, subtropical e temperado, apesar das variações proporcionadas pelas diferentes condições ambientais. O número de folhas e o tempo térmico em girassol de corte tem relação bi-linear, resultando em dois filocronos. O período de colheita de statice pode variar de 5 a 18 semanas no rendimento e componentes de produção de flores variam em cada semana de colheita. Os resultados fornecem informações importantes aos produtores de flores sobre ambiente e seus efeitos nos processos ecofisiológicos no cultivo de girassol de corte e statice e compõe uma base sólida para o desenvolvimento futuro de modelos de simulação do desenvolvimento baseados em processos destas espécies.

Palavras-chave: Floricultura. Girassol de Corte. Statice. Ambiente. Cultivo a campo.

ABSTRACT

ECOPHYSIOLOGY, MODELLING AND AGRONOMIC PERFORMANCE OF HELIANTHUS ANNUUS L. AND LIMONIUM SINUATUM MILL. AS CUT FLOWERS

AUTHOR: Regina Tomiozzo
ADVISOR: Nereu Augusto Streck

Brazilian floriculture is a promising and typical activity of family farming, which grew at an average rate of 12% per year between 2012 and 2023. It is an activity aligned with the needs of global agricultural production, which faces the challenge of increasing productivity without expanding cultivated areas. The Covid-19 pandemic brought numerous losses to this sector, causing an intense period of vulnerability. A key issue is how to strengthen the entire Brazilian production chain of flowers and ornamental plants on a national scale to face future uncertainties. Could this be achieved by making improvements that align with international market trends, from production to marketing? In this regard, there are two possible paths. One is through local production and trade, which reduce costs and promote domestic consumption of flowers. This modern floriculture model is popular in European and North American countries, and in Brazil, it is a path that has already been pursued and has been consolidated with the "Flowers for All" Project, the largest inclusive floriculture extension project in Brazil. The other path is to develop innovation and generate cutting-edge technologies for floriculture, creating models that simulate the development of flower species. Together, these paths have the potential to consolidate sustainable and successful growth for Brazilian floriculture and increase Brazil's participation in the international market for flowers and ornamental plants. Combining these strategic approaches, field trials were conducted in various regions of Brazil and in the Tuscany region of Italy to deepen understanding of the ecophysiological processes governing the development of two cultivated species as cut flowers: sunflower and statice. Thus, this thesis is divided into three chapters with the following objectives: i) evaluate the growth, development, and production of cut sunflowers in tropical, subtropical, and temperate environments; ii) estimate the phyllochron in field-grown cut sunflower genotypes considering various locations and sowing times to estimate the phyllochron using a single and a bilinear model in field-grown cut sunflower genotypes considering several sowing dates in tropical, subtropical, temperate locations, and; and iii) describe the flowering pattern of the statice crop in the subtropics of Brazil, investigating factors that influence its reproductive phase. The cut sunflower genotypes used in this study are well adapted to tropical, subtropical, and temperate environments, despite variations due to different environmental conditions. The number of leaves and thermal time in cut sunflowers show a bi-linear relationship, resulting in two phyllochrons. The harvesting period of statice can vary from 5 to 18 weeks, and flower yield and production components vary each harvesting week. The results provide important information to flower producers about the environment and its effects on ecophysiological processes in cut sunflower and statice cultivation, forming a solid foundation for the future development of developmental simulation models based on these species.

Keywords: Floriculture. Cut sunflower. Statice. Environment. Field grown.

SUMÁRIO

1 INTRODUÇÃO

Em 2023, o mercado brasileiro de flores e plantas ornamentais movimentou o montante de U$S3,798 bilhões e teve um crescimento de 8% em relação a 2022, sendo a floricultura responsável por 17% do PIB interno do setor (IBRAFLOR, 2024), comprovando a importância e o alto potencial de crescimento deste setor no país como uma atividade do agronegócio atrativa, estratégica e economicamente rentável (SCHWAB et al., 2014; JUNQUEIRA; PEETZ, 2018). Além disso, é um mercado ávido por produtos de qualidade por um preço acessível, e que possuam maior durabilidade e baixa manutenção, demandas que se acentuaram durante a pandemia do Covid-19.

De acordo com Junqueira e Peetz (2018), a Cadeia Produtiva de Flores e Plantas Ornamentais brasileira se encaminha para a implantação de um modelo de qualidade internacional de gestão, governança e intensificação dos processos de introdução e adaptação de novas espécies, cultivares e híbridos no Brasil. Esse avanço promove a atualização do setor ao acompanhar as tendências do mercado mundial de flores, podendo alcançar o reconhecimento e a excelência internacional de maneira competitiva, eficiente e sustentável.

A priorização da pesquisa na área da floricultura em escala nacional e global permite aumentar essa capacidade, com alto grau de sofisticação de manejo, aplicando práticas agronômicas e utilizando variedades com boa relação custo-benefício, visando a máxima eficiência do uso dos recursos disponíveis. Segundo Cavalcante (2017) ao olhar para as perspectivas de expansão deste setor, é necessário estar em sintonia com os avanços na produção vegetal, garantir melhorias na qualidade das flores e plantas ornamentais cultivadas e atender os consumidores cada vez mais exigentes. A autora ainda salienta que realizar mudanças nas práticas de cultivo visando tornar o setor mais viável, especialmente para pequenos produtores, implica na adaptação das habilidades e conhecimentos. Visando melhorar o cultivo e manejo de espécies globalmente, cada vez mais a pesquisa está voltada para desenvolver tecnologias que tragam inovação, otimização dos recursos e sustentabilidade para o produtor. Dentre as tecnologias disponíveis, os modelos de simulação do desenvolvimento vegetal são importantes ferramentas de gestão que integradas ao dia a dia e tornam-se essenciais para os diversos setores do agronegócio brasileiro, inclusive para a floricultura.

A capacidade de expansão e aumento do volume de produção por área de maneira sustentável torna a floricultura uma excelente oportunidade de gerar emprego e renda para a agricultura familiar. Por isso, além de valorizar o espaço da propriedade rural e maximizar os lucros, inserir espécies da floricultura para diversificação da produção é essencial para o enfrentamento de períodos de vulnerabilidade, por proporcionar a redução dos riscos econômicos e incertezas do produtor rural. Uma das alternativas da floricultura para atender a esta demanda é a produção de flores de corte como o *Helianthus annuus* L. e o *Limonium sinuatum* (L.) Mill, popularmente conhecidas como girassol e statice, respectivamente (LORENZI; SOUZA, 2001). Tanto o girassol de corte como a statice são consideradas “flores de corte especiais”, pois apresentam as seguintes características conforme Darras (2021): são espécies anuais que podem ser produzidas sazonalmente em pequenas quantidades, favorecendo a venda em mercados locais de flores. Além disso, são espécies de flores rústicas, apropriadas para o cultivo a campo e que não requerem grandes investimentos financeiros e de infraestrutura. Por demanda de produtores e extensionistas, de acordo com Streck e Uhlmann (2021), estas espécies de flores de corte foram introduzidas no projeto “Flores para Todos”, um projeto de extensão com abrangência nacional que visa levar a floricultura como uma alternativa de renda para agricultores familiares e manter o jovem no campo.

Dada a extensão territorial brasileira, com latitudes desde 5ºN até 34ºS, com climas que variam desde clima úmido e quente o ano todo (Região Norte) até subtropical com invernos frios e úmidos (Região Sul) passando pelo clima tropical monsônico nas Regiões Centro-Oeste e Sudeste e pelo clima de savana em transição para um regime mediterrâneo em precipitação (Região Nordeste), o primeiro passo antes de desenvolver um modelo robusto e com alta taxa de acerto, é compreender o desenvolvimento e crescimento destas espécies nos distintos ambientes de cultivo. Considerando as diferenças de temperatura, fotoperíodo e radiação solar, que são variáveis meteorológicas que exercem uma influência significativa nos processos ecofisiológicos fundamentais de desenvolvimento do girassol e da statice (BAHUGUNA; JAGADISH, 2015; SHILLO; ZAMSKI, 1985), a sua adaptabilidade pode variar em diferentes localizações brasileiras. Nesse sentido, estudos que descrevam detalhadamente os processos ecofisiológicos envolvidos no desenvolvimento e produção de girassol de corte e statice necessitam ser realizados.

1.1 HIPÓTESES

O crescimento, desenvolvimento e produção de girassol de corte são influenciados por variações climáticas, com o potencial de apresentar características distintas em cada região.

Há um ponto de inflexão entre a sexta e a sétima folha em genótipos de girassol de corte que alterará a velocidade de emissão de folhas ao longo do desenvolvimento foliar.

O padrão de florescimento da cultura da statice em ambiente subtropical seguirá uma determinada sequência temporal, influenciada por fatores como temperatura e fotoperíodo, com potenciais variações em seu ciclo reprodutivo em outras regiões e épocas do ano.

1.2 OBJETIVO GERAL

Aprimorar o conhecimento dos processos ecofisiológicos que governam o desenvolvimento de duas espécies cultivadas como flores de corte, o girassol e a statice, através de ensaios de campo multi-anos e multi-locais, visando a sua aplicação em modelos futuros de simulação do desenvolvimento vegetal para área da floricultura.

1.2.1 Objetivos específicos

1. Avaliar o crescimento, desenvolvimento e produção de girassol de corte em ambientes tropicais, subtropicais e temperados.
2. Estimar o filocrono em genótipos de girassol de corte cultivado em campo considerando diversos locais e épocas de semeadura.
3. Descrever o padrão de florescimento da cultura da statice em ambiente subtropical, investigando fatores que influenciam seu ciclo reprodutivo.

2 REFERENCIAL TEÓRICO

2.1 MERCADO BRASILEIRO DE FLORES E PLANTAS ORNAMENTAIS

No Brasil, o setor de flores e plantas ornamentais registrou um montante de US$ 1,157 milhões em 2021, representando um crescimento de 15% em relação a 2020. Nos últimos 10 anos, esse setor tem mantido uma taxa média de crescimento de 12% ao ano (IBRAFLOR, 2022). Em 2022, observou-se um aumento de 17% em relação a 2021 e em 2023, o setor cresceu 8% em relação a 2022, movimentando U$S 3,798 bilhões (IBRAFLOR, 2024). Países como Itália e Estados Unidos alcançaram respectivamente, em 2019, US$ 1,439 milhões e US$ 3,715 milhões, e a Inglaterra registrou valores de US$ 534 milhões em 2020, respectivamente (AIPH, 2021). No entanto, o consumo *per capita* de flores no Brasil ainda é baixo, cerca de US$ 19,57/ano (IBRAFLOR, 2024), em comparação com países como a Itália (US$ 82,33/ano), Estados Unidos (US$ 129,26/ano) e Inglaterra (US$ 152,07/ano) em 2021 (AIPH, 2022). Se metade dos brasileiros consumissem esse valor (US$ 19,57/ano) por mês, o faturamento anual do setor da floricultura no Brasil subiria para US$ 25.2 bilhões/ano, ou seja, um crescimento de 631.7%.

A atividade de flores e plantas ornamentais tem atraído muitos investidores, pela sua performance no mercado comercial, uma vez que esta é uma atividade familiar, e por ser um mercado comercial em expansão, comprovando a importância e o alto potencial de crescimento da floricultura no país (JUNQUEIRA; PEETZ, 2018; REIS et al., 2020). O Brasil possui mais de 8.000 produtores de flores e plantas ornamentais que cultivam mais de 350 espécies e 3.000 cultivares. No entanto, a maior parte da produção de flores e plantas ornamentais brasileira está concentrada na região Sudeste do país, no estado de São Paulo (JUNQUEIRA; PEETZ, 2017; REIS et al., 2020; IBRAFLOR, 2024). A concentração da produção nesta região do Brasil dá-se pela imigração holandesa iniciada na década de 50, onde estabeleceu-se um formato de floricultura empresarial e comercial sob a gestão da Cooperativa Veiling Holambra e a partir disso, polos de consumo foram criados em outras regiões brasileiras (por exemplo Minas Gerais, Rio de Janeiro, Rio Grande do Sul, Santa Catarina e Ceará) para o escoamento da produção a curtas, médias e longas distâncias (JUNQUEIRA; PEETZ, 2008).

A principal demanda de flores no Brasil ocorre em datas específicas, concentrando as vendas em datas como Dia das Mães e Dia dos Namorados (JUNQUEIRA; PEETZ, 2017).

Da produção brasileira, 97,5% são absorvidos pelo mercado nacional e ainda são importados produtos da Colômbia, Equador, China, Chile e Holanda (AIPH, 2022; IBRAFLOR, 2024). Por isso, segundo Castro et al. (2022), a oferta regular de produtos padronizados e de melhor qualidade pode abastecer muitos mercados, causando influência e homogeneização dos hábitos de consumo. Além disso, a variedade de produtos encontrados no varejo brasileiro é limitada e praticamente indistinguível de Norte a Sul do país. Em virtude disso, os produtos oriundos deste setor apresentam alto custo para o consumidor final em outras regiões brasileiras, intensificado em parte pelo custo do transporte dos produtos que está embutido no preço final estabelecido ao consumidor e, em parte pelo baixo poder aquisitivo dos brasileiros em relação aos demais países, que impedem o aumento do consumo de flores e plantas ornamentais no país.

Este cenário se acentuou durante a pandemia do Covid-19, que trouxe para a floricultura brasileira um forte e intenso período de vulnerabilidade econômica (CAVALCANTE, 2021). O cancelamento em massa dos eventos e o fechamento do comércio, especialmente no início da pandemia em 2020, impediu o escoamento da produção, levando a perda massiva de produtos perecíveis não comestíveis (flores de corte) e elevando o preço dos poucos produtos disponíveis (ANACLETO et al., 2021). Isto instalou uma forte crise em toda a cadeia produtiva, acarretando a falência de inúmeros produtores, especialmente aqueles que investiram na especialização e não na diversificação da produção. No entanto, com os atuais conflitos geopolíticos que o mundo está vivendo em decorrência de Guerras entre Rússia e Ucrânia e entre Israel e Hamas, um cenário de aumento dos preços dos produtos deve persistir em 2024 e, o consumo de flores e plantas ornamentais fica em segundo plano na lista de prioridades dos brasileiros.

Apesar das dificuldades, o mercado de flores e plantas ornamentais brasileiro está expandindo e gerando empregos, com 60% da mão-de-obra feminina das 272.000 pessoas envolvidas no setor (IBRAFLOR, 2024). Com os resultados positivos de crescimento dos últimos anos, a regularização e reconhecimento do setor no âmbito nacional como parte integrante da horticultura, tem sido incentivada também através da criação de uma nova Política Nacional de Incentivo à Cultura de Flores e de Plantas Ornamentais de Qualidade que tem o objetivo de fomentar a produção de flores e plantas ornamentais no Brasil, bem como a sua comercialização nos mercados interno e externo, pela Lei n. 14.637, de 25 de julho de 2023 (DIÁRIO OFICIAL DA UNIÃO, 2023).

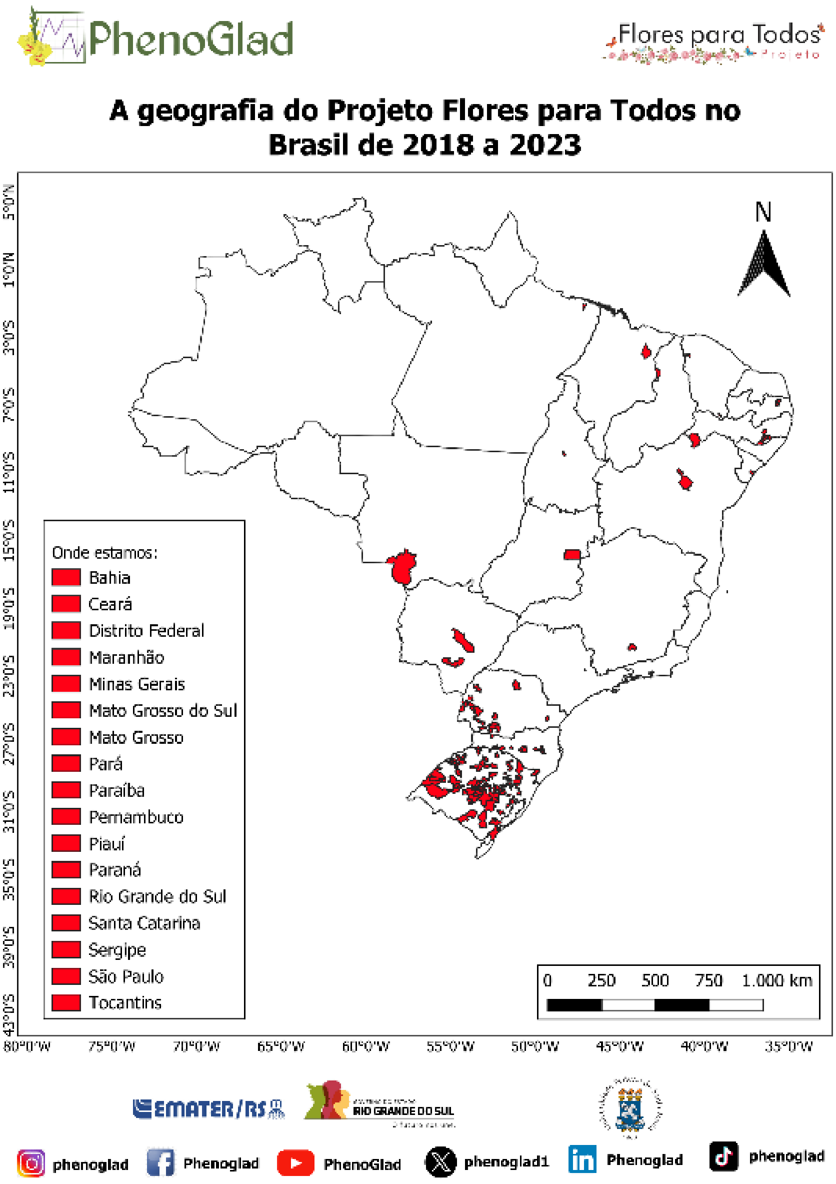
2.2 PROJETO FLORES PARA TODOS

Investir no fortalecimento e crescimento do setor de flores e plantas ornamentais no Brasil é fundamental e, uma forma de fazer isso, é através da introdução da floricultura como alternativa de diversificação da produção em pequenas propriedades rurais. Além de valorizar o espaço da propriedade rural e maximizar os lucros, a diversificação da produção é essencial para o enfrentamento de períodos de vulnerabilidades como esse, por proporcionar a redução dos riscos econômicos e incertezas. Esta atividade permite ao agricultor familiar empreender, criar e inovar dentro da sua propriedade, agregando valor e crescendo economicamente. Além disso, permite a descentralização da produção, criando outros canais de comercialização, produzindo espécies mais adaptadas ao clima e cultura local e, ainda, encurtar cadeia, reduzindo o custo ao consumidor, alavancando o consumo per capita, tornando-a uma cadeia sustentável economicamente, socialmente e ambientalmente.

O modelo moderno de floricultura, com produção e comercialização local tem dado certo em outros países do mundo, como nos Estados Unidos com o projeto chamado "Local Flowers, Local Farmers: a Growing Movement" (https://localflowers.org/; https://www.youtube.com/watch?v=PEXs9UUgqqg), uma iniciativa da Association of Specialty Cut Flowers Growers, que visa o resgate no cultivo de flores de corte e as floriculturas e feiras locais comercializam apenas as flores produzidas no seu município. No Brasil, um projeto inclusivo de extensão que utiliza este modelo moderno em todo o território nacional gerando renda para agricultores familiares, mulheres rurais e jovens do campo é o Projeto "Flores para Todos" (STRECK; UHLMANN, 2021) (https://www.youtube.com/watch?v=-sR6LW_P8dU). Desde seu início em 2018 até 2023, este projeto já alcançou, em nível de Brasil, 324 famílias e 59 escolas do campo de 151 municípios em 17 estados de regiões brasileiras (Figura 1). Em 2024, o projeto continua em andamento e estes números seguem aumentando.

As espécies de flores são escolhidas visando atender as seguintes premissas básicas agronômicas do Projeto Flores para Todos: i) rusticidade; ii) cultivo a céu aberto; iii) fácil propagação e manejo; iv) baixo custo de implantação e produção e, v) ótima aceitação pelos consumidores. A cultura pioneira do projeto é o gladíolo, uma bulbosa com forte importância como flor de corte no país para o dia das Mães e o dia de Finados (UHLMANN et al., 2019). Com a expansão do projeto por todo o Brasil e dada a sua extensão territorial, houve a necessidade de introduzir novas espécies de flores para aumentar as opções de diversificação ao longo do ano. Por isso, novas culturas já foram introduzidas no projeto: statice (*Limonium sinuatum* Mill.) https://youtu.be/YK_J73zMqvk), girassol de corte (*Helianthus annus* L.) (https://youtu.be/cQqUg3zrAkI) , dália (*Dahlia pinnata*) (https://youtu.be/Jtrl_I20QEc) e ornitogalum (*Ornithogalum saundersiae*) (https://www.youtube.com/watch?v=v5yXkGxoVIA).

Figura 1 - Geografia do Projeto Flores Para Todos no Brasil de 2018 a 2023.



2.3 GIRASSOL DE CORTE

O girassol (*Helianthus annuus*) é uma planta dicotiledônea, herbácea de ciclo anual. Pertencente à família Asteraceae e nativa da região temperada da América do Norte (KAYA; JOCIC; MILADINOVIC, 2011; SHATOORI et al, 2021). Como planta ornamental, o girassol tem grande representatividade como flor de corte por sua beleza exuberante e imponente, sendo uma das culturas de flores mais conhecidas e apreciadas em todo o mundo (MLADENOVÌC et al. 2020; PUTTHA et al., 2024).

Morfologicamente, possui um caule ereto e robusto, que pode atingir alturas significativas, variando de acordo com a cultivar e as condições de crescimento. Suas folhas são grandes, de formato oval ou em formato de coração, com uma textura áspera e uma cor verde vibrante, que contribui para sua estética visualmente marcante. A inflorescência do girassol é do tipo capítulo, que se caracteriza pela dilatação do pedúnculo na parte superior, formando um receptáculo, sobre o qual se inserem as flores sésseis (CURTI et al., 2012). Envolvendo o receptáculo, está o invólucro, um conjunto de brácteas que protege e impede a queda dos frutos (aquênios). Apresenta dois tipos de flores sésseis: as liguladas e as tubulares. As liguladas (corola amarela) são incompletas e inférteis e servem como atrativo para insetos, como abelhas. As tubulares são as flores do disco, completas e férteis, que formarão os aquênios. No entanto, para o girassol ornamental, as flores do disco também são estéreis, pois para ornamentação o pólen é indesejável (CURTI et al., 2012; NEVES et al., 2005).

É uma planta propagada por sementes e sua emergência ocorre rapidamente, cerca de 8 dias após a semeadura. Responsiva a temperatura do ar, a duração do ciclo é calculada em °C dia, que geralmente é curto (50 a 70 dias) dependendo da cultivar (ARMITAGE; LAUSHMAN, 2003; SHATOORI et al., 2021). Segundo Alberio et al. (2015), a temperatura base do girassol pode variar de 4,0 °C a 8,0 °C. Em condições de baixa umidade relativa do ar e temperatura elevada, o ciclo é acelerado antecipando o florescimento (CURTI et al., 2012). O fotoperíodo também apresenta influência no desenvolvimento do girassol, sendo classificado como uma planta neutra ao fotoperíodo (DN), uma planta facultativa de dias longos ou como planta facultativa de dias curtos, resultando na antecipação do florescimento (GOUNE; HAMMER, 1982; YAÑEZ et al., 2012). Não há um consenso entre autores sobre qual seria essa resposta e entende-se que é pode ser variável com a cultivar.

O estresse hídrico é a principal limitante para produção de hastes florais de qualidade e em condições sem limitação de água, é uma planta que apresenta alta taxa de transpiração (ALBERIO et al., 2015). Um mecanismo de defesa da planta, em situações de deficiência hídrica é o murchamento das folhas (redução da transpiração), que fará com que a água fique conservada no solo por mais tempo, protegendo-as do estresse térmico. Nutricionalmente, o girassol é exigente em macro e micronutrientes. Na implantação da cultura exige-se uma adubação de base com NPK e posterior adubação de cobertura, durante a fase vegetativa, quando ocorre maior absorção dos nutrientes (ALBERIO et al., 2015; CURTI et al., 2012).

A produtividade do girassol ornamental pode ser medida através do comprimento da haste floral e da qualidade da sua inflorescência, pelo diâmetro do capítulo e aspectos visuais (NEVES et al., 2005) e isto pode variar com a genética da planta e o ambiente em que estão expostas. A colheita é realizada conforme o estágio de abertura floral, geralmente quando as pétalas das flores liguladas apresentam abertura em um ângulo de 90°. O ponto de colheita pode diferir conforme a demanda do mercado. Colhe-se mais fechada, quando o objetivo é a comercialização em mercados distantes e mais abertas para mercados próximos. Após o corte, o girassol continua a abertura das flores tubulares, por isso devem ser acondicionadas em recipiente com água. A vida de vaso pode variar de acordo com a região, época do ano, genética, sistema de cultivo e distância do consumidor (CURTI et al., 2012). De modo geral, a durabilidade pós-colheita é em torno de 7 a 10 dias. Por essas características, é uma espécie que tem grande potencial para conquistar o mercado regional de flores de corte, pela crescente demanda local por flores de qualidade a um baixo custo.

2.4 A CULTURA DA STATICE

O gênero *Limonium* pertence à família Plumbagianaceae e possui mais de 300 espécies, dentre as quais está o *Limonium sinuatum* L. Mill., natural da região do Mediterrâneo e popularmente conhecida como statice, estátice, lavanda do mar ou sempre viva (LORENZI; SOUZA, 2001; CIOTTA; NUNES, 2011). É uma planta herbácea de ciclo anual, multiplicada por sementes, de caule com entrenós muito curtos durante a fase vegetativa e por isso as folhas basais crescem em forma de roseta, inflorescências eretas ramificadas e duráveis que podem ser ora do tipo cacho ou racimo (flores situadas em pedicelos saindo de diversos níveis no eixo primário e atingindo diferentes alturas) e ora do tipo corimbo (flores situadas em pedicelos saindo de diversos níveis no eixo primário e atingindo todas a mesma altura), numerosas flores de cálice azulado e corola branca, amarela, roxa e rósea (BARROSO et al., 2004). De acordo com Blas (1992), classifica-se como um rácemo-corimbiformes.

A produção de statice é de especial interesse, pois é amplamente utilizada por floristas e decoradores na composição arranjos e vasos para ornamentar interiores e ocasiões especiais, como datas comemorativas. A preferência pela utilização desta flor ocorre pela sua longevidade quando secas, podendo também ser usada fresca, além da variedade de cores (WHIPKER; HAMMER, 1994; NATARAJ et al., 2009). Tanto no Brasil como em outras regiões do mundo, como é o caso de Taiwan, o cultivo de grande parte das cultivares de statice atualmente disponíveis inicia no outono, passando por um período de vernalização natural durante o inverno, florescendo na primavera e verão em regiões subtropicais (CHANG; YEH; YANG, 2010). Em função destas exigências bioclimáticas, o período de colheita das flores de statice em cultivo de campo no Sul do Brasil é de setembro a dezembro.

O cultivo da statice é realizado, preferencialmente, a campo e pleno sol (BARROSO et al., 2004) e em pequenas áreas. A planta de statice adapta-se bem a diferentes tipos de solos desde que tenha boa aeração e drenagem (GONZÁLES; RE, 2003). O solo deve ser previamente preparado antes do plantio, a fim de proporcionar uma boa estrutura para o desenvolvimento da planta. Solos menos férteis são preferíveis para controlar a floração e evitar a emissão demasiada de folhas (crescimento vegetativo intenso e pouco crescimento reprodutivo). Adapta-se bem em solos com pH de 6,0 a 6,5 e durante seu cultivo é necessário realizar adubação suplementar de potássio e magnésio (GONZÁLES; RE, 2003).

O plantio pode ser realizado em canteiros com fileiras duplas espaçadas 50 cm e com 30 cm entre plantas, para proporcionar o bom crescimento e desenvolvimento das plantas. Densidades maiores diminuem a qualidade das hastes, além favorecer o aparecimento de doenças fúngicas devido à falta de ventilação dentro do dossel. Nataraj et al. (2009) estudaram o crescimento e o desenvolvimento de cinco cultivares de statice e verificaram que seu ciclo pode durar de 70 a 90 dias até a floração. Dependendo da cultivar e da época de cultivo, uma planta de statice pode emitir cerca de 180 a 200 folhas durante seu ciclo (BLAS, 1992; NATARAJ et al., 2009).

A desenvolvimento da statice é influenciado principalmente pela temperatura do ar e pelo fotoperíodo (SHILLO, 1976; SHILLO; ZAMSKI, 1985). Altas temperaturas promovem o crescimento das folhas, mas inibem a indução floral (SHILLO; ZAMSKI, 1985). A statice é considerada uma planta de dia longo, com fotoperíodo crítico (a partir do qual o florescimento é induzido) de 13 horas (SEMENIUK; KRIZEK, 1972; SHILLO; ZAMSKI, 1985; CHEN et al., 2010). Além disso, seu crescimento é maior quando exposta a alta intensidade luminosa (SHILLO; ZAMSKI, 1985).

Shillo e Zamski (1985) descrevem como os fatores ambientais afetam o desenvolvimento da statice. Segundo os autores, o requerimento de temperatura está interrelacionado com a cultivar. Por exemplo, as cultivares de cores amarela e branca podem florescer em altas temperaturas em relação as cultivares de cor rósea e roxa. Caso não ocorra a indução floral, a planta de statice permanecerá emitindo folhas, aumentando a fase vegetativa e atrasando a floração. Shillo (1976) descreve que a faixa ideal de temperatura para o ciclo de desenvolvimento da statice é de 12 °C a 16 °C durante a noite e de 22 °C a 27 °C durante o dia.

A vernalização das sementes de statice não é efetiva para o desenvolvimento da cultura (SHILLO; ZAMSKI, 1985). No entanto, a exposição das plantas a baixas temperaturas durante a fase plântula (a partir da quinta folha) é essencial para desencadear o florescimento. As necessidades de vernalização são alcançadas expondo plântulas de statice a temperaturas de 11 a 13 °C durante três semanas, sendo que, o fotoperíodo durante a vernalização não influencia o florescimento (SHILLO, 1976; SHILLO; ZAMSKI, 1985) e esta necessidade de frio é alcançada nos cultivos de campo nos estados do Sul do Brasil quando o transplantio é realizado no outono e as plantas ficam expostas no inverno.

Segundo Nataraj et al. (2009) apesar da ampla utilização desta flor, alguns gargalos estão associados à sua produção, como: indisponibilidade de material propagativo, falta de variedades melhoradas e alta flutuação de mercado. Quanto à indisponibilidade de material propagativo, atualmente no Brasil, este é encontrado no mercado de duas maneiras: por sementes e por *plugs*. As sementes disponíveis no mercado brasileiro são *mixes* de cultivares, com custo mais acessível, porém com alguns obstáculos para o cultivo pela diferença de duração de ciclo, cor da flor e em número e tamanho de folhas, pois cada cor da flor é uma cultivar de statice no mesmo lote de sementes. Sementes importadas e *plugs* (produzidos a partir da cultura de tecidos) proporcionam uma produção uniforme com cultivares específicas, porém com alto custo decorrente da legislação e burocracia para importação deste material de outros países.

3 RESULTADOS E DISCUSSÕES

3.1 CAPÍTULO 1 – DEVELOPMENT, GROWTH, AND FLOWER PRODUCTION OF CUT SUNFLOWER IN TROPICAL, SUBTROPICAL, AND TEMPERATE ENVIRONMENTS

(Submetido à *Horticulture, Environment*, *and Biotechnology,* portanto as normas estão de acordo com as diretrizes exigidas)

Development, growth, and flower production of cut sunflower under tropical, subtropical, and temperate environments

Regina Tomiozzo[1*], Lilian Osmari Uhlmann[1], Leosane Cristina Bosco[2], *Márkilla Zunete* Beckmann-*Cavalcante*[3], *Petterson Baptista da Luz*[4], José Carlos Sorgato[5], Simone Novaes Reis[6], Lívia Mendes de Carvalho[6], Anelise Tessari Perboni[7], Luana Moraes da Luz[8], Heberte Fernandes de Figueredo[3], Sebastião Marcos Silva Valentim[4], Luana Gabriele Oliveira da Silva[1], Tiago Ledesma Taira[5], Thais Pires Roso[1], Gustavo Vieira Nakahada[7], Vitória Beatriz Soares Oliveira[8], João Batista Tolentino Júnior[2], Adriana Terumi Itako[2], Dislaine Becker[9], Charles Patrick de Oliveira de Freitas[1], Beatrice Nesi[10], Andrea Mansuino[11], Cesar Mauricio Torres Martinez[12], Lais Leite Barreto[13], Josabete Salgueiro Bezerra de Carvalho[14], Ana Marcela Ferreira Barros[15], Alencar Junior Zanon[1], Nereu Augusto Streck[1*]

[1] Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brazil.
[2] Universidade Federal de Santa Catarina (UFSC), Campus Curitibanos, SC, Brazil.
[3] Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina, PE, Brazil.
[4] Universidade do Estado de Mato Grosso (UNEMAT), Campus Cáceres, MT, Brazil.
[5] Universidade Federal da Grande Dourados (UFGD), Dourados, MS, Brazil.
[6] Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG), São João Del Rei, MG, Brazil.
[7] Universidade Tecnológica Federal do Paraná (UTFPR), Campus Dois Vizinhos, PR, Brazil.
[8] Universidade Federal Rural da Amazônia (UFRA), Campus Capanema, PA, Brazil.
[9] Colônia Alberguini, Herval D Oeste ,SC, Brazil .
[10] CREA Research Center for Vegetable and Ornamental Crops (CREA OF), Pescia, PT, Italy.
[11] Mansuino S.R.L., Sanremo, LI, Italy.
[12] Brazilian Flowers Agrofloricultura LTDA, Holambra, SP, Brazil.
[13] Universidade Federal da Paraíba (UFPB), Campus II, Areia, PB, Brazil
[14] Universidade Federal do Agreste de Pernambuco (UFAPE), Garanhuns, PE, Brazil.
[15] ETE Adriano Vilar Suassuna, Garanhuns, PE, Brazil.
*Corresponding authors.

Abstract

Sunflower (*Helianthus annuus L.*) is globally recognized as a popular cut flower, boasting an annual developmental cycle influenced primarily by temperature and photoperiod. To assess the response of field grown cut sunflower in tropical, subtropical, and temperate environments, 28 genotypes of cut sunflower were tested in field trials conducted for 4 years (2020 – 2023) in different locations from Northern to Southern Brazil and in the Tuscany region, Italy. These trials provided a large and robust dataset containing results of developmental cycle (in days and °C day), vegetative and reproductive phase (°C day), final leaf number (FLN), leaf number at R1 stage (LN at R1), number of leaves still to appear after R1 stage [FLN – (LN at R1)], phyllochron (°C day leaf), leaf area index (LAI), plant height (cm), capitulum diameter (cm) and stem diameter (cm). The dataset was divided into three environments (tropical, subtropical, and temperate) and relationships were applied by linear regressions. As a result, cut sunflower genotypes used for this study are well adapted to tropical, subtropical, and temperate environments, despite the variations provided by different climatic regimes. In general, it is possible to establish the following relationship: the longer the developmental cycle, the greater the LN at R1, the higher the FLN, and bigger the plant height. The novelty of this study is the response of several cut sunflower in three major climates worldwide (tropical, subtropical and temperate) that provides a basis for futures studies by identifying significant patterns that influence their development, growth, and flower production.

Key words: *Helianthus annuus*, floriculture, cut flower, field grown, multilocation trial.

3.1.1 Introduction

Ornamental crops with short developmental cycle, ease of cultivation, low production cost, wide adaptability to different environmental conditions, and profitability are more and more preferred among farmers (Curti et al., 2012; Junqueira and Peetz, 2018). Sunflower (*Helianthus annuus*), native of North America (Seiler and Gulya, 2016), as a cut flower fulfills these requirements with impressive beauty and aesthetic features of its vibrant capitulum-type inflorescence.

With the advancement of genetic improvement, new genotypes of ornamental crops including cut sunflower with selected characteristics for quality that fits well in floral compositions and gardens are released every year (Ahn et al., 2020). Breeders around the world have been dedicated to generating ornamental sunflower genotypes that meet market needs, such as garden plants, potted plants, or cut flowers, that differ in visual characteristics such as size of the flower head, plant height, flower color, branching, longer vase life, and sterile and pollen-free genotypes (Atlagić et al., 2005; Sloan and Harkness, 2006).

As a cut flower, sunflower has high potential and increasingly conquering the Brazilian flower market. Additionally, its popularity has been boosted for diversifying production and profit increase through the Flowers for All Project, a nationwide initiative in Brazil led by PhenoGlad Teams (Uhlmann, 2019, Streck and Uhlmann, 2021). However, one of the challenges is the introduction of new genotypes to keep up with international market trends, given that Brazil lacks tradition in genetic improvement of floriculture species and has large territorial extension and diversity of climates and soils.

Genotypes can respond differently in each location because of differences in temperature, photoperiod, and solar radiation that drive sunflower development and growth processes (Aiken, 2005; Ungaro et al., 2009, Bahuguna and Jagadish, 2015). Despite its ability to tolerate different climatic conditions, temperature and photoperiod have been shown to significantly affect the timing of sunflower flowering according to the genotype (Villalobos et al., 1996; Yañez et al., 2005). The duration of the vegetative phase, leaf area index (LAI), and leaf appearance rate (or its inverse, the phyllochron), primarily depend on temperature, whereas the final leaf number (FLN), which is genetically a fixed trait (Alberio et al., 2015), may be affected by the photoperiod. Some authors classify the sunflower as a day-neutral plant (DN) or facultative long-day plant, while others classify it as a facultative short-day plant (Goune and Hammer, 1982; Yañez et al., 2012). Thus, temperature and photoperiod are major factors that drive sunflower developmental rate in field conditions (Connor and Sadras, 1992).

Studies on the adaptability and stability have been conducted for sunflower genotypes for grain and oil production purposes (Grunvald et al., 2013; Porto et al., 2008, 2009; Matta et al., 2020) but basic studies on development and growth in ornamental sunflower as cut flower are scarce. Improving knowledge about cut sunflower development and growth in different growing environments is essential for the fine tuning of management practices and therefore to improve farmers profit and may help breeders to define priorities and shorten their breeding programs. Therefore, the objective in this study was to evaluate the development, growth, and flower production of field grown cut sunflower genotypes in tropical, subtropical, and temperate environments. Development variables such as final leaf number, phyllochron, duration of development cycle, vegetative and reproductive phases, as well as growth variables such as leaf area index and quantitative parameters of the floral stem (plant height, capitulum and stem diameter) and their relationships were performed.

3.1.2 Material and Methods

3.1.2.1 Field studies

Five field trials were performed for four years, from 2020 to 2023, in several locations, sowing dates, and regions of Brazil, South America (Fig. 1A), and in Pescia/Tuscany, Italy, Europe (Fig. 1B). Details of each location are in Table 1. The locations and sowing dates represent a wide variety of soil types and climate conditions.

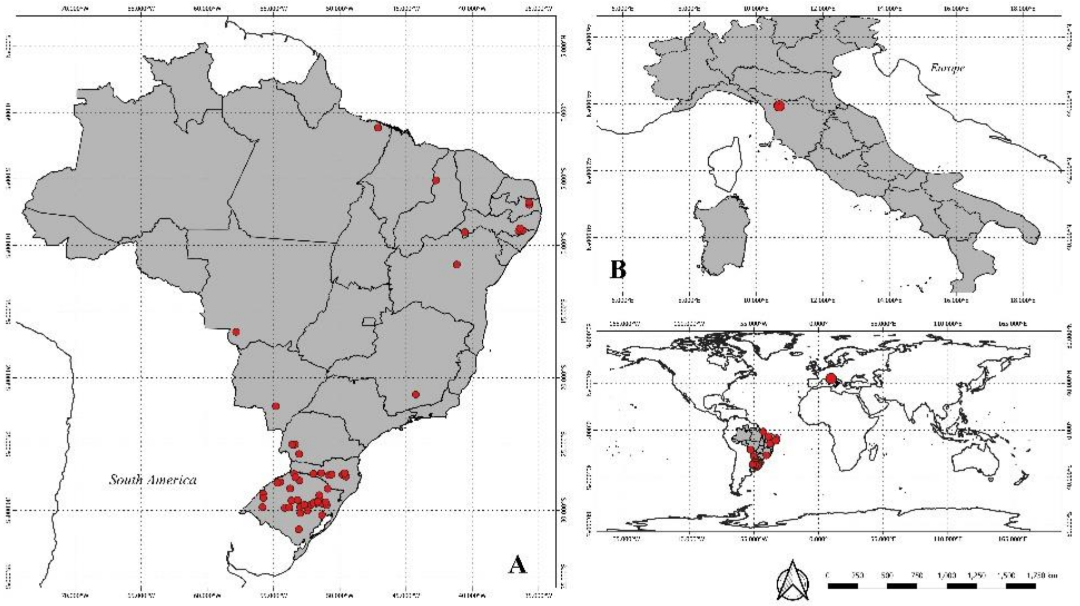


Figure 1. Geographic location of the field trials with cut sunflower genotypes conducted in Brazil (A) and in Italy (B).

All trials followed the same protocol. The sunflower seeds were sown in polystyrene trays containing a commercial substrate, with one seed per hole at a depth of one centimeter. The trays were kept in a protected location until seedlings had the first pair of true leaves with a blade length of 2 cm and a well-developed root system forming a clod in the substrate, when they were then transplanted to 1m in width and 25-30 cm in height beds in the field. Plant spacing was 0.20 m among rows and 0.125 m within rows, with 4 rows per bed, resulting in a plant density of 32 plants/m². The length of the beds varied according to the location and each genotype or sowing date was separated in the bed by a 50 cm empty area. In the two central rows, ten plants (five plants per row) were tagged for data collection.

Table 1. Locations in Brazil and in Italy and their characteristics of climate, biome, latitude, longitude, altitude, sowing date (mm/ dd/yyyy), transplanting date (mm/dd/yyyy), and institution used in field trials with cut sunflower genotypes.

Trial	Location	Climate	Biome	Latitude	Longitude	Altitude	Sowing date	Transplant date	Institution
1	Santa Maria, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°43’S	53°43’W	95 m	08/06/2020	08/17/2020	UFSM
2	Santa Maria, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°43’S	53°43’W	95 m	01/22/2021	01/30/2021	On farm
							02/26/2021	03/06/2021	
	Júlio de Castilhos, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°23’S	53°68’W	529 m	2/25/2021	03/06/2021	On farm
	Herval D’Oeste, SC, Brazil	Cfa	Atlantic Forest	27°19’S	51°49’W	520 m	1/29/2021	02/13/2021	On farm
							2/26/2021	03/06/2021	
3	Cáceres, MT, Brazil	Awa	Cerrado/ Amazon/Pantanal	16°07’S	57°41’W	143 m	09/02/2022	09/12/2022	UNEMAT
	Capanema, PA, Brazil	Ami	Amazon	01°11’S	47°10’W	32 m	09/10/2022	09/17/2022	UFRA
	Curitibanos, SC, Brazil	Cfb	Atlantic Forest	27°16’S	50°30’W	992 m	09/16/2022	10/17/2022	UFSC
	Dois Vizinhos, PR, Brazil	Cfa	Atlantic Forest	24°44’S	53°04’W	565 m	01/27/2023	02/04/2023	UTFPR
	Dourados, MS, Brazil	Am	Cerrado/Pantanal	22°13’S	54°48’W	430 m	01/19/2023	01/27/2023	UFGD
	Petrolina, PE, Brazil	Bsh	Caatinga	09°23’S	40°30’W	380 m	08/08/2022	08/16/2022	UNIVASF
	Santa Maria, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°43’S	53°43’W	95 m	08/08/2022	08/25/2022^{a}	UFSM
	São João Del Rei, MG, Brazil	Cwa	Atlantic Forest	21°08’S	44°15’W	904 m	09/13/2022	09/23/2022	EPAMIG
4	Pescia, PT, Italy	Csa	Appenine^{b}	43°54’N	10°41’E	42 m	02/28/2023	03/17/2023	CREA-OF
5	Morro do Chapéu, BA, Brazil	BSh	Caatinga	11°33’S	41°9’W	1017 m	04/17/2023^{c}	04/25/2023	On farm

Cont. **Table 1**

Dourados, MS, Brazil	Am	Cerrado/Pantanal	22°13’S	54°48’W	430 m	10/15/2021[c]	10/15/2021	UFGD
Teresina, PI, Brazil	Aw	Cerrado	5°5’S	42°48’W	87 m	16/08/2021	08/25/2021	On farm
						09/30/2021 [c]	10/07/2021	
						03/09/2022 [c]	03/22/2022	
Areia, PB, Brazil	As	Caatinga	6°57’S	35°41’W	573 m	09/11/2022[c]	09/22/2022	On farm
Solânea, PB, Brazil	As	Caatinga	6°45’S	35°43’W	589 m	09/11/2022[c]	09/22/2022	On farm
Canhotinho, PE, Brazil	As	Atlantic Forest /Caatinga	8°52’S	36°11’W	552 m	11/03/2022[c]	11/16/2022	On farm
Garanhuns, PE, Brazil	As	Atlantic Forest /Caatinga	8°53’S	36°29’W	841 m	04/03/2023 [c]	04/12/2023	On farm
Jupí, PE, Brazil	As	Caatinga	8°42’S	36°25’W	788 m	04/05/2023[c]	04/15/2023	On farm
Petrolina, PE, Brazil	Bsh	Caatinga	09°23’S	40°30’W	380 m	02/03/2022[c]	02/11/2022	UNIVASF
						05/26/2022[c]	06/03/2022	
Cascavel, PR, Brazil	Cfa	Atlantic Forest	24°57’S	53°27’W	782 m	09/29/2021[c]	10/12/2021	FAG
Santa Tereza do Oeste, PR, Brazil	Cfa	Atlantic Forest	29°7’ S	51°42’W	749 m	03/17/2022[c]	03/28/2022	On farm
Aurora, SC, Brazil	Cfa	Atlantic Forest	27°18’S	49° 38’W	259 m	10/05/2021[c]	10/15/2021	On farm
Brunópolis, SC, Brazil	Cfb	Atlantic Forest	27°18’S	50°52’W	843 m	03/17/2021 [d]	03/31/2021	On farm
						03/31/2021 [d]	04/14/2021	
Concórdia, SC, Brazil	Cfa	Atlantic Forest	27°14’S	52°1’W	578 m	10/06/2021[c]	10/25/2021	On farm
Curitibanos, SC, Brazil	Cfb	Atlantic Forest	27°16’S	50°30’W	992 m	09/08/2022[c]	10/05/2022	On farm
Ituporanga, SC, Brazil	Cfa	Atlantic Forest	27°24’S	49°36’W	347 m	10/18/2021[c]	10/27/2021	On farm
Herval D’Oeste, SC, Brazil	Cfa	Atlantic Forest	27°19’S	51°49’W	520 m	03/22/2021 [d]	03/29/2021	On farm
Rio do Sul, SC, Brazil	Cfa	Atlantic Forest	27°12’S	49°38’W	332 m	03/29/2021 [d]	04/09/2021	On farm
						10/05/2021 [d]	10/15/2021	

Cont. **Table 1**

Seara, SC, Brazil	Cfa	Atlantic Forest	27°9’S	52°18’W	517 m	09/26/2022[c]	10/13/2022	On farm
Trombudo Central, SC, Brazil	Cfa	Atlantic Forest	27°17’S	49°47’W	323 m	10/18/2021[c]	10/26/2021	On farm
Cachoeira do Sul, RS, Brazil	Cfa	Pampa	30°0’S	52°55’W	73 m	03/20/2021[d]	03/29/2021	On farm
						04/13/2021[d]	04/27/2021	
Júlio de Castilhos, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°23’S	53°68’W	529 m	04/15/2021[d]	04/25/2021	On farm
						10/13/2021[c]	10/22/2021	
						11/04/2021[c]	11/16/2021	
						01/08/2022[c]	01/20/2022	
						04/12/2022[c]	04/26/2022	
Dilermando de Aguiar, RS, Brazil	Cfa	Pampa	29°42’S	54°12’W	133 m	03/15/2021[d]	03/24/2021	On farm
						10/07/2022[c]	10/14/2022	
						10/24/2022[c]	11/04/2022	
Santa Maria, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°43’S	53°43’W	95 m	03/05/2021[e]	03/13/2021	On farm
						03/05/2021[f]	03/16/2021	On farm
						03/16/2021[d]	03/23/2021	On farm
						05/11/2021[d]	06/01/2021	On farm
						06/08/2021[d]	07/02/2021	On farm
						07/02/2021[d]	07/13/2021	On farm
						07/13/2021	08/10/2021	On farm
						09/07/2021	09/24/2021	On farm
						10/15/2021[c]	10/26/2021	On farm
						01/27/2022[c]	02/04/2022	On farm
						04/20/2022[c]	04/29/2022	On farm
						09/16/2022[c]	09/29/2022	On farm
	Cfa	Atlantic Forest	29°36’S	52°11’W	29 m	03/15/2021[d]	03/23/2021	On farm

Cont. **Table 1**

Venâncio Aires, RS, Brazil						04/05/2021 [d]	04/13/2021	
Caiçara, RS, Brazil	Cfa	Atlantic Forest	27°16’S	53°25’W	580 m	09/27/2021[c]	10/08/2021	On farm
Novo Xingú, RS, Brazil	Cfa	Atlantic Forest	27°43’S	53°3’W	451 m	09/23/2021[c]	10/05/2021	On farm
						10/09/2021[c]	10/21/2021	
						10/25/2021[c]	11/10/2021	
						11/16/2021[c]	11/30/2021	
Seberi, RS, Brazil	Cfa	Atlantic Forest	27°28’S	53°24’W	526 m	09/27/2021[c]	10/08/2021	On farm
						10/22/2021[c]	11/04/2021	On farm
						10/21/2021[c]	11/04/2021	On farm
Vale do Sol, RS, Brazil	Cfa	Atlantic Forest	29°36’S	52°40’W	213 m	10/20/2021[c]	11/12/2021	On farm
Boa Vista do Sul, RS, Brazil	Cfa	Atlantic Forest	29°21’S	51°40’W	526 m	03/12/2022[c]	03/22/2022	On farm
Novo Cabrais, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°44’S	52°57’W	60 m	02/22/2022[c]	03/02/2022	On farm
						03/11/2022[c]	03/19/2022	
Picada Café, RS, Brazil	Cfa	Atlantic Forest	29°26’S	51°8’W	121 m	03/12/2022[c]	03/28/2022	On farm
						09/29/2022 [c]	10/14/2022	On farm
Santa Bárbara do Sul, RS, Brazil	Cfa	Atlantic Forest /Pampa	28°21’S	53°14’W	511 m	03/14/2022[c]	03/26/2022	On farm
Teutônia, RS, Brazil	Cfa	Atlantic Forest	26°56’S	51°48’W	47 m	03/14/2022[c]	03/23/2022	On farm
Piratini, Brazil	Cfa	Pampa	31°26’S	53°6’W	345 m	03/11/2022[c]	03/24/2022	On farm
Rio Pardo, RS, Brazil	Cfa	Atlantic Forest /Pampa	29°59’S	52°22’W	41 m	02/04/2022[c]	02/14/2022	On farm
						02/14/2022[c]	02/24/2022	
Bom Princípio, RS, Brazil	Cfa	Atlantic Forest	29°29’S	51º21’W	29 m	02/22/2022[c]	03/02/2022	On farm
Cândido Godói, RS, Brazil	Cfa	Atlantic Forest/Pampa	27° 7’S	54° 45’W	308 m	03/11/2022[c]	03/21/2022	On farm

Cont. **Table 1**

Maçambará, RS, Brazil	Cfa	Pampa	29°8'S	56° 4'W	88 m	03/15/2022 [c]	03/22/2022	On farm
Estrela Velha, RS, Brazil	Cfa	Atlantic Forest/Pampa	29°10'S	53°9'W	388 m	03/10/2022[c]	03/21/2022	On farm
São Marcos, RS, Brazil	Cfa	Atlantic Forest	28°58'S	51°4'W	724 m	09/15/2022[c]	10/07/2022	On farm
Lajeado, RS, Brazil	Cfa	Atlantic Forest	29°28'S	51°57'W	21 m	09/10/2022[c]	10/01/2022	On farm
Faxinalzinho, RS, Brazil	Cfa	Atlantic Forest	27°24'S	52°39'W	694 m	09/29/2022[c]	10/17/2022	On farm
Barra do Ribeiro, RS, Brazil	Cfa	Pampa	30°17'S	51°18'W	14 m	10/17/2022[c]	10/28/2022	On farm
Colinas, RS, Brazil	Cfa	Atlantic Forest	23°19'S	51°52'W	36 m	09/20/2022[c]	10/03/2022	On farm
Santa Rosa, RS, Brazil	Cfa	Atlantic Forest/Pampa	27°52'S	54°28'W	268 m	09/17/2022[c]	09/27/2022	On farm
Alegrete, RS, Brazil	Cfa	Pampa	29°47'S	55°46'W	76 m	02/23/2023[c]	03/02/2023	On farm
						03/02/2023[c]	03/09/2023	
						03/09/2023[c]	03/16/2023	
						03/16/2023[c]	03/23/2023	
Bozano, RS, Brazil	Cfa	Atlantic Forest	28°22'S	53°46'W	429 m	01/27/2023[c]	02/03/2023	On farm
						02/03/2023[c]	02/10/2023	
						02/10/2023[c]	02/17/2023	
						02/17/2023[c]	02/24/2023	
Vila Flores, RS, Brazil	Cfb	Atlantic Forest	28°52'S	51°33'W	702 m	04/03/2023[c]	04/18/2023	On farm
Vacaria, RS, Brazil	Cfb	Atlantic Forest	28°30'S	50°55'W	960 m	04/03/2023[c]	04/13/2023	On farm
Nova Petrópolis, RS, Brazil	Cfa	Atlantic Forest	22°57'S	51°70'W	581 m	04/03/2023[c]	04/14/2023	On farm
Bento Gonçalves, RS, Brazil	Cfa	Atlantic Forest	29°10'S	51°31'W	671 m	04/04/2023[c]	04/22/2023	On farm
Sapiranga, RS, Brazil	Cfa	Atlantic Forest	29°38'S	51°00'W	47 m	04/05/2023[c]	04/21/2023	On farm

Cont. **Table 1**

São Borja, RS, Brazil	Cfa	Pampa	28°40’S	55°58’W	74 m	04/01/2023[c]	04/14/2023	On farm

a. Genotype VO-09 transplanted on 08/29/2022, due to low germination and late emergence.

b. According to Blasi et al. (2014).

c. Only genotype VC-12.

d. Only genotypes SO-06 and AG-01.

e. Only genotype DD-03.

f. Only genotype DD-04.

For each location, a soil sampling was taken for physical and chemical test. Soil acidity was corrected along with nutrient supplementation based on the soil analysis and technical recommendations for sunflowers. Before transplanting, base fertilization was applied with 50 g per square meter of NPK Formula 05-20-20, spread and incorporated into the soil. Approximately 10 to 15 days after transplanting, when the plants had about 10 leaves, topdressing fertilization was applied using 25 g/m^2 of Potassium Chloride and 25 g/m^2 of Urea, also incorporated into the soil. Pest and disease control were performed as needed with chemicals. Weed control was carried out through manual hoeing. Drip irrigation was applied as needed in order to avoid soil water deficit. Each plot received individual staking with bamboo stakes or wooden slats at the four external corners and the use of raffia string at 2 to 3 heights as the plants increased in height throughout the developmental cycle. Twenty-eight sunflower genotypes for cutting purposes were used (Table 2) from different private international breeding companies.

Table 2. Cut sunflower genotypes names and codes used in each field trial in Brazil and in Italy.

Trial	Code	Genotype name
Trial 1	AG-01	Amalfi Golden
	AO-02	Amalfi Orange
	SO-06	Stromboli Orange
	VO-09	Vesuvio Orange
	VT-11	Vesuvio Tangy
	MO-03	Magic Orange
Trial 2	AG-01	Amalfi Golden
	AO-02	Amalfi Orange
	SO-06	Stromboli Orange
	VO-09	Vesuvio Orange
	VT-11	Vesuvio Tangy
	MO-03	Magic Orange
	OBS-11	OBS-11
	OBS-29A	OBS-29A
	OBS-36	OBS-36
	OBS37	OBS37
	FV - 01	FV - 01
	FV-07	FV-07
	FV-13	FV-13
	FV-33	FV-33

Cont. **Table 2**

Trial 3	AG-01	Amalfi Golden
	AO-02	Amalfi Orange
	VT-11	Vesuvio Tangy
	LT-05	Luxor Tangy
	DD-03	Double Delight Black Center
	MP-06	Magic Orange Pro
	VO-09	Vesuvio Orange
	FA-04	Favola
	ST-08	Stromboli Tangy
	SP-07	Stromboli Orange Pro
	VP-10	Vesuvio Orange Pro
	VC-12	Vincent’s Choice
Trial 4	MP-06	Magic Orange Pro
	VP-10	Vesuvio Orange Pro
	VT-11	Vesuvio Tangy
	MP-01	Marco Polo Orange
	MP-02	Marco Polo Tangy
	MP-03	Marco Polo Deep Orange Pro
	MP-04	Marco Polo Deep Tangy
	MP-05	Marco Polo Sun Orange
	ST-08	Stromboli Tangy
	SO-06	Stromboli Orange
	SP-07	Stromboli Orange Pro
	AG-01	Amalfi Golden
	FA-04	Favola
Trial 5	AG-01	Amalfi Golden
	SO-06	Stromboli Orange
	DD-03	Double Delight Black Center
	DD-04	Double Delight Green Center
	VC-12	Vincent’s Choice

Specific details of each trial were as follows:

Trial 1 – The first field trial was conducted from August to November 2020, in Santa Maria - RS, Brazil. The experimental design was a randomized complete block with four replications and 6 treatments (6 cut sunflower genotypes) (Table 2). In each replication, 6 plants per genotype were selected and tagged for data collecting.

Trial 2 – Data of the second field trial was collected from January to April 2021, in three locations of Southern Brazil (Santa Maria - RS, Júlio de Castilhos – RS, and Herval D'Oeste – SC). The experimental design was completely randomized with 6 replications, where each plant evaluated was considered one replication. The treatments were formed by the combination of locations (Santa Maria - RS, Júlio de Castilhos – RS, and Herval D'Oeste – SC), sowing dates, and genotypes. Two sowing dates were carried out in Santa Maria - RS and Herval D'Oeste – SC and one sowing date was carried out in Júlio de Castilhos – RS. Six cut sunflower genotypes were tested in the three locations, and on the second sowing date in Santa Maria - RS eight additional sunflower genotypes were tested (Table 2). In each replication, 6 plants per genotype were selected and tagged for data collecting.

Trial 3 - A multilocation field trial named Brazilian Cut Sunflower Trial was conducted from August 2022 to May 2023 in eight states (Table 1), covering all regions and biomes of Brazil. The experiment was conducted using a randomized block design with two replicates in a factorial arrangement. The treatments were formed by the combination of 8 locations x 12 cultivars x 7 sowing dates. Each block consisted of a bed measuring 25 meters in length. In each block, 10 plants per genotype were selected and tagged for data collecting.

Trial 4 – From February to June 2023, a trial was conducted at the Research Centre for Vegetable and Ornamental Crops (CREA-OF), located in Pescia, Tuscany, Italy. The methodology followed the same protocol of the trials in Brazil. Sunflower seeds were sown in polystyrene trays containing substrate prepared with vermiculite + perlite + sphagnum peat. Thirteen genotypes were used (Table 2). The experimental design was completely randomized, with eight replications. Each replication constituted a plant in the plot. Each plot consisted of one genotype with an area of 0.80 m², and 30 plants distributed in three rows spaced 20 cm apart, with 0.125 m between plants in the row. In the plots, 50 g per plot of 16-9-12 NPK fertilizer was used at transplanting. Nitrogen and phosphorus were supplied with 50 g per plot of 18-46 NP fertilizer as side dressing at 28 days after transplanting when plants had 6-8 leaves. It was not necessary to correct the soil pH.

Trial 5 – On farm trials were conducted from 2020 to 2023, across various regions of Brazil, from North to the South, as part of the "Flowers for All" Project (Streck and Uhlmann, 2021). Following the project methodology, the activities were led by rural extensionists from Emater/RS-Ascar and PhenoGlad Teams from research centers and universities in Brazil. The activities comprised the following steps: a) selection of the family farmers or rural schools with an affinity for flower production; b) an initial meeting with the family farmers and rural extensionists for training and taking their doubts; c) send seeds and installing; d) cultivation and data collection with support from the PhenoGlad teams; e) tabulation and data analysis; f) final meeting for delivering results to the farmers and feedback.

A detailed protocol for implementation, management and collecting data was provided during the training, including spreadsheets for recording the data. The farmers received 100 seeds, which were sown in polystyrene trays and seedlings were transplanted to the beds. Five cut sunflowers genotypes were cultivated in this approach (Table 2). In each genotype, 10 plants were selected and tagged for data collecting.

3.1.2.2 Data collecting and statistical analysis

One week after transplanting to the beds, some selected plants (according to the Trials described in 3.1.2.1) were tagged with colored labels. In the tagged plants, the flowing variables were measured or observed: the accumulated number of leaves (ANL) once or twice a week, depending on the location, until reaching the final leaf number (FLN) using the criterion to consider a leaf with blade length of greater than 2 cm, and the date of the phenological stages R1 (visible bud) and R5 (corolla at 90^o with the capitulum disk, harvest point) according to the phonological scale for sunflower by Schneiter and Miller (1981). At the R1 stage, the accumulated leaf number in the plant (LN at R1) was counted and then the number of leaves still to appear until the FLN [FLN-(LN at R1)] was calculated.

On the day of harvest, the total height of the plant (from the soil surface to the insertion of the inflorescence), stem diameter at 70 cm from the top of insertion of the inflorescence, and capitulum diameter (excluding petals) were measured. Additionally, at flower harvest the greatest length (L) and width (W) of each green leaf was measured from the base towards the apex and individual leaf area (LA) was calculated by (Maldaner et al., 2009): $LA = 0.7330 \cdot (L \times W)$. Total leaf area was calculated by summing the individual leaf area and then the leaf area index (LAI) was calculated as LAI = leaf area / area occupied by each plant in the plant spacing.

In Trial 4 a destructive approach for calculating specific leaf area was used, which consisted of selecting sub-samples of leaves (20% of the total weight of green leaves) and measuring through a scanner (WinDIAS Image Analysis System, Delta-T Devices, Cambridge, UK). The fresh material was dried at 65 °C and weighed until the weight was constant to determine the dry matter. The leaf area, in cm^2, was calculated by LA = (DM_{leaves} * $LA_{20\%}$)/$DM_{20\%}$, where DM_{leaves} is the dry matter of all leaves, $LA_{20\%}$ is the leaf area of the sub-sample measured by scanner and $DM_{20\%}$ is the dry matter of the sub-sample measured by scanner. Subsequently, the LAI was calculated.

Daily minimum and maximum air temperature were collected from the meteorological stations located as close as possible to each site during the experimental period. The daily mean air temperature (Tmean) was calculated by arithmetic average between the daily minimum and maximum temperature. The daily thermal time (DTT, °C day) was calculated by (Gilmore and Rogers, 1985; Arnold, 1960):

DTT = {(Topt – Tb)*[(TB-Tmean)/(TB-Topt)]}
If Tb > Tmean > TB, DTT = 0
If Tmean < Topt, DTT = Tm– Tb
If Tmean > Topt, DTT = $To - Tb * \left(\frac{Tmean-TB}{To-TB}\right)$

where Tb, Topt and TB are the lower base, the optimum, and the upper base temperatures for sunflower development defined by Villalobos et al. (1996) as 4 °C, 28 °C and 40 °C, respectively. Accumulated thermal time (ATT, °C day) from the sowing (SO) to FLN, to R1, and to R5 was calculated by accumulating the DTT values.

The phyllochron (PHY, °C day leaf $^{-1}$) was calculated by the inverse of the slope of linear regression between ANL and ATT (Streck et al., 2009, Ferreira et al., 2019). Also, we calculated the time in °C day for the vegetative phase (from sowing to R1), for the reproductive phase (from R1 to R5) and the total developmental cycle (from sowing to R5).

The five trials conducted for four years provided a large and robust dataset on cut sunflower development and growth. We divided the data into three environments: tropical (Northeast, Central and South-eastern Brazil), subtropical (Southern Brazil), and temperate (Italy). Relationships that influence the development, growth, and flower production components were tested using linear or quadratic regressions as follows. Relationships between accumulated thermal time (°C day) for the total developmental cycle (SO-R5), the vegetative (SO-R1) and the reproductive (R1-R5) phases as well as between the vegetative phase and LN at R1, reproductive phase and FLN-(LN at R1). Reproductive phase, vegetative phase, LN at R1 and FLN – (LN at R1) as a function of the final leaf number

(FLN), and Phyllochron (°C day leaf^{-1}) against FLN, LN at R1, vegetative and reproductive phase were also regressed.

The relationship between leaf area index (LAI) against FLN and phyllochron was also tested. To understand how LAI influences the flower production components, we applied linear regression between plant height, stem diameter and capitulum diameter and LAI. Some relationships among the production components were also applied such as plant height and developmental cycle (°C day), plant height and FLN, capitulum diameter and plant height and finally, stem diameter and plant height. Furthermore, descriptive statistics such as minimum and maximum values, median, mean, 25% percentile and 75% percentile were calculated for developmental cycle, phyllochron, final leaf number, plant height, stem diameter and capitulum diameter (Supplementary File 1). We also calculated dispersion statistics as standard deviation and coefficient of variation, and distribution statistics as Skewness and Kurtosis. The relationships with probability (p) lower than 5% by the Test F were assumed to be significant. Statistics analyses were performed with the GraphPad 8.0.2 version software.

3.1.3 Results

3.1.3.1 Meteorological data

The five trials provided a wide variation in edaphoclimatic conditions where the plants were exposed (Supplementary File 2). In Southern Brazil, considered as subtropical environment, temperature varied from -2 °C to 39 °C. In this region, the temperature amplitude was the highest, mostly because of the large dataset with sowing dates along the twelve months of the year for four years. The other Brazilian regions, considered as tropical environment presented temperatures varying from 8 °C to 41.5 °C. The temperate environment is represented by the trial conducted in Italy and the temperatures varied from 0.5 °C to 32.7 °C.

3.1.3.2 Sowing date

The sowing date had a strong effect on the duration in days of the total developmental cycle in cut sunflower genotypes grown in the subtropical locations throughout the year whereas in the tropical locations the duration was the shortest and did not vary throughout the year and in the temperate location the duration was among the longest (Fig. 2A). When the duration of the total developmental cycle is described in thermal time, with unit of °C day, there is no variation throughout the year in the subtropics and the developmental cycle in all locations and regions fall into around the mean duration, represented by the line in Fig. 2B, confirming that thermal time is a better time descriptor for plants than calendar days (Streck et al., 2011).

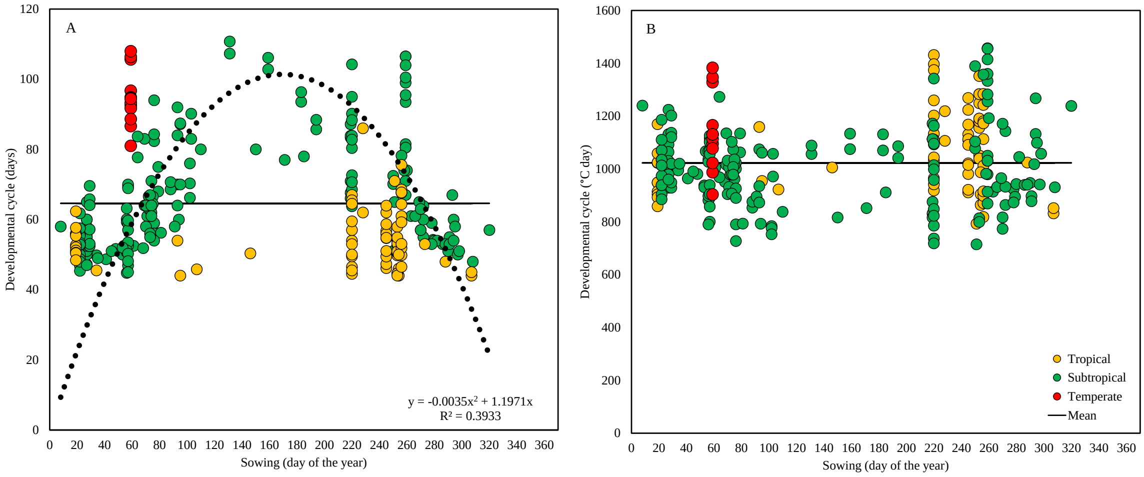


Figure 2. Developmental cycle of field grown cut sunflower genotypes in days (A) and in °C day (B) as a function of sowing date. Data from 28 field grown cut sunflower genotypes in cultivated in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype in a trial. Dashed line in panel A indicates the quadratic equation for the subtropical dataset. The solid line in panel B indicates the mean value of the dataset.

Sowing date and climate type did not affect LN at R1 (Fig. 3A). FLN and phyllochron demonstrated to be dependent of sowing date when analyzed all the dataset, without separating the environments (Fig. 3B and 3C, respectively). LAI was the variable most influenced by sowing date and the only that showed influence in the tropical and subtropical locations separately (Fig. 3D). As only one growing season was conducted in Italy, it was not possible to identify any relationship between the sowing date and the variables analyzed in temperate environment.

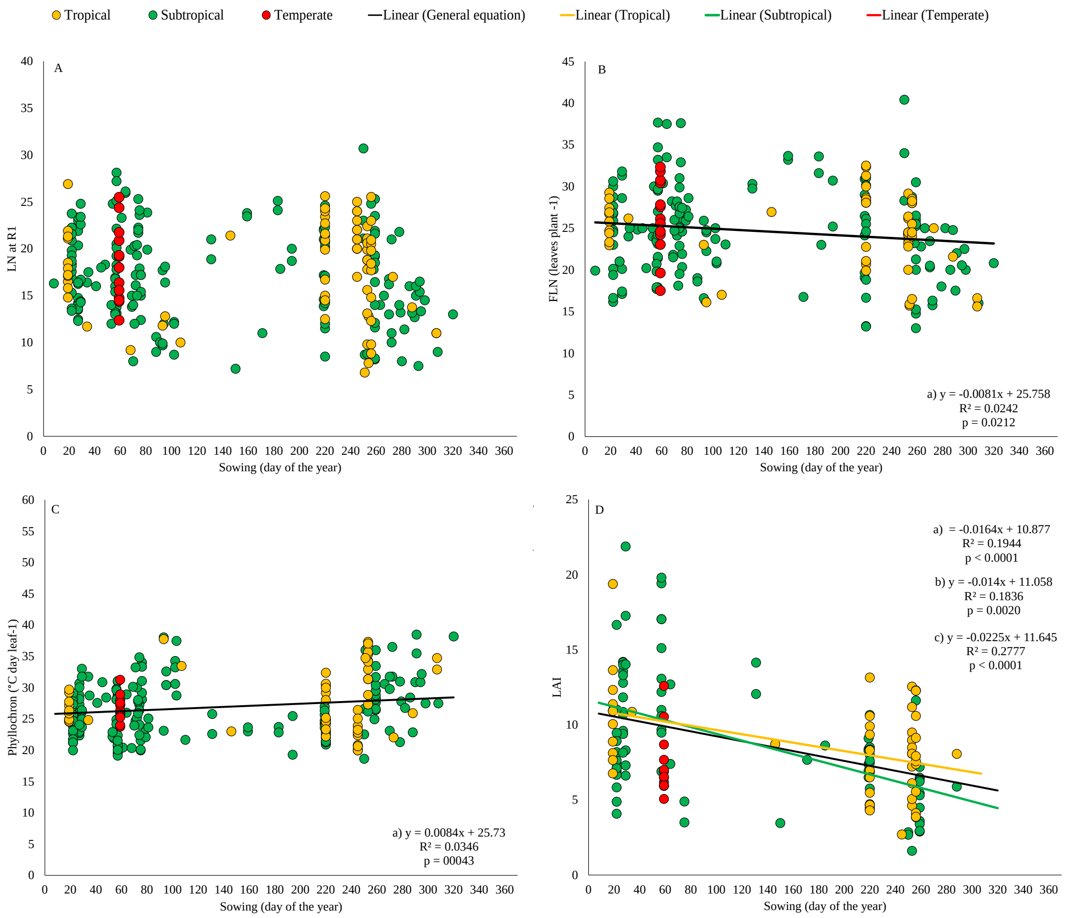


Figure 3. Relationship between (A) LN at R1, (B) final leaf number (FLN), (C) phyllochron and (D) leaf area index (LAI) and sowing date (day of the year). Data from 28 field grown cut sunflower genotypes in cultivated in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype in a trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate.

3.1.3.3 Developmental variables and their relationships

The relationships between developmental phases and total developmental cycle are considered only for thermal time used as time descriptor. Pooling all data, the duration of the total developmental cycle (°C day), from sowing to R5 stage, is influenced primarily by the vegetative phase ($R^2 = 0.6954$, $p < 0.001$, Fig. 4A) but also by the reproductive phase ($R^2 = 0.3125$, $p < 0.001$, Fig. 4B), with a trend for an increase in the developmental cycle as the duration of the vegetative and reproductive phases prolong. Analyzing separately the environments, tropical, subtropical, and temperate locations also presented significant relationships between the duration of total developmental cycle and the duration of vegetative and reproductive phases. The duration of the vegetative phase depends on the leaf number at R1 stage (LN at R1) in all three environments (Figure 3C). Conversely, the duration of reproductive phase does not depend on the number of leaves still to appear after the R1 stage [FLN-(LN at R1)] until FLN (Figure 4D).

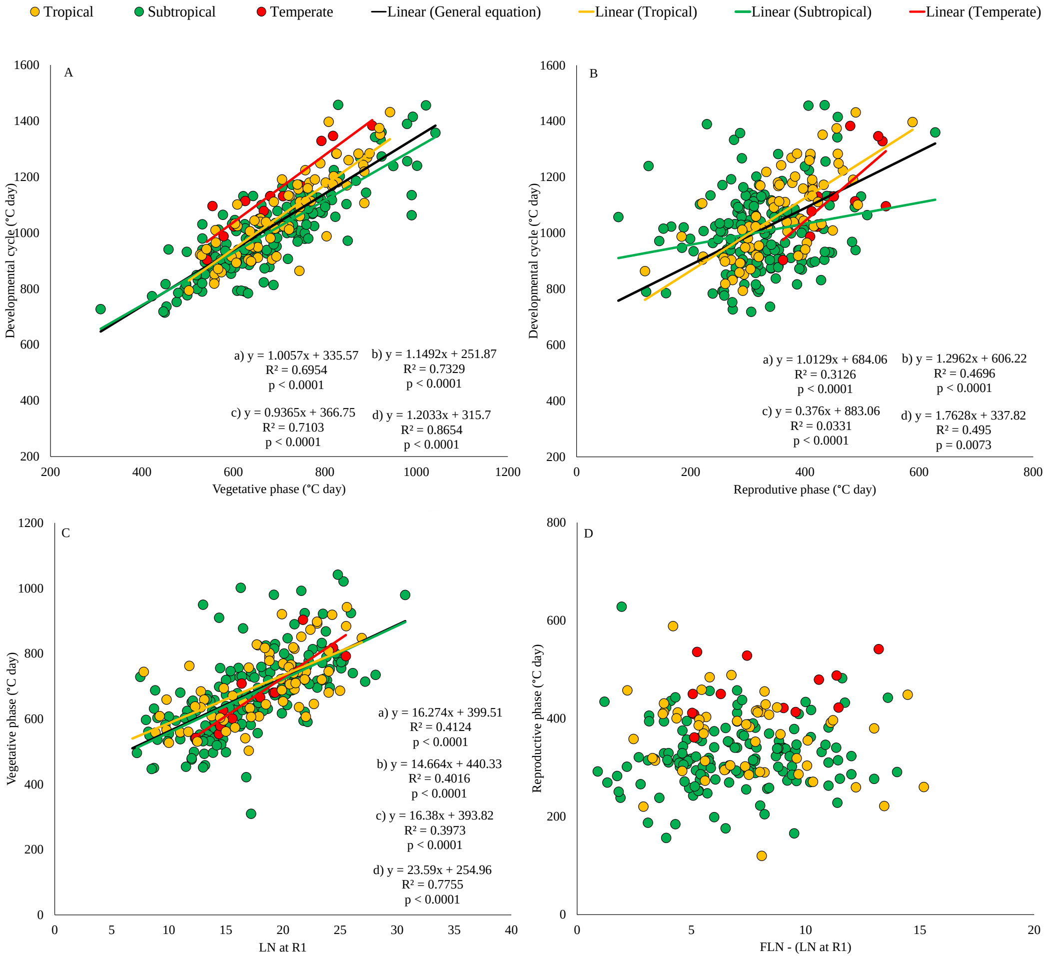


Figure 4. Relationship between the duration of total developmental cycle and (A) duration of the vegetative phase and (B) duration of the reproductive phase, (C) between the duration of the vegetative phase and the accumulated leaf number (LN) at the R1 Stage, and (D) duration of the reproductive phase and the leaf number after R1 [FLN – (LN at R1)]. Data from 28 field grown cut sunflower genotypes in cultivated in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype in a trial. Each equation corresponds to a) General equation, b)

Tropical, c) Subtropical and d) Temperate. Test F with p-value 5% of probability, when appear is significant.

3.1.3.4 Final leaf number

Overall, final leaf number (FLN) presented a significant relationship with all four variables analyzed (LN at R1, FLN – (LN at R1), duration of vegetative and duration of reproductive phases – Fig. 5). Here, we describe the results before and after the R1 stage. Before the R1 stage, the variable LN at R1 was dependent on the FLN (Fig. 5A), i.e., the higher the FLN, the greater the accumulated leaf number at the R1 stage, and the longer the vegetative phase (Fig. 5C). After R1 stage, FLN - (LN at R1) showed to be dependent on FLN in subtropical locations (Fig. 5B) and the reproductive phase was dependent on FLN only in tropical and temperate locations (Fig. 5D).

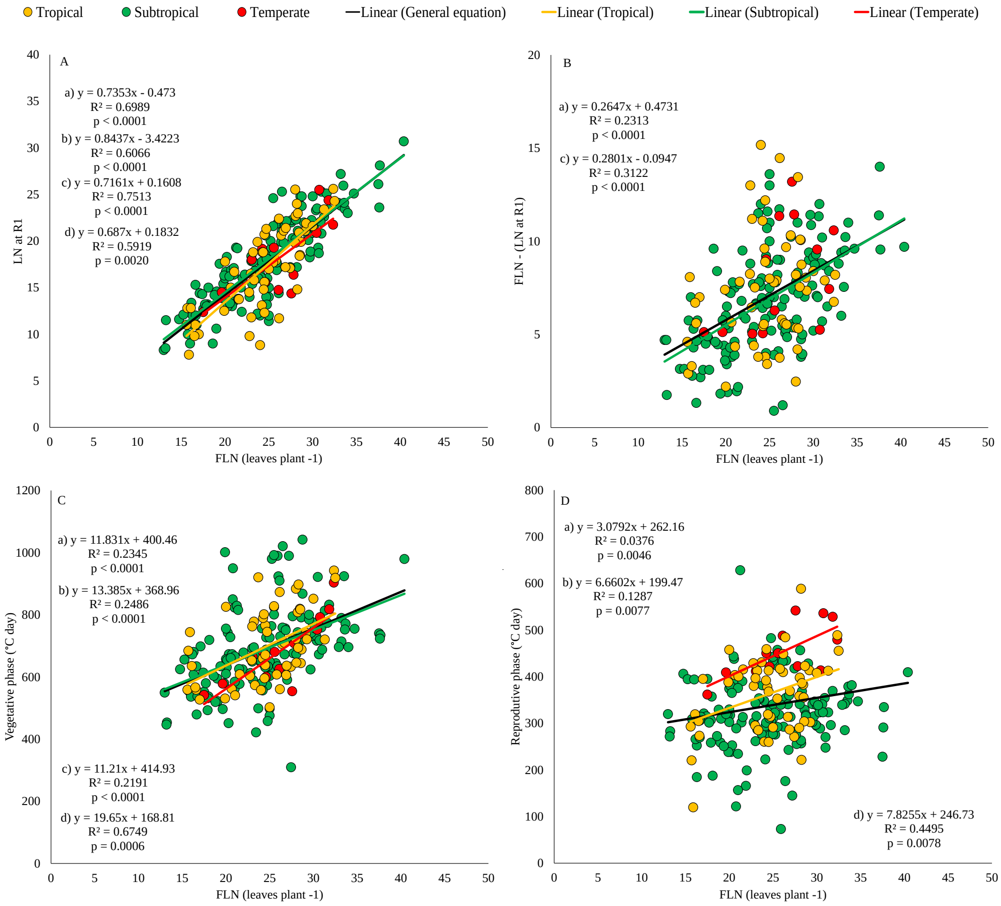


Figure 5. Relationship between (A) LN at R1 and final leaf number (FLN), (B) FLN – (LN at R1) and FLN, (C) vegetative phase and FLN and (D) reproductive phase and FLN. Data from 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype in a trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate.

The significant relationships found in Figures 2-5 are hypothesized to be due to genotypes. Aiming to test this hypothesis, we fit linear regressions separately for each genotype. Table 3 and 4 show the equations, *p value,* and R^2 for each genotype. Genotypes AG-01, VC-12, SP-07, MO-03 and DD-03 were the genotypes that had significance (Table 3) between FLN and FLN – (LN at R1). The “Other genotypes” was a group of genotypes that had only one point.. We also analyzed each genotype for the FLN and LN at R1 relationship (Table 4). Five genotypes (VO-09, LT-05, SP-07, ST-08 and VP-10) did not show significant relationship.

Table 3. Equation, probability (*p*) value, and coefficient of determination (R^2) of linear regression of leaf number at R1 stage ([FLN – (LN at R1)] = y) against final leaf number (FLN = x) in 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial).

Genotype	**Linear regression**		
	Equation	***p***	**R^2**
AG-01	y = 0.3213x - 1.098	0.0055^{s}	0.2796
AO-02	y = 0.01495x + 7.213	0.9536^{ns}	0.0004
SO-06	y = 0.1247x + 5.179	0.2815^{ns}	0.0607
VC-12	y = 0.3551x - 0.6953	$< 0.0001^{s}$	0.3087
VT-11	y = 0.4440x - 4.156	0.0880^{ns}	0.2633
VO-09	y = 0.5606x - 3.847	0.0530^{ns}	0.3915
LT-05	y = 0.7059x - 15.39	0.1196^{ns}	0.6085
SP-07	y = 0.8550x - 17.00	0.0138^{s}	0.7341
MP-06	y = 0.2531x - 0.006715	0.1122^{ns}	0.4256
ST-08	y = 0.6193x - 8.926	0.1093^{ns}	0.4308

FA-04	$y = 0.1744x + 0.09671$	0.0716^{ns}	0.5619
MO-03	$y = 0.5146x - 4.849$	0.0246^{s}	0.8549
DD-03	$y = 0.2865x - 1.907$	0.4945^{ns}	0.1235
VP-10	$y = 0.5553x - 5.207$	0.0450^{s}	0.5854
Other genotypes	$y = 0.3816x - 3.078$	0.0345^{s}	0.3460

s. Significative 5% of probability **ns.** Not significant

Table 4. Equation, probability (p) value, and coefficient of determination (R^2) of linear regression of leaf number at R1 stage (LN at R1 = y) against final leaf number (FLN = x) in 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial).

Genotype	**Linear regression**		
	Equation	***p***	$\mathbf{R^2}$
AG-01	$y = 0.6767x + 1.179$	$<0.0001^{s}$	0.6343
AO-02	$y = 1.035x - 8.759$	0.0014^{s}	0.6940
SO-06	$y = 0.8802x - 5.236$	$<0.0001^{s}$	0.7578
VC-12	$y = 0.6445x + 0.7072$	$< 0.0001^{s}$	0.5947
VT-11	$y = 0.5072x + 4.778$	0.1514^{s}	0.1777
VO-09	$y = 0.4401x + 3.964$	0.0945^{ns}	0.2795
LT-05	$y = 0.2941x + 15.39$	0.4345^{ns}	0.2125
SP-07	$y = 0.1547x + 16.75$	0.5314^{ns}	0.0828
MP-06	$y = 0.7505x - 0.04923$	0.0024^{s}	0.8648
ST-08	$y = 0.3807x + 8.926$	0.2854^{ns}	0.2224
FA-04	$y = 0.8256x - 0.09671$	0.0323^{s}	0.6335
MO-03	$y = 0.4758x + 5.144$	0.0098^{s}	0.8427

Cont. **Table 3**

DD-03	y = 0.7152x + 1.876	0.0063^{s}	0.7379
VP-10	y = 0.4447x + 5.207	0.0866^{ns}	0.4752
Other genotypes	y = 0.6156x + 3.154	0.0003^{s}	0.6856

s. Significative 5% of probability **ns.** Not significant

3.1.3.5 Phyllochron

Phyllochron was dependent on FLN ($R^2 = 0.1815$, $p < 0.0001$, Fig. 6A), decreasing as FLN increases. This decreasing relationship was also observed between phyllochron and LN at R1 ($R^2 = 0.1264$, $p < 0.0001$, Fig. 6B), where genotypes with higher phyllochron exhibited lower LN at R1. Duration of the vegetative and reproductive phases were not related to the phyllochron (Fig. 6C and 6D). In temperate climate, no relationships were identified. Tropical and subtropical presented significant relationship between phyllochron and FLN ($R^2 = 0.1417$ and $R^2 = 0.2323$, respectively) and between phyllochron and LN at R1 ($R^2 = 0.1481$ and $R^2 = 0.2393$). The slope of the linear regressions indicates a decrease in both cases.

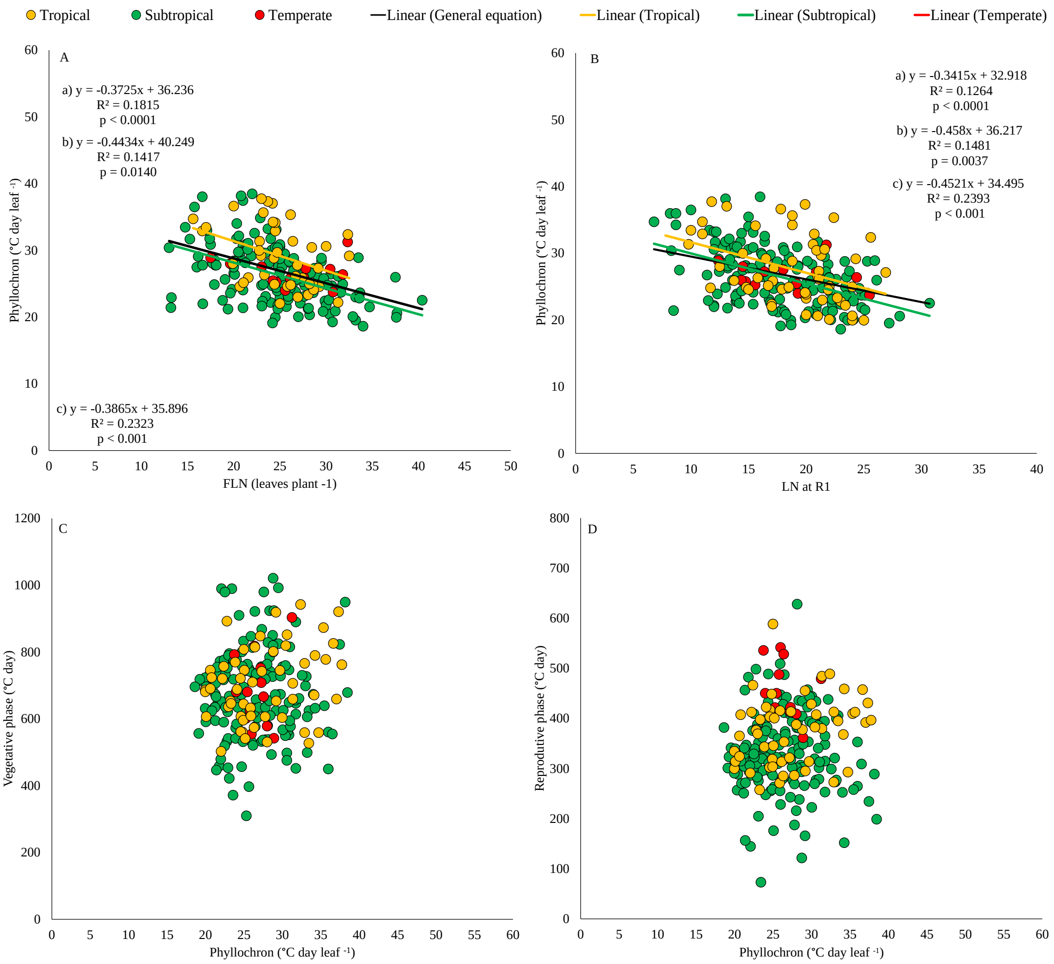


Figure 6. Relationship between (A) phyllochron (°C day leaf^{-1}) and final leaf number (FLN), (B) phyllochron and LN at R1, (C) vegetative phase (°C day) and phyllochron and, (D) reproductive phase (°C day) and phyllochron. 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype in a trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate. Test F with p-value 5% of probability, when appear is significant.

3.1.3.6 *Leaf area index*

Leaf area index (LAI) was shown to be dependent on FLN and phyllochron (Fig. 7). Thus, cut sunflower plants with higher FLN tend to have a higher LAI. This increasing trend was identified in tropical and subtropical locations (Fig. 7A). On the other hand, plants with a higher phyllochron tend to exhibit lower LAI values (Fig. 7B). This characteristic was more evident in the subtropical environment.

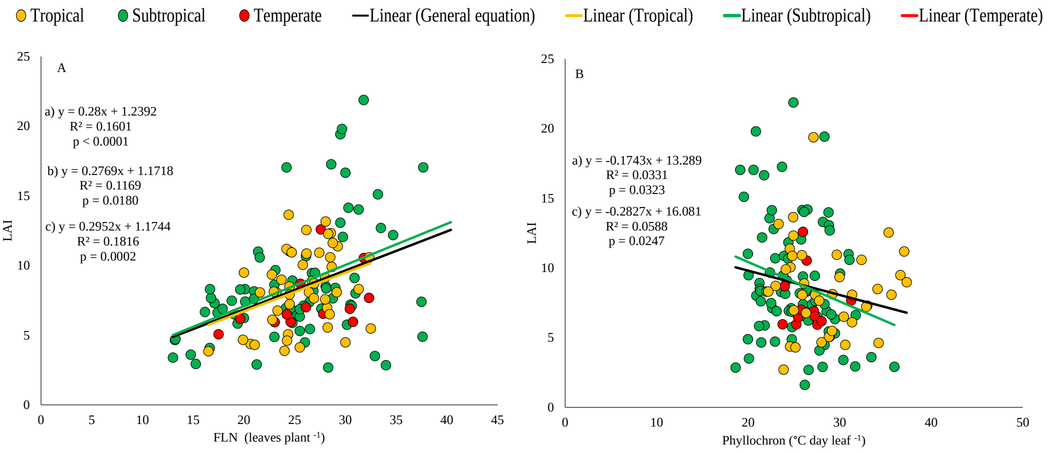


Figure 7. Relationship between leaf area index (LAI) and (A) final leaf number (FLN) and between (B) LAI and phyllochron (°C day leaf^{-1}). Data from 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype inside the trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate. Test F with p-value 5% of probability, when appear is significant.

3.1.3.7 Flower production components

Relationships among flower production components were also analyzed by linear regressions (Fig. 8). It was observed that plants with a higher accumulation of thermal time from sowing to R5 stage, represented by developmental cycle (°C days), had the tallest plants (Fig. 8A). Similarly, plant height was also related to FLN (Fig. 8B). This trend was observed in all three climates. As for head diameter, it is dependent on plant height, so plants with greater height have larger inflorescences (Fig. 8C). No relationship between stem diameter and plant height was observed (Fig. 8D).

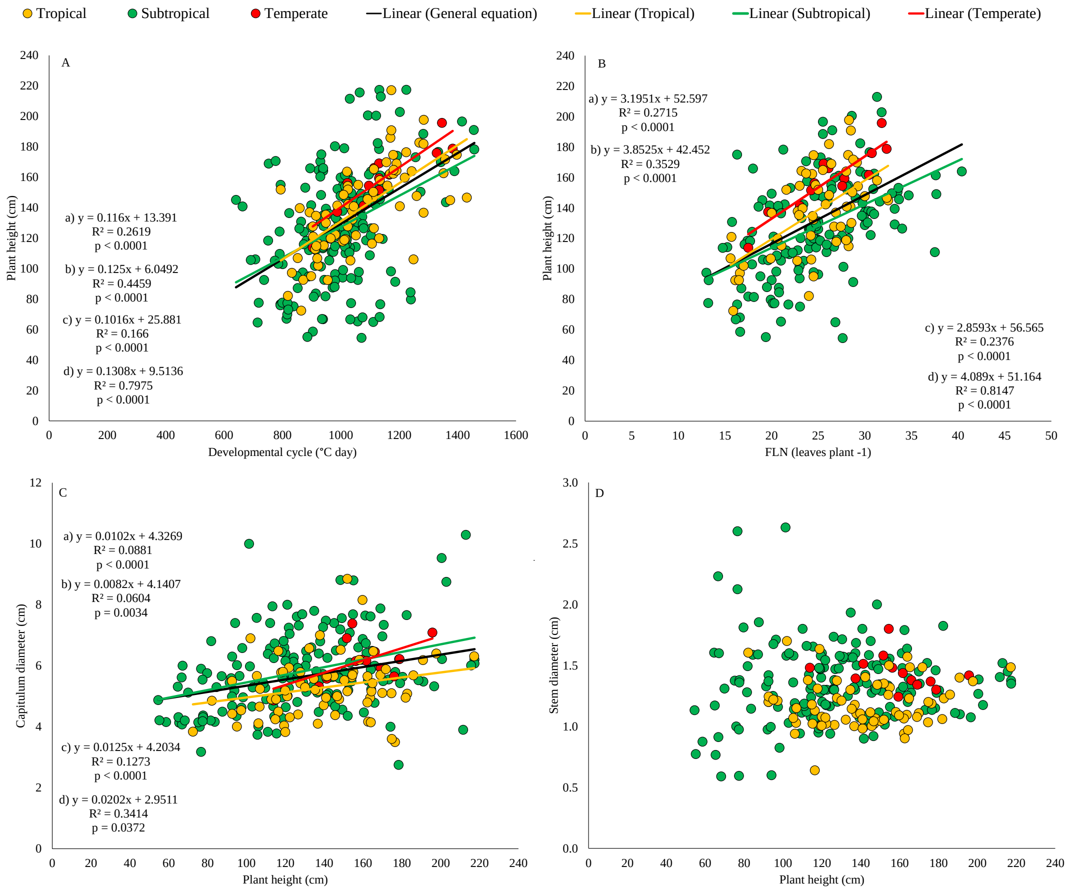


Figure 8. Relationship between (A) plant height (cm) and developmental cycle (°C day), (B) plant height (cm) and FLN (leaves plant $^{-1}$), (C) capitulum diameter (cm) and plant height (cm) and (D) stem diameter (cm) and plant height (cm). Data from 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype inside the trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate. Test F with p-value 5% of probability, when appear is significant.

The investigation of the relationship between leaf area index and plant height ($R^2 = 0.1947$, $p < 0.0001$), capitulum diameter ($R^2 = 0.3127$, $p < 0.0001$) and stem diameter ($R^2 = 0.1357$, $p < 0.0001$) revealed a positive and significant association through linear regression analysis (Fig. 9). In all tropical, subtropical, and temperate locations, positive relationships were found between LAI and flower production components so that plants with higher LAI exhibit larger plant height, capitulum diameter, and stem diameter. Only for temperate environment there was no significant relationship between LAI and stem diameter (Fig. 9C).

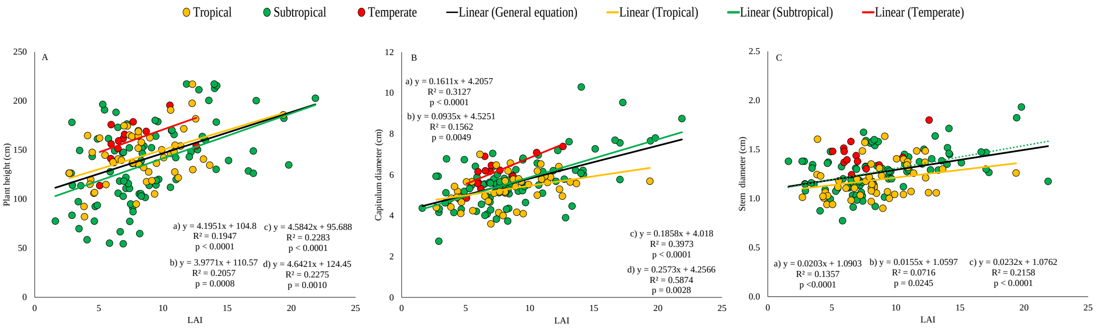


Figure 9. Relationship between leaf area index (LAI) and (A) plant height, (B) capitulum diameter and (C) stem diameter. Data from 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial) are pooled. Each point represents one genotype inside the trial. Each equation corresponds to a) General equation, b) Tropical, c) Subtropical and d) Temperate. Test F with p-value 5% of probability, when appear is significant.

3.1.3.8 Pooled data analysis

A pooled analysis of the three environments provided an overall summary about each single variable. The result from this analysis is presented in Supplementary File 1 and in box plots in Figure 10. The subtropical environment exhibits the greatest variation, especially in the FLN (Fig. 10D), LN at R1 (Fig. 10E), FLN – (LN at R1) (Fig. 10F), plant height (Fig. 10G), capitulum and stem diameter (Fig. 10H and 10I, respectively) variables. For example, FLN varied from 15.6 to 32.5 leaves plant^{-1} in the tropics, from 13.0 to 40.4 leaves plant^{-1} in the subtropics and from 17.5 to 32.3 leaves plant^{-1} in temperate environment (Supplementary File 1). Variable FLN – (LN at R1) had the highest coefficient of variation in tropical (41.53%), subtropical (40.93%) and temperate (36.84%) environments.

Under subtropical environment, the coefficient of variation for plant height (CV = 28.85 %), capitulum diameter (CV = 21.88 %) and stem diameter (28.14 %) was higher than in tropical environment, with CV = 20.54 %, CV = 18.44 %, CV = 16.90 % for plant height, capitulum diameter and stem diameter, respectively. The smallest variation was in the temperate environment for all three production components (Plant height, CV = 12. 99%; Capitulum diameter, CV = 11.49 %; Stem diameter, CV = 10.44 %).

Values of the duration of total development cycle varied from 792.8 to 1431.0 °C day, 714.7 to 1457.0 °C day and 903.5 to 1383.0 °C day for tropical, subtropical, and temperate environments with median 1042.0, 999.0 and 1131.0 °C day, respectively. For the duration of total developmental cycle in days, only descriptive analyses were applied (Supplementary Table S1). The shortest cycle was 43, 40 and 81 days and the longest cycle 78.2, 110.8, 108 days for tropical, subtropical, and temperate environments, respectively.

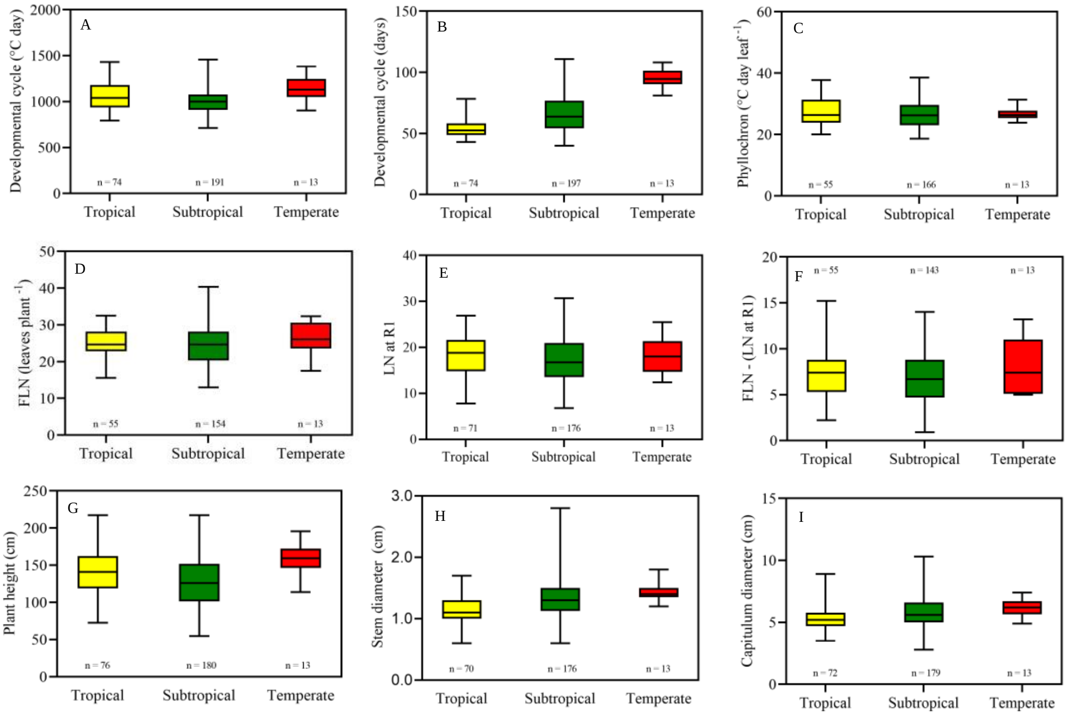


Figure 10. Box plots for (A) duration of total developmental cycle (°C day), (B) duration of total developmental cycle (days), (C) phyllochron, (D) final leaf number, (E) LN at R1, (F) FLN – (LN at R1), (G) plant height, (H) stem diameter and (I) capitulum diameter of 28 field grown cut sunflower genotypes in tropical, subtropical, and temperate environments in Brazil (four trials) and Italy (one trial). Solid line in the boxes is the median. n = number of samples.

3.1.4 Discussion

The network established among different Brazilian regions and Italy provided a robust dataset for understanding the genotype x environment x management x farmer (G x E x M x F) interaction for cut sunflower, providing robust information about adaptability and stability, as suggested by Matta et al. (2020). As a species of tropical and subtropical environments, that grow at an extensive range of latitudes in both hemispheres (northern and southern), sunflowers are affected by different environmental conditions (Schneiter, 1997, Hussain et al. 2018, Silva et al., 2022). According to Curti et al. (2012) sowing date is a key factor to obtain success in sunflower cultivation, prioritizing seasons that can satisfy the edaphoclimatic exigences on temperature, photoperiod, solar radiation, and water availability. Our trials provided sowings all year round, exposing the cut sunflower plants to several environmental conditions.

The time required for development depends on the genetic and growing season environment (Proietti et al., 2022). Also, different sunflower genotypes require different accumulated thermal time for development (Schneiter, 1997). Figures 2A and 2B graphically demonstrate the differences in total cycle time in days and in degree days, respectively. In the temperate environment, the cultivation of cut sunflowers occurred in late Winter in the Northern Hemisphere, extending into Spring. This condition exposed the genotypes to lower temperatures for a longer period, resulting in cycle (days) above average, and varying among genotypes. In the Southern Hemisphere, cut sunflower genotypes were grown in the tropics and subtropics of Brazil. The climate is warm in a tropical environment leading to the total development cycle being shorter than the average. The values above the mean value, represented by the black line, occurred only in the cultivation carried out in São João Del Rei/MG for some genotypes. This location is indicated as a subhumid tropical environment and the temperatures during the growing season were lower than the other locations in the same environment, influencing the duration of the developmental cycle in days (Supplementary File 2).

However, in ºC day, there is less variation between environments than in days, and the duration of the developmental cycle is maintained within the same range (Fig. 3B and Fig. 10A). Essentially, these results reassure that the biological clock of cut sunflowers is regulated by air temperature and that thermal time is a better descriptor of time than calendar days (Streck et al., 2008, Streck et al., 2009a, Streck et al., 2011, Silva et al., 2020). The duration of total developmental cycle in ºC day is driven by the duration of the vegetative and the reproductive phases, i.e., longer vegetative, and reproductive phases result a longer development cycle. These results agree with those for *Gladiolus* x *grandiflorus* (Streck et al., 2011), a cut flower that also strongly responds to temperature.

During the developmental cycle of cut sunflower, there is an overlap between the vegetative and reproductive phases, so that leaf appearance continues after the R1 stage. The duration of the vegetative phase tends to be longer as the leaf number at the R1 stage (LN at R1) increases, while the reproductive phase does not depend on the number of leaves still to appear after this stage [FLN - (LN at R1)]. Our hypothesis is that when the cut sunflower plant initiates the reproductive phase at the R1 stage, the final leaf number is already defined, as reported by Anderson et al. (1978). These two main phases occur concurrently with the elongation sub-phase; thus, after the R1 stage, the leaves that have not yet emerged visually begin to become apparent due to the elongation of the internodes, which is more evident after the R1 stage. Additionally, the variables LN at R1 and FLN - (LN at R1) were found to be dependent on FLN, as well as the vegetative and reproductive phases (Fig. 5). Meanwhile, when genotypes were analyzed separately (Tables 3 and 4), just some genotypes demonstrate a relationship between these variables. Streck et al. (2009b) found similar results in *Oryza sativa* L., with differences among genotypes, among sowing dates and among years.

The phyllochron also showed a linear relationship with FLN and LN at R1. However, there is no relationship between the phyllochron and the duration of the phases in ºC day. Villalobos and Ritchie (1992) found phyllochron for sunflower ranging from 20 to 25 °C day leaf^{-1} and reported that low temperatures at the beginning of development are associated with low phyllochron, and there may be an inverse relationship between the phyllochron and the duration of the developmental cycle. Similarly, Aiken (2005) found a mean phyllochron of 25.3 °C day leaf^{-1} for grain sunflower. Our results indicate a variation from 18.6 to 38.5 °C day leaf^{-1}, with greater variation in subtropical environments. These differences can be attributed to the wide range of genotypes evaluated and how each one responds to the conditions of each environment, as already demonstrated for *Dahlia* spp. (Fernandes et al., 2023), especially in countries like Brazil, which has a vast territorial extension and temperature conditions can vary within each environment, depending on latitude. The lack of relationship between the phyllochron and the developmental phases is not a characteristic found only in cut sunflowers. For instance, Walter et al. (2009) found the same lack of relationship for *Triticum aestivum* L., indicating that the trait responsible for the duration of the vegetative phase in cut sunflower is the final number of leaves and not the rate at which these leaves appear on the stem.

The sowing date plays a significant role in influencing the leaf area index, which decreased as the sowing date progressed throughout the year (Fig. 3D). But it also is influenced by the FLN and phyllochron (Fig. 7). This is an ecophysiological factor that has a significant influence on defining the flower production components of distinct species, especially in Southern Brazil where there is a wide variation in temperature and solar radiation throughout the year (Tagliapietra et al., 2018, Höhn et al., 2023). Due to its robustness and ease of field cultivation, cut sunflower producers typically sow from January to December, aiming to supply the flower market periodically and increasing the number of produced plants for specific celebrating dates. As shown in Figure 9, LAI has a major influence on the production components studied and considerable variation among genotypes. Moreover, cut sunflower genotypes with a longer developmental cycle and greater FLN produce plants with a bigger plant height and consequently, inflorescences with a large capitulum, in tropical and subtropical environments. Recent studies about ornamental sunflower conducted in the tropical semi-arid climate in Brazil by Silva et al. (2018) found interesting results among the cut sunflower growth, validating our results on the relationship between plant height and FLN. Contradictory to our results, a strong relationship between plant height and stem diameter was verified by the authors.

For cut sunflower, long stem are a desirable feature due to the stem management usually practiced until the flower reaches the final consumer (Mladenovìc et al., 2020). The association of plant height, stem diameter, and inflorescence diameter are the main flower production components for commercial purposes (Silva et al., 2018). Furthermore, the results underscore the importance of considering temperature and other climatic variables in positioning the genotypes at sowing dates that provide suitable growing conditions and consequently improve aesthetic aspects. This is essential to ensure the supply of products that meet the standards required by the flower market.

The results from our study indicate that cut sunflower genotypes are well adapted to tropical, subtropical, and temperate environments. Indeed, the performance of cut sunflowers across such a wide range of temperatures provided by this extensive exposure is outstanding. Originality, *Helianthus annus* as species, is from temperate climate. This knowledge about species associated with the advances in biotechnology aiming improve genetic variability allow conditions for cultivation in different climatic zones, as highlighted by Paiva and Cavalcante (2023). From the standpoint of the production chain, our results support the premise used by the "Flowers for All" project that, despite variations among genotypes and environments, cut sunflowers are versatile and well adapted for the different edaphoclimatic conditions across Brazil, becoming an excellent opportunity for small and medium-sized farmers who wish to diversify their production throughout the year, holding considerable economic significance and represent a promising avenue for agricultural development, as emphasized by Puttha et al. (2023).

3.1.5 Conclusion

The results presented in this study demonstrated a significant impact of the tropical, subtropical, and temperate environments on the development, growth, and flower production of cut sunflower. The duration of vegetative phase has positive linear relationship with developmental cycle, as so reproductive phase, and it is determinate by final leaf number. Leaf number at R1 stage are positively related to vegetative phase, but number of leaves still to appear after R1 stage are not related to reproductive phase. On the other hand, leaf area index has negative linear relationship with sowing dates, likewise phyllochron and final leaf number. Flowers' production components are defined by leaf area index and final leaf number. Briefly, cultivars with longer development cycle have high final leaf number, low phyllochron and greater plant height than cultivars with shorter cycle. These findings contribute to expanding the knowledge about sunflower cultivation as a cut flower and offer valuable insights for developing more effective and sustainable strategies for floriculture not only in Brazil but also in regions with similar climatic characteristics.

Funding

This work was co-supported by Brazilian Federal Agency for Support and Evaluation (CAPES) who provided the scholarship during the doctorate degree of R. Tomiozzo. National Council for Scientific and Technological Development (CNPq) for the financial support provided through Process 200233/2022-2 for the Sandwich Doctorate Program in Italy.

Credit authorship contribution statement

R.T. Writing – review & editing, Writing - original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **L. O. U.** Methodology, Investigation, Data curation. **L. C. B.** Investigation, Resources. **M. Z. B.-C.** Investigation, Resources. **P. B. L.** Investigation, Resources. **J. C. S.** Investigation, Resources. **S. N. R.** Investigation, Resources. **L. M. C.** Investigation, Resources. **A. T. P.** Investigation, Resources. **L. M. L.** Investigation, Resources. **H. F. F.** Investigation, Data curation. **S. M. S. V.** Investigation, Data curation. **L. G. O. S.** Investigation, Data curation. **T. L. T.** Investigation. **T. P. R.** Investigation, Data curation. **G. V. N.** Investigation, Data curation. **V. B. S. O.** Investigation, Data curation. **J. B. T. J**. Investigation. **A. T. I. C.** Investigation **D. B.** Investigation, Resources. **C. P. O. F.** Investigation, Data curation**. B. N.** Investigation, Resources. **A. M.** Conceptualization, Resources. **C. M. T. M.** Conceptualization, Methodology, Resources. **L. B.** Investigation, Data curation. **J. S. F. C.** Investigation, Data curation. **A. M. F. S.** Investigation, Data curation**. A. J. Z.** Supervision. **N.A.S.** Supervision, Project Administration, Conceptualization, Methodology, Resources.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledge

We would like to thank Emater/RS-Ascar and its extensionists, rural schools, and family farmers for their collaboration in the "Flowers for All" Project. We also extend our acknowledge to the partner institutions of the Brazilian Cut Sunflower Trial: UFGD, UNIVASF, UFSC, UNEMAT, UFRA, EPAMIG, UTFPR. Special thanks to CREA-OF Pescia, Farao Seeds, and Mansuino Breeding Emotions for their collaboration.

3.1.6 References

Ahn CH, Ramya M, An HR, Park PM, Kim, Y-J, Lee, SY, Jang, S (2020) Progress and Challenges in the Improvement of Ornamental Plants by Genome Editing. Plants 9(6):687. https://doi.org/10.3390/plants9060687

Aiken RM (2005) Applying thermal time scales to sunflower development. Agronomy Journal 97:746-754. https://doi.org/10.2134/agronj2004.0181

Alberio C, Izquierdo NG, Aguirrezábal LA (2015) Sunflower crop physiology and agronomy. In: Sunflower: Chemistry, production, processing, and utilization (Editors: Martínez-Force, E; Dunford, N T; Salas, J J). AOCS Press. https://doi.org/10.1016/B978-1-893997-94-3.50001-5

Anderson WK, Smith RCG, McWilliam JR (1978) A systems approach to the adaptation of sunflower to new environments I. Phenology and development. Field Crops Research 1:141-152. https://doi.org/10.1016/0378-4290(78)90017-5

Arnold CY (1960) Maximum-minimum temperatures as a basis for computing heat units. Journal of the American Society for Horticultural Sciences 76:682-692.

Atlagić J, Šećerov-Fišer V, Marinković R (2005) Interspecific hybridization and cytogenetic studies in ornamental sunflower breeding. Australian Journal of Experimental Agriculture 45:93–97. https://doi.org/10.1071/EA01109

Bahuguna RN, Jagadish KSV (2015) Temperature regulation of plant phenological development. Environmental and Experimental Botany 111:83-90. https://doi.org/10.1016/j.envexpbot.2014.10.007

Blasi C, Capotorti G, Copiz R, Guid D, Mollo B, Smiraglia D, Zavattero L (2014) Classification and mapping of the ecoregions of Italy. Plant Biosystems, 148:1255-1345. http://dx.doi.org/10.1080/11263504.2014.985756

Connor DJ, Sadras Von (1992) Physiology of yield expression in sunflower. Field Crops Research 30:333-389. https://doi.org/10.1016/0378-4290(92)90006-U

Connor DJ, Hall AJ (1997) Sunflower physiology. In Sunflower production and technology, Schneiter, AA (ed.). https://doi.org/10.2134/agronmonogr35.c4sch

Curti GL, Martin TN, Ferronato ML, Benin G (2012) Girassol ornamental: caracterização, pós-colheita e escala de senescência. Revista de Ciências Agrárias 35:240-250.

Dyer HJ, Skok J, Scully NJ (1959) Photoperiodic behavior of sunflower. Botanical Gazette 121: 50-55. https://doi.org/10.1086/336041

Fernandes ME, Roso TP, Ferronato L, Freitas CP de O, Tomiozzo R, Uhlmann LO, Zanon AJ, Streck NA (2023) Determining the phyllochron and the final leaf pair number in on-farm cut dahlia cultivars. Ornamental Horticulture 29:299-312. https://doi.org/10.1590/2447-536X.v29i2.2650

Ferreira MC, Martins FB, Florêncio GWL, Pasin LAAP (2019) Cardinal temperatures and modeling the vegetative development of seedlings of guava. Revista Brasileira De Engenharia Agrícola e Ambiental 23:819–825. https://doi.org/10.1590/1807-1929/agriambi.v23n11p819-825

Gilmore EC Jr, Rogers JS (1958) Heat units as a method of measuring maturity in corn. Agronomy Journal 50:611-615. https://doi.org/10.2134/agronj1958.00021962005000100014x

Goyne PJ, Hammer GL (1982) Phenology of sunflower cultivars. II. Controlled-environment studies of temperature and photoperiod effects. Australian Journal of Agricultural Research 33:51–261. https://doi.org/10.1071/AR9820251

Goyne PJ, Schneiter AA, Cleary KC, Creelman RA, Stegmeier WD, Wooding FJ (1989) Sunflower genotype response to photoperiod and temperature in field environments. Agronomy Journal 81:826-831. https://doi.org/10.2134/agronj1989.00021962008100050025x

Grunvald AK, Carvalho CGP, Oliveira ACB, Pires JLF, Carvalho HWL, Oliveira IR (2013) Adaptability and stability of conventional and high oleic sunflower genotypes cultivates in southern Brazil. Revista Ciências Agrárias 57: 217-223. http://dx.doi.org/10.4322/rca.ao1270

Junqueira AH, Peetz M Da S (2018) Sustainability In Brazilian floriculture: introductory notes to a systemic approach. Ornamental Horticulture 24:155-162. http://dx.doi.org/10.14295/oh.v24i2.1253

Höhn D, Peil RMN, Marchi PM, Grolli PR, Trentin R, Shaun WS (2023) Base temperature estimates for lisianthus cultivars grown in different planting seasons. Pesquisa Agropecuária Brasileira 58:e03447. https://doi.org/10.1590/ S1678-3921.pab2023.v58.03447

Hussain M, Farooq S, Hasan W, Ul-Allah S, Tanveer M, Farooq M, Nawaz A (2018) Drought stress in sunflower: physiological effects and its management through breeding and agronomic alternatives. Agricultural Water Management 201:152-166. https://doi.org/10.1016/j.agwat.2018.01.028

Maldaner IC, Heldwein AR, Loose LH, Lucas DDP, Guse IF, Bortoluzzi MP (2009) Models for estimating leaf area in sunflower. Ciência Rural 39:1356–1361. https://doi.org/10.1590/S0103-84782009000500008

Marc J, Palmer JH (1981) Photoperiodic sensitivity of inflorescence initiation and development in sunflower. Field Crops Research 4:155-164. https://doi.org/10.1016/0378-4290(81)90065-4

Matta LB, Cruz CD, Santos IG, Carvalho CGP, Filho ABB, Alves AD (2020) Optimum environment number for the national sunflower trials network. Acta Scientiarum. Agronomy 42:e42792. https://doi.org/10.4025/actasciagron.v42i1.42792

Mladenović E, Cvejić S, Jocić S, Ćuk N, Čukanović J, Jocković M, Marjanović-Jeromela A (2020) Effect of plant density on stem and flower quality of single-stem ornamental sunflower genotypes. Horticultural Science 47:45-52. https://doi.org/10.17221/10/2019-HORTSCI

Paiva PD de O, Beckmann-Cavalcante MZ (2023) What does Tropical and Subtropical plant mean?. Ornamental Horticulture 29:122-123. https://doi.org/10.1590/2447-536X.v29i2.2656

Porto WS, Carvalho CGP, Pinto RJB, Oliveira MF, Oliveira ACB (2008) Evaluation of sunflower cultivars for central Brazil. Scientia Agricola 65:139-144. https://doi.org/10.1590/S0103-90162008000200005

Porto WS, Carvalho CGP, Pinto RJB, Oliveira MF, Oliveira ACB (2009) Adaptability and stability of sunflower genotypes for the sub-tropical region of Brazil. Ciência Rural 39:2452-2459. https://doi.org/10.1590/S0103-84782009005000207

Proietti S, Scariot V, Da Pascale S, Paradiso R (2022) Flowering mechanisms and environmental stimuli for flower transition: bases for production scheduling in greenhouse floriculture. Plants 11:432. https://doi.org/10.3390/plants11030432

Puttha R, Venkatachalam K, Hanpakdeesakul S, Wongsa J, Parametthanuwat T, Srean P, Pakeechai K, Charoenphun N (2023) Exploring the potential of sunflowers: agronomy, applications, and opportunities within bio-circular-green economy. Horticulturae 9:1079. https://doi.org/10.3390/horticulturae9101079

Schneiter AA, Miller JF (1981) Description of Sunflower Growth Stages. Crop Science 21:901–903. https://doi.org/10.2135/cropsci1981.0011183X002100060024x

Seiler GJ, Gulya TJ (2016) Sunflower: Overview. In: Encyclopedia of Food Grains (Second Edition), 1:247-253. https://doi.org/10.1016/B978-0-12-394437-5.00027-9

Silva SDP da, Beckmann-Cavalcante MZ, Souza GP de, Oliveira TS de, Lima R da R, Chaves AR de M (2018) Growth of ornamental sunflowers in two growing seasons under semiarid conditions. Emirates Journal of Food and Agriculture 30:381–388. https://doi.org/10.9755/ejfa.2018.v30.i5.1681

Silva JR da, Heldwein AB, Puhl AJ, Amarante AA do, Salvadé DM, Leonardi M, Rocha L da (2020) Phenology and productive performance of chamomile in sowing dates and spacing between plants. Comunicata Scientiae 11:e3285. https://doi.org/10.14295/cs.v11i0.3285

Silva SDP da, Souza GP de, Chaves AR de M, Silva MA da, Souza RR de, Beckmann-Cavalcante, MZ (2022) Morphophysiological aspects of ornamental sunflowers cultivated in different growing seasons under semi-arid conditions, Revista Brasileira de Engenharia Agrícola e Ambiental 26:299-305. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n1p3-9

Sloan RC, Harkness SS (2006) Field evaluation of pollen-free sunflower cultivars for cut flower production. HortTechnology 16:324-327. https://doi.org/10.21273/HORTTECH.16.2.0324

Streck NA, Lago I, Gabriel LF, Samboranha FK (2008) Simulating maize phenology as a function of air temperature with a linear and a nonlinear model. Pesquisa Agropecuária Brasileira 43:449-455. https://doi.org/10.1590/S0100-204X2008000400002

Streck NA, Lago I, Samboranha FK, Gabriel LF, Schwantes AP, Schons A (2009a) Base temperature for leaf appearance and phyllochron of the BRS Missões maize variety. Ciência Rural 39:224-227. https://doi.org/10.1590/S0103-84782009000100035

Streck NA, Lago I, Bosco LC, Paula GM, Oliveira FB, Gabriel LF, Schwantes AP (2009b) Relationship between panicle differentiation and main stem leaf number in rice genotypes and red rice biotypes. Scientia Agricola 66:195-203. https://doi.org/10.1590/S0103-90162009000200008

Streck NA, Bellé RA, Backes FAAL, Gabriel LF, Uhlmann LO, Becker CC (2011) Desenvolvimento vegetativo e reprodutivo em gladíolo. Ciência rural 42:1968-1974. https://doi.org/10.1590/S0103-84782012001100010

Streck NA, Uhlmann LO (2021) Flowers for all: bridging the gap between science and society. Chronica Horticulturae 61:32-34. https://www.ishs.org/chronica-horticulturae/vol61nr3

Tagliapietra EL, Streck NA, da Rocha TSM, Richter GL, da Silva MR, Cera JC, Guedes JVC, Zanon AJ (2018) Optimum leaf area index to reach soybean yield potential in subtropical environment. Agronomy Journal 110:932-938. https://doi.org/10.2134/agronj2017.09.0523

Uhlmann LO, Becker CC, Tomiozzo R, Streck NA, Schons A, Balest DS, Braga MS, Schwab NT, Langner JA (2019) Gladiolus as an alternative for diversification and profit in small rural property. Ornamental Horticulture 25:200-209. http://dx.doi.org/10.14295/oh.v25i2.1541

Ungaro MRG, Castro C, Farias JRB, Barni N, Ramos NP, Sentelhas PC (2009) Girassol, In: Moneiro JEBA (Ed.) Agrometeorologia dos Cultivos – o fator meteorológico na produção agrícola. Brasília, INMET. P. 203-221.

Villalobos FJ, Hall AJ, Ritchie JT, Orgaz F (1996) OILCROP-SUN: A Development, Growth, and Yield Model of the Sunflower Crop. Agronomy Journal 88:403-415. https://doi.org/10.2134/agronj1996.00021962008800030008x

Villalobos J, Ritchie JT (1992) The effect of temperature on leaf emergence rates of sunflower genotypes. Field Crops Research 29:37-46. https://doi.org/10.1016/0378-4290(92)90074-J.

Walter LC, Streck NA, Rosa HT, Alberto CM, Oliveira FB (2009) Vegetative and reproductive development of wheat cultivars and its association with leaf appearance. Ciência Rural 39:2320-2326. https://doi.org/10.1590/S0103-84782009005000169

Yañez P, Ohno H, Ohkawa K (2005) Photoperiodic response and vase life of ornamental sunflower cultivars. HortTechnology 15:386–390. https://doi.org/10.21273/HORTTECH.15.2.0386

Yañez P, Chinone S, Hirohata R, Ohno H, Ohkawa K (2012) Effects of time and duration of short-day treatments under long-day conditions on flowering of a quantitative short-day sunflower (*Helianthus annuus* L.) ‘Sunrich Orange’. Scientia Horticulturae 140:8–12. https://doi.org/10.1016/j.scienta.2012.03.008

3.2 CAPÍTULO 2 – IMPROVING THE KNOWLEDGE ABOUT PHYLLOCHRON IN CUT SUNFLOWER

(Submetido à *Annals of Botany*, portanto as normas estão de acordo com as diretrizes exigidas)

Issue section: Original Article

Improving knowledge about the phyllochron in cut sunflower

Regina Tomiozzo[1,*], Lilian Osmari Uhlmann[1], Gizelli Moiano de Paula[2], Fabiana Lazzerini da Fonseca Barros[3], Márkilla Zunete Beckmann-Cavalcante[4], José Carlos Sorgato[5], Josabete Salgueiro Bezerra de Carvalho[6], Alexandra Goede de Souza[7], Beatrice Nesi[8], Mércia de Carvalho Almeida Rego[9], Dislaine Becker[10], Nereu Augusto Streck[1,*]

[1]*Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brazil*
[2]*Universidade Federal de Santa Maria (UFSM), Campus Frederico Westphalen, RS, Brazil*
[3]*Universidade do Estado do Rio Grande do Sul (UERGS), Vacaria, RS, Brazil*
[4]*Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina, PE, Brazil.*
[5]*Universidade Federal da Grande Dourados (UFGD), Dourados, MS, Brazil.*
[6]*Universidade Federal do Agreste de Pernambuco (UFAPE), Garanhuns, PE, Brazil.*
[7]*Instituto Federal Catarinense (IFC), Campus Rio do Sul, SC, Brazil*
[8]*CREA Research Center for Vegetable and Ornamental Crops (CREA OF), Pescia, PT, Italy.*
[9]*Floricultura Pé de Flor, Teresina, PI, Brazil*
[10] *Colônia Alberguini, Herval D'Oeste, SC, Brazil*

[*] *For Correspondence. Email: re.tomiozzo@gmail.com, nstreck2@yahoo.com.br*

Abstract

- **Background and Aims:** A breakpoint in leaf appearance rate of *Helianthus annuus* L., suggest a bilinear relationship to estimate phyllochron, an important developmental variable that can be used to predict leaf appearance in crop simulation models. We aimed (i) to estimate the phyllochron using a single and a bilinear model in field-grown cut sunflower genotypes considering several sowing dates in tropical, subtropical, temperate locations, and (ii) to test the hypothesis of a breakpoint as the indicator of change in phyllochron during the ontogeny of cut sunflower.
- **Methods:** Leaf number was evaluated in several trials carried out during from 2020 to 2023 in different locations in Brazil, South America, and one location in Italy, Europe. Leaf number was counted in fourteen cut sunflower genotypes until the final leaf number and the accumulated thermal time was calculated from transplanting date. The phyllochron was estimated by linear and bilinear regression between the leaf number and the accumulated thermal time, and expressed in °C day leaf^{-1}.
- **Key Results:** Field observations have identified a breakpoint in leaf appearance between V6 and V7 stages in cut sunflower genotypes resulting in an early and a late phyllochron. The early phyllochron is higher (34.87°C day leaf^{-1}) than the late (21.82°C day leaf^{-1}) and single (23.83°C day leaf^{-1}) phyllochron phases. The division of the phyllochron into two phases is hypothesized to be related to leaf phyllotaxy and stem elongation.
- **Conclusions**: We confirmed the existence of a breakpoint between the V6 and V7 stages, as evidenced by the bilinear regression between leaf number and thermal time, in cut sunflower genotypes. This led to identify two phyllochron phases, an early and a late. These results enhance our knowledge about the phyllochron and also provide an

ecophysiological basis for developing a chronology response function in process-based models for cut sunflower.

Key words: Floriculture, cut flower, development, phenology, leaf appearance, temperature, thermal time, breakpoint, *Helianthus annuus* L.

3.2.1 Introduction

Helianthus annuus L., commonly known as sunflower, is an annual dicotyledonous plant that belongs to the Asteraceae family, native to temperate North America (Azania et al., 2003; Baldotto and Baldotto, 2015). Widely grown as an oilseed crop, the use of sunflower as ornamental plant started more than 200 years ago (Kutschera and Briggs, 2015; Cvejić et al., 2016). Over the decades, the importance of sunflower increased largely, expanding the number of genotypes available for gardens, as a pot flower, and as a cut flower, been considered one of the most valuable floriculture crops (Curti et al., 2012; Neves et al., 2015; Shatoori et al., 2021; Puttha et al., 2023).

Basic studies on plant development and growth are important for several reasons as they give information that have practical application such as for improving crop simulation models and the fine tunning of management practices for farmers (Oteng-Darko et al., 2013; Jones et al., 2016; Pasquel et al., 2022). Plant development and plant growth are related but different processes: while plant development refers to cell differentiation, organ initiation and appearance, and extends to plant senscence, plant growth is usually refered to an irreversible increase in the physical dimension of an individual or organ with time (Anderson et al., 1978; Wilhelm and McMaster, 1995; Dellai et al., 2005). In sunflowers, a few basic studies on plant development and growth are available (Robison, 1971; Marc and Palmer, 1981; Sadras and Hall, 1988), and sunflower development was described by Schneiter and

Miller (1981) in developmental stages, dividing the developmental cycle into vegetative and reproductive phases. Vegetative phase details the leaf appearance on the stem (Walter et al., 2009; Schwab et al., 2015; Buffon et al., 2022). Leaf number depends upon the rate of primordium formation at the stem apical meristem (apex) and the rate of leaf appearance (Tenorio et al., 2017). In sunflower, the first leaves appear in opposite alternate pairs and gradually develop a spiral phyllotaxy of alternate leaves (Schneiter and Miller, 1981). A widely used variable to describe the rate that leaves appear in a plant is the phyllochron, defined as time required for two successive leaves to appear on a stem, having as unit time leaf^{-1} (Wilhelm and McMaster, 1995; Xue et al., 2004).

Photoperiod plays an important role in sunflower development (Goyne and Hammer, 1982), but temperature is the major environmental factor driving leaf appearance in sunflower (Doyle, 1975; Connor and Sadras, 1992) and many other floriculture crops as *Chrysanthemum x morifolium* Ramat. (Streck, 2004), *Gladiolus x grandiflorus* (Streck et al., 2012), *Eustoma grandiflorum* (Raf.) Shinners (Höhn et al., 2023), and *Dahlia* sp. (Fernandes et al., 2023). For sunflower, the base temperature for leaf appearance is 4°C (Villalobos and Ritchie, 1992). One approach to consider the effect of temperature on plants from a biological point of view is thermal time (TT), with units of °C day (Streck et al., 2009a; Ongarato et al., 2020). Assuming a linear relationship between leaf appearance (leaves stem^{-1}) and thermal time (°C day), it is possible to estimate the phyllochron with unit of °C day leaf^{-1} (Wilhelm and McMaster, 1995; Xue et al., 2004).

In sunflower with grain purposes, Villalobos and Ritchie (1992) and Sadras and Villalobos (1993) suggested an inflection point at six leaves in the relationship between accumulated leaf number and acumulated thermal time from emergence, indicating that there is a breakpoint in leaf appearance of sunflower between V6 and V7 stages (6 and 7 leaves, respectively). The hypothesis to explain a change in phyllochron during the ontogeny of a sunflower plant is that the inflection point occurs when sunflower leaf phyllotaxis changes from opposite to alternate leaves (Schneiter and Miller, 1981; Sadras and Villalobos, 1993). A breakpoint in leaf appearance and consequently two phyllochrons during the leaf appearance phase was also reported for *Triticum aestivum* L. (Streck at al., 2003), *Hordeum vulgare* L. (Abeledo et al. 2004), *Fragaria x ananassa* (Rosa et al., 2011), *Opuntia stricta* Haw. (Silva et al., 2023), and *Oryza sativa* L. (Egle et al., 2015).

The fact that the phyllochron is not constant during the vegetative phase may have direct impact on eco-physiological variables such as leaf area. The final leaf area is determined by the emergence of new leaves during the ontogeny, which intercept solar radiation and consequently influence several physiological processes, including crop photosynthesis, growth, transpiration, photon interception, and defining yield components (Rouphael et al., 2007; Tagliapietra et al., 2018). Moreover, practical applications of the phyllochron concept extend to crop simulation models, which either utilize or are based on the phyllochron to model the dynamics of leaf development such as for *Triticum aestivum* L. (Streck et al., 2003; Xue et al., 2004), *Glycine Max* L. (Setiyono et al., 2007), and *Oryza sativa* (Streck et al., 2008a). The hypothesis of a change in leaf appearance rate and consequently a change in the phyllochron during the leaf appearance phase in ornamental sunflower has not been tested, which constitutes a rationale for this study. The objectives in this study were (i) to estimate the phyllochron using a single and a bilinear model in field-grown cut sunflower genotypes considering several sowing dates in tropical, subtropical, temperate locations, and (ii) to test the hypothesis of a breakpoint as the indicator of change in phyllochron during the ontogeny of cut sunflower.

3.2.2 Material and methods

3.2.2.1 Field studies

Data used in this study are from four years (from 2020 to 2023) of field on farm trials conducted at different locations and sowings to evaluate the leaf appearance of several cut sunflowers (Table 1). The regions of the study were the Northeast, Midwest, and South regions in Brazil, South America, and one location in Tuscany, Italy, Europe (Fig. 1). In Brazil, the regions of study are divided in two climatic zones: tropical and subtropical. The tropics in Brazil represents 81.4% of the territory and have high temperatures (above 18 ºC), with a wet and dry season. Southern Brazil is located below the Tropic of Capricorn and has Cf climate (humid subtropical climate with no dry season), as defined in the Köppen climate classification (Alvares et al. 2013; Roth, 2007). According to Blasi et al. (2014) the region of study in Italy is in an Apennine province with temperate climate, where the minimum temperature in the coldest month is below 3 °C and maximum temperatures can exceed 30 °C in the hottest month.

Twelve *Helianthus annuus* L. genotypes for cutting purposes were used from different private international breeding companies: 'Amalfi Gold' (AG-01), 'Amalfi Orange' (AO-02), 'Stromboli Orange' (SO-06), 'Vesuvio Orange' (VO-09), 'Vesuvio Tangy' (VT-11), 'Magic Orange' (MO-03), 'Magic Orange Pro' (MP-06), 'Vesuvio Orange Pro' (VP-10), 'Favola' (FA-04), 'Stromboli Orange Pro' (SP-07), 'Stromboli Tangy' (ST-08), and 'Vincent's Choice' (VC-12). Information about experimental design and treatments of the trials are described in Supplementary 1.

The trials in Brazil followed the same management practices. Sowing was carried out in plastic trays with commercial substrate and kept protected until transplanting to beds, which was performed when the first pair of true leaves had a blade length of 2 centimetres and well-developed roots system. Beds were previously prepared with base fertilization of 500 g m^{-2} of lime and 50 g m^{-2} of NPK Formula 05-20-20, spread and incorporated into the soil. Each bed was one meter in width and 25 – 30 cm in height. Plant density was 32 plants m^{-2} distributed in 4 rows spaced 0.20 m among rows and 0.125 m within rows. About 10 to 15 days after transplanting, a topdressing fertilization was applied using 25 g m^{-2} of potassium chloride and 25 g m^{-2} of urea. Cultural practices, including pest and disease control as required, manual hoeing for weed control, and drip irrigation applied as necessary to prevent soil water deficit, were conducted. Each plot was individually staked with bamboo stakes or wooden slats at the four corners, and raffia string was used at 2 to 3 heights as the plants grew taller during their developmental cycle.

The field grown trial conducted in Pescia - Tuscany/Italy, at the Research Centre for Vegetable and Ornamental Crops (CREA-OF), followed the same methodology of the trials in Brazil adapting the cultural practices for the local conditions. Plants were cultivated in plots standardized at 0.80 m^2 with 30 plants distributed in three rows spaced 20 cm apart, with 0.125 m among plants in the row. Each plot received 50 g of 16-9-12 NPK fertilizer at transplanting and 50 g of 18-46 NP fertilizer 28 days after transplanting, as side dressing.

In addition, a field trial was conducted in Santa Maria, located in the Central Region of Rio Grande do Sul State, Southern Brazil, from August to November 2020. The objective of this trial was to assess the influence of planting methods, namely direct sowing and transplanting, on the phyllochron of cut sunflower. Six cut sunflower genotypes were evaluated in a factorial randomized complete block experimental design with four replications.

3.2.2.2 Data collecting and meteorological data

Plants in the central rows were tagged with coloured wires one week after transplanting. The number of tagged plants varied from 10 to 24 according to the trial. The accumulated leaf number (ALN) on the stem was counted once or twice a week in the tagged plants from V1 (one leaf) until the final leaf number (FLN), which occurred near the R4 stage (Schneiter and Miller, 1981). A leaf was assumed and counted when it presented blade length of at least 2 centimetres. This approach rended a thorough and detailed dataset on ALN. Weather data in Brazil were from the Brazilian National Institute of Meteorology meteorological stations or private meteorological stations located as close as possible to each site and weather data in Italy were from the meteorological station Research Centre for Vegetable and Ornamental Crops (CREA-OF). Mean daily air temperature (Tmean) was calculated as the average of daily minimum and maximum temperature.

3.2.2.3 Thermal time approach

Different methods can be used to calculate the thermal time(Streck et al., 2009). In this study, was used the same method to calculate thermal time as previously used by several authors such as Paula et al. (2005), Streck et al. (2008, 2009), Rosa et al. (2009), Delatorre et al. (2022). Daily thermal time (TT, °C day) was estimated according to the equation proposed by Gilmore and Rogers (1985) and Arnold (1960):

$$\mathrm{TT} = \{(\mathrm{Topt} - \mathrm{Tb}) * [(\mathrm{TB}-\mathrm{Tmean})/(\mathrm{TB}-\mathrm{Topt})]\}$$

$$\text{If } \mathrm{Tb} > \mathrm{Tmean} > \mathrm{TB},\ \mathrm{TT} = 0$$

$$\text{If } \mathrm{Tmean} < \mathrm{Topt},\ \mathrm{TT} = \mathrm{Tm} - \mathrm{Tb}$$

$$\text{If } \mathrm{Tmean} > \mathrm{Topt},\ \mathrm{TT} = Topt - Tb * \left(\frac{Tmean-TB}{Topt-TB}\right)$$

where Tb, Topt and TB are the cardinal (minimum, optimum, and maximum) temperatures for sunflower development defined by Villalobos et al. (1996) as 4 °C, 28 °C and 40 °C, respectively. The accumulated thermal time (ATT, °C day) from transplanting was calculated by accumulating the TT values, that is, ATT = ∑TT (Streck et al., 2008b).

3.2.2.4 Phyllochron

The phyllochron (PHYL, °C day leaf $^{-1}$) was calculated by the inverse of the slope of the linear regression (1/b) between ALN as dependent variable and ATT as independent variable (Streck et al., 2009, Ferreira et al., 2019). Three phyllochron values were estimated and named as Single, Early, and Late phyllochron phases. The Single phyllochron ($PHYL_{single}$) was estimated considering the leaf appearance from V1 to FLN. The Early and Late phyllochrons were estimated by dividing the leaf appearance into two phases, from V1 to V6 stage ($PHYL_{early}$), and from V7 to FNL ($PHYL_{late}$) as suggested by Villalobos and Richie (1992).

3.2.2.5 Statistical analysis

Phyllochron data were analysed for planting methods and for sowing dates of multi-location and multi-year dataset, that were grouped in seasons (Spring, Summer, Autumn, and Winter), locations, and genotypes. Shapiro-Wilk and Levene tests were applied for test the normality and homogeneity. The planting methods trial presented normal and homogeneous data and was analysed using ANOVA. The significance of differences was tested with Tukey's test at 5% probability, to compare the phyllochron phases in the different planting methods. Tha dataset for seasons, locations and genotypes presented non-normality and non-homogeneity and were analysed with Kruskall-Wallis non parametric test and a post-hoc Dunn test, with p-value adjusted as Bonferroni's methodology. Location, season and genotype were tested for each phyllochron phase. The statistical analysis was performed using RStudio program (R Core Team).

3.2.3 Results

3.2.3.1 Meteorological data

There was variation in meteorological conditions during the leaf appearance phase in the fourteen locations over the years (Table 2). Temperature varied from -2.0 °C in Vacaria/RS (lower than the lower base temperature for sunflower) to 37.7 °C in Santa Maria/RS (near to upper base cardinal temperature for sunflower). Photoperiod varied from 11.2 hours to 14.5 hours along the different growing seasons, especially in subtropical locations, where photoperiods change as temperatures change, from Spring to Winter. This variation in meteorological conditions provides a robust dataset of different environments that sunflower genotypes were exposed during their leaf appearance phase.

3.2.3.2 ALN and ATT relationship

A linear highly correlated relationship between accumulated leaf number (ALN) and accumulated thermal time (ATT), with an overall coefficient of determination (R^2) higher than 0.90 was found for all genotypes, locations and sowing dates. These results indicate that temperature was a major factor driving leaf appearance and therefore the estimate of the phyllochron from the inverse of the slope of the relationship is a suitable approach (Streck et al., 2009b; Rosa et al., 2011) Fig. 2 depicts an example when ALN was regressed against ATT for a single phyllochron for the genotype AO-02 in Brazil (sowing in 06/08/2020, Fig. 2A) and for the genotype AG-01 in Italy (sowing in 28/02/2023, Fig. 2B), and for the two phases of the phyllochronbreakpoint between six and seven leaves (Fig. 2C and D). It was observed that in all locations and genotypes the breakpoint occurred between 200 and 300 °C day.

3.2.3.3 Planting methods

Shapiro-Wilk test indicates normality of the residuals (p-value = 0.1974) and Levene's test indicates homogeneity (p-value = 0.4735). Among single-factor, ANOVA indicates significative differences in planting methods, genotypes and phyllochron phases. Between planting methods, transplanting has higher phyllochron (29.15 °C day leaf $^{-1}$) than direct sowing (27.38 °C day leaf $^{-1}$). There are no significative interactions among three-factor interactions planting methods x genotypes x phyllochron phase (p-value = 0.9179), at 5%. Among two-factor interactions, planting methods x genotypes (p-value = 0.7946), and planting methods x phyllochron phases (p-value = 0.7129) were not significant. On other hand, the interaction genotype x phyllochron phases was significant (p-value = 0.0005). Differences are presented in Table 3. Phyllochron differed between phyllochron phases, with the $PHYL_{early}$ having the highest values. $PHYL_{single}$ does not differ between genotypes, varying from 23.78 to 25.93 °C day leaf $^{-1}$. On contrary, $PHYL_{early}$ and $PHYL_{late}$ differ between genotypes, with 'AG-01' having the highest phyllochron in the early phase (41.75 °C day leaf $^{-1}$) and 'SO-06' in the late phase (23.91 °C day leaf $^{-1}$). Among genotypes, 'AG-01', 'MO-03' and 'VO-09' differed between $PHYL_{single}$ and $PHYL_{late}$ and, for the other tree genotypes single and late phyllochron are equals by Tukey test.

3.2.3.4 Phyllochron phase

Dataset present non-normality by Shapiro-Wilk test (p – value < 0.0000) and non-homogeneity by Levene's test (p – value = 0.0002) and the phyllochron data were presented as median with interquartile range. Among the phyllochron phases (Fig. 3), there was a statistical difference by Kruskall-Wallis (p – value < 0.0000). Early phyllochron presented the higher value (34.87 °C day leaf $^{-1}$), followed by single phyllochron (23.83 °C day leaf $^{-1}$) and late phyllochron (21.82 °C day leaf $^{-1}$), i.e. $PHYL_{early} > PHYL_{single} > PHYL_{late}$.

The main effects on phyllochron (location, season, and genotype) were analysed for each phyllochron phase. Among locations, Kruskall-Wallis and post hoc Dunn Test detected differences (Fig. 4). Júlio de Castilhos/RS differed from Pescia/Italy, Santa Maria/RS and Teresina/PI for the single phyllochron, while Santa Maria/RS differed from Rio do Sul/SC, Novo Xingú/RS, Herval D'Oeste/SC and Bozano/RS (Fig. 4A). Median values of the single phyllochron were 31.10 °C day leaf $^{-1}$ for Júlio de Castilhos/RS and 22.49 °C day leaf $^{-1}$ for Santa Maria/RS. Differences in early phyllochron were also detected (Fig. 4B). Rio do Sul/SC (51.17 °C day leaf $^{-1}$) and Pescia/Italy (45.30 °C day leaf $^{-1}$) obtained the highest values of early phyllochron and differred from Boa Vista do Sul/RS, Herval D'Oeste/SC, Santa Maria/RS, Dourados/MS and Teresina/PI. The lowest median value of the late phyllochron was observed in Santa Maria/RS (20.27 °C day leaf $^{-1}$) which differed from other locations, such as Herval D'Oeste/SC, Júlio de Castilhos/RS, Novo Xingú/RS and Bozano/RS, which presented higher values (Fig. 4C).

Among growing seasons, phyllochron differs between seasons for single phyllochron (Fig. 5A) and late phyllochron (Fig. 5C). Dunn test indicates that the single and late phyllochron of cut sunflowers sown in Autumm and Spring differred from those sown in Winter. Single phyllochron varied from 23.22 °C day leaf $^{-1}$ in Winter to 26.09 °C day leaf $^{-1}$ in Spring and late phyllochron varied from 20.82 °C day leaf $^{-1}$ in Winter to 24.41 °C day leaf $^{-1}$ in Spring. The early phyllochron did not differ among seasons, ranging from 32.21 °C day leaf $^{-1}$ in Summer to 37.39 °C day leaf $^{-1}$ in Autumm (Fig. 5B).

Among genotypes (Fig. 6) no statistical differences were found between genotypes in early phyllochron by Kruskal-Wallis (p – value = 0.2872). Early phyllochron varied from the lower value of 27.2 °C day leaf $^{-1}$ for FA-04 to the greater value of 40.30 °C day leaf $^{-1}$

for MP-06. On other hand, Kruskal-Wallis indicated statistical differences in single phyllochron (p – value = 0.0002) and late phyllochron (p – value = 0.0181). The genotype VT-11 presented a single phyllochron of 21.40 °C day leaf $^{-1}$ and differed from SO-06 and VC-12, with 25.15 °C day leaf $^{-1}$ and 24.30 °C day leaf $^{-1}$, respectively (Fig. 6A). However, the post-hoc Dunn test with p-value adjusted as Bonferroni's did not show differences among genotypes in late phyllochron (Fig. 6C).

3.2.4 Discussion

The multi-location, multi-year, and multi-environment field on farm trials conducted in Brazil, along with the trial conducted in Italy, allowed for the assessment of leaf appearance in different cut sunflower genotypes exposed to various edaphoclimatic conditions, management practices, and variations in temperature and photoperiod. Our approach advances by overcoming the limitations of previous studies about phyllochron in sunflower (Vilallobos and Ritchie, 1992), by employing a comprehensive robust dataset regarding leaf appearance in cut sunflower under field grown conditions, covering a wide range of cut sunflower genotypes for analyzing patterns in the phyllochron. Exposing cut sunflowers plants to a wide range of growing conditions provide robustness in studies assessing basic plant growth and development processes, as well as in using thermal time as a measure of biological time in plants (Streck et al., 2005; Streck et al., 2008a,b).

The relationship between accumulated leaf number and accumulated thermal time showed a bilinear relationship with a hight coefficient of determination (Fig. 2). Previous studies on phyllochron in sunflower crops have indicated differences in leaf appearance rates, emphasizing the necessity of measuring leaf emergence in two phyllochron phases compared to a single phyllochron (Aiken, 2005). Similar studies have described the occurrence of more than one phyllochron phase in other species. In strawberry, breaking the phyllochron into vegetative and reproductive phases better repesented leaf development dynamic compared to a single phyllochron (Rosa et al., 2011). In long-cycle crops, such as sugarcane and forage cactus, the phyllochron was also broken into early and late phases (Streck et al., 2010; Silva et al., 2023).

The hyphotesis that the planting method (direct sowing or transplanting) could contribute to changes in the phyllochron was tested, given that transplanting seedlings could accelerated maturity by 16 days compared to sunflowers grown by direct sowing (Ahmad et al., 2020). However, the results of the planting methods trial (Table 3) demonstrated that the planting method does not influence the phases of the phyllochron, thereby rejecting this hypothesis. Furthermore, genotypes exhibited variation within both the early and late phyllochron phases, contrary to the results obtained for the single phyllochron.

As mentioned, the results showed no difference among genotypes within the early and late phyllochron phases. The greatest differences within the phases occurred mainly due to location. Differences among mainly occurred for the late phyllochron. The results can be explained by the environment, as they differ in temperature and photoperiod. From emergence to the R1 stage, sunflower is more sensitive to long days, and after the R1 stage, to short days (Aiken, 2005). According to MacDonough et al. (2004) the phyllochron in Spring-sown (photoperiod 12-14 hours) ranged from 30 to 45 °C day leaf^{-1} as a single phyllochron, and this range was reduced to 30 to 35 °C day leaf^{-1} when the photoperiod was extended by 2 hours, reducing the final leaf number, in the same season.

Among the multilocation trials, the results demonstrate that in cut sunflower genotypes the interquartile range of phyllochron varies from 21 to 27 °C day leaf^{-1} in single phyllochron, 30 to 42 °C day leaf^{-1} in early phyllochron and 19 to 25 °C day leaf^{-1} in late phyllochron. These ranges are similar to the findings of Villalobos and Ritchie (1992), where the single phyllochron in sunflower crop tipically ranges from 20 to 25 °C day leaf^{-1}, the early phyllochron (until six leaves) ranges from 35 to 43 °C day leaf $^{-1}$ and late phyllchron (seven leaves upwards) ranges from 18 to 29 °C day leaf $^{-1}$. These results confirm that phyllochron in cut sunflower is slower for the first six leaves (early phyllochron) and faster from seven leaves upwards (late phyllochron). On the contrary, in some grass species such as rice (Streck et al., 2008a) and sorghum (Clerget et al., 2008), the early phyllochron is faster and the late phyllochron is slower. For wheat, ontogeny was identified as the cause of these changes in leaf appearance (Streck et al., 2003; Baumont et al., 2019). The seed reserves increases the leaf appearance rate for the first two leaves, and the subsequent leaves take more time to appear due to the distance that each leaf tip needs to traverse until its exposure, as a result of the elongation of the whorl (Streck et al. 2003).

In cut sunflower ontogeny, the opposite occurs. Seeds reserves are responsible for seed germination and early seedlings development, until the development of cotyledons and first leaves, when the photosynthetic actitity starts to increase (Erbaş et al., 2016). Until the V6 stage, leaves emerge in opposite pairs, and internode elongation is slow in an acropetal direction, beginning only when the first pair of true leaves is about two to three centimeters long (Garrison, 1973). As leaf expansion takes place, a subtle internode elongation is noted to emit the next pair of leaves. From the V7 stage onwards, leaves appear in an alternate sequence, and stem elongation follows a sigmoidal pattern (Seiler, 1997). As alternate leaves appear and the R1 stage (bud appearance) approaches, the rate of internodes elongation increases fastly until reaching their maximum length near the R4 stage. At the meantime, there is an overlapping of the leaf development and the reproductive phase, so that the leaf appearance continues after the R1 stage and the final leaf number occurs close to R4 stage, when stem elongation stabilizes.

The change in leaf phyllotaxy (from opposite leaf pairs to alternate single leaves) at V6 and V7 stages has been hypthesized to be in charge of the change in phyllochron in sunflower (Sadras and Villalobos, 1993). We hypothesize that the change is phyllochron may be or is also related to stem elongation, i.e. ontogeny represented by the change in leaf phyllotaxy combined with stem elongation composes the main hypothesis to explain the breakpoint and the difference between phylochron phases in cut sunflower. Garrison (1973) concluded that ordely patterns of shoot growth reflect a close relatioship between leaf and stem in sunflower. the. In maize and others cereal crops, the changes in phyllochron occurs around the time of the shift from vegetative to reproductive phase, indicating that there is a relationship between the breakinpoint and the reproductive organ development (Xu et al., 2023). In cut sunflower this relationship with the transition from vegetative to reproductive phase and phyllochron is not clear, requiring more studies.

This study investigated deeper into leaf development dynamics in cut sunflower genotypes. The novelty of our results is that phenological scales of sunflower, such as Schneiter and Miller (1981) and even the BBCH scale (2001), may be too simplistic and do not adequately describe the role of stem elongation on the growth and development of sunflower, nor do they capture its nuances in relation to the dynamics of leaf appearance or bud appearance. . Furthermore, our findings provide important insights for parameterizing or enhancing leaf appearance models in sunflower. The bilinear relationship between leaf number and thermal time indicates changes in leaf appearance rate (LAR), particularly since the phyllochron from V7 upwards accelerates. Some existing sunflower simulation models already employ a bilinear function to calculate leaf appearance using the phyllochron approach (Chapman et al., 1993; Villalobos et al., 1996; Casadebaig et al., 2011). These models rely on the concept of thermal time to link development with temperature and compute leaf appearance. This approach serves as a simple and efficient descriptor when compared to calendar days (Streck et al., 2002). However, the relationship between development and temperature for calculating leaf appearance does not follow a single linear pattern. Considering non-linear models to simulate leaf appearance may offer a more accurate descriptor for cut sunflower, as already proposed for other species such as gladiolus (Uhlmann et al., 2017), maize (Langner et al., 2018) and wheat (Paff et al., 2023). From this perspective, one approach to enhance these models is to incorporate a chronological response function into process-based models that takes into acoint a breakpoint in leaf appearance. This adjustment would provide a more realistic and biologically meaningful prediction of leaf appearance, as proposed for wheat by Streck et al. (2003).

3.2.5 Conclusion

We confirmed the existence of a breakpoint between the V6 and V7 stages, as evidenced by the bilinear regression between leaf number and thermal time, in cut sunflower genotypes. This led to identify two phyllochron phases: an early one of 34.87 °C day leaf^{-1}, and a late one of 21.82 °C day leaf^{-1}. Phyllochron phases are consistency across genotypes, and is affeted by environmental influences, such as location variability. These results not only enhance our knowledge about the phyllochron but also provide an ecophysiological basisfor developing a chronology response function in process-based models for cut sunflower.

Acknowledgments

We thank to the Brazilian PhenoGlad Teams and their institutions, to Emater/RS-Ascar and its extensionists, to rural schools and to farmers of the "Flowers for All" Project, and to the Research Centre for Vegetable and Ornamental Crops (CREA-OF) – Pescia/Italy for the collaborative networking in collecting data in Brazil and in Italy. Special thanks to Andrea Mansuino and Cesar Mauricio Torres Martinez for tecnhical support and advise.

Funding

This work was supported by Brazilian Federal Agency for Support and Evaluation (CAPES) who provided the scholarship during the doctorate degree of R. Tomiozzo and by National Council for Scientific and Technological Development (CNPq) for the financial support provided through Process 200233/2022-2 for the Sandwich Doctorate Program in Italy of R. Tomiozzo.

3.2.6 References

Abeledo LG, Calderini DF, Slafer GA. 2004. Leaf appearance, tillering and their coordination in old and modern barleys from Argentina. *Field Crops Research*, **86:** 23-32.

Ahmad S, Ghaffar A, Rahman MH, Haq T, Khan MA, Mahmood A. 2020. Evaluation of different production systems in combination with foliar sulphur application for sunflower (*Helianthus annuus* L.) under arid climatic conditions of Pakistan. *Sarhad Journal of Agriculture*, **36:** 1266-1278. http://dx.doi.org/10.17582/journal.sja/2020/36.4.1266.1278

Aiken RM. 2005. Applying thermal time scales to sunflower development. *Agronomy Journal*, **97:** 746-754. https://doi.org/10.2134/agronj2004.0181

Alvares CA, Stape JL, Sentelhas PC, et al. 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, **22:** 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Anderson WK, Smith RCG, McWilliam JR. 1978. A systems approach to the adaptation of sunflower to new environments I. Phenology and development. *Field Crops Research*, **1:** 141-152. https://doi.org/10.1016/0378-4290(78)90017-5

Arnold CY. 1960. Maximum-minimum temperatures as a basis for computing heat units. *Journal of the American Society for Horticultural Sciences*, **76:** 682-692.

Azania AAPM, Azania CAM, Alves PLCA. et al. 2003. Allelopathic plants. 7. Sunflower (Helianthus annuus L.). *Allelopathy Journal*, **11:** 1 – 20.

Baldotto LEB, Baldotto MA. 2015. Growth and production of ornamental sunflower grown in the field in response to application of humic acids. *Ciência Rural*, **45:** 1000-1005.

Baumont M, Parent B, Manceau L, Brown HE, Driever SM, Muller B, Martre P. 2019. Experimental and modeling evidence of carbon limitation of leaf appearance rate for spring and winter wheat. *Journal of Experimental Botany*, **70:** 2449–2462. https://doi.org/10.1093/jxb/erz012

Blasi C, Capotorti G, Copiz R. et al. 2014. Classification and mapping of the ecoregions of Italy. *Plant Biosystems*, **148:** 1255-1345. http://dx.doi.org/10.1080/11263504.2014.985756

Jones JW, Antle JM, Basso B. et al. 2016. Brief history of agricultural systems modeling. *Agricultural systems*, **115:**240-254. https://doi.org/10.1016/j.agsy.2016.05.014

Buffon PA, Streck NA, Schwab NT. et al. 2022. A phenological scale of statice. *Annals of Applied Biology*, **181:** 275-287. https://doi.org/10.1111/aab.12765

Casadebaig P, Guilioni L, Lecoeur J, Christophe A, Champolivier L, Debaeke P. 2011. SUNFLO, a model to simulate genotype-specific performance of the sunflower crop in contrasting environments. *Agricultural and Forest Meteorology*, **151:** 163-178. https://doi.org/10.1016/j.agrformet.2010.09.012

Chapman SC, Hammer GL, Palta JA. 1993. Predicting leaf area development of sunflower. *Field Crops Research*, **34:** 101-112. https://doi.org/10.1016/0378-4290(93)90114-3.

Connor DJ, Sadras VO. 1992. Physiolofy of yield expression in sunflower. *Field Crops Research*, **30:** 333-389. https://doi.org/10.1016/0378-4290(92)90006-U

Clerget B, Dingkuhn M, Gozé E, Rattunde HFW, Ney B. 2008. Variability of Phyllochron, Plastochron and Rate of Increase in Height in Photoperiod-sensitive *Sorghum* Varieties. *Annals of Botany*, **101:** 579–594. https://doi.org/10.1093/aob/mcm327

Curti GL, Martin TN, Ferronato ML, Benin G. 2012. Girassol ornamental: caracterização, pós-colheita e escala de senescência. *Revista de Ciências Agrárias*, **35:** 240-250.

Cvejić S, Jocić S, Mladenović E. 2016. Inheritance of floral colour and type in four new inbred lines of ornamental sunflower (*Helianthus annuus* L.). *The Journal of Horticultural Science and Biotechnology*, **91:** 30–35. 10.1080/14620316.2015.1110989

Dellai J, Trentin G, Bisognin DA, Streck NA. 2005. Phyllochron at different plant densities in potato. *Ciência Rural*, **35:** 1269-1274. https://doi.org/10.1590/S0103-84782005000600007

Delatorre CA, Duarte,V. F., Wairich, A., Fraga, G. P., Ribeiro, M. P., & Lazzari, H. E. 2022. Oat development in response to temperature. *Ciência Rural*, 52(1), e20210198.

Doyle AD. 1975. Influence of temperature and daylength on phenology on sunflowers in the field. *Australian Journal of Experimental Agriculture*, 15: 88-92. https://doi.org/10.1071/EA9750088

Erbaş S, Tonguç M, Karakurt Y, Şanli A. 2016. Mobilization of seeds reserves during germination and early seedling growth of two sunflower cultivars. *Journal of Applied Botany and Food Quality*, 89: 217-222. https://doi.org/10.5073/JABFQ.2016.089.028

Fernandes M, Roso TP, Ferronato L. et al. 2023. Determining the phyllochron and the final leaf pair number in on-farm cut dahlia cultivars. *Ornamental Horticulture*, **29:** 299-312. https://doi.org/10.1590/2447-536X.v29i2.2650

Ferreira MC, Martins FB, Florêncio GWL, Pasin LAAP. 2019. Cardinal temperatures and modeling of vegetative development in guava. *Revista Brasileira de Engenharia Agrícola e Ambiental*, **23:** 819-825. https://doi.org/10.1590/1807-1929/agriambi.v23n11p819-825

Garrison R . 1973. The Growth and Development of Internodes in Helianthus. *Botanical Gazette*, **134:** 246-255. https://doi.org/10.1086/336711

Gilmore ECJr, Rogers JS. 1958. Heat units as a method of measuring maturity in corn. *Agronomy Journal*, **50:** 611-615.

Goyne PJ, Hammer GL. 1982. Phenology of sunflower cultivars. II. Controlled-environment studies of temperature and photoperiod effects. *Australian Journal of Agricultural Research*, **33**: 51–261. https://doi.org/10.1071/AR9820251

Höhn D, Peil RMN, Marchi PM, Grolli PR, Trentin R, Shaun WS. 2023. Base temperature estimates for lisianthus cultivars grown in different planting seasons. *Pesquisa Agropecuária Brasileira*, **58:** e03447. https://doi.org/10.1590/ S1678-3921.pab2023.v58.03447

Kutschera U, Briggs WR. 2016. Phototropic solar tracking in sunflower plants: an integrative perspective. *Annals of Botany*, **117:** 1–8. https://doi.org/10.1093/aob/mcv141

Langner JA, Streck NA, Durigon A. et al. 2018. Emissão de folhas observada e estimada de cultivares crioulas e melhoradas de milho. *Ciência Rural*, **48:** e20160775. https://doi.org/10.1590/0103-8478cr20160775

MacDonough R, Balbi MC, Hall AJ. 2004. Phasic development and phyllochron responses to extended photoperiods and sowing date. Proc. 16th International Sunflower Conference, Fargo, ND.

Marc J, Palmer JH. 1981. Photoperiodic sensitivity of inflorescence initiation and development in sunflower. *Field Crops Research*, **4**: 155-164. https://doi.org/10.1016/0378-4290(81)90065-4

McMaster GS. 2005. Phytomers, phyllochrons, phenology and temperate cereal development. *The Journal of Agricultural Science*, **143:** 137-150. https://doi.org/10.1017/S0021859605005083

Neves MB, Buzetti S, Castilho RMM, Boaro CSF. 2005. Development of ornamental sunflower plants (*Helianthus annuus* L.) in flowerpots, two substrata with nutritive solution and in soil. *Científica*, 33: 127-133.

Ongaratto F, Rocha MG, Pötter L. et al. 2020. Canopy structure and morphogenesis of Italian ryegrass intercropped with red clover under cutting intervals determined by thermal sum. *Ciência Rural*, **50:** e20190989. https://doi.org/10.1590/0103-8478cr20190989

Oteng-Darko P, Yeboah S, Addy SNT, Amponsah S, Owusu Danquah E. 2013. Crop modeling: A tool for agricultural research – A review. *Journal of Agricultural research and Development*, **2:**001-006.

Paff K, Timlin D, Fleisher DH. 2023. A comparison of wheat leaf-appearance rate submodules for DSSAT CROPSIM-CERES (CSCER). *Ecological Modelling*, **482:** 110406. https://doi.org/10.1016/j.ecolmodel.2023.110406.

Pasquel D, Roux S, Richetti J, Cammarano D, Tisseyre B, Taylor JA. 2022. A review of methods to evaluate crop model performance at multiple and changing spatial scales. *Precision Agriculture*, **23:**1489-1513. https://doi.org/10.1007/s11119-022-09885-4

Paula FLM, Streck NA, Heldwein AB, Bisognin DA, de Paula AL, Dellai J. 2005. Thermal time of some developmental phases in potato (*Solanum tuberosum* L.). *Ciência Rural*, **35:** 1034-1042. https://doi.org/10.1590/S0103-84782005000500008

Puttha R, Venkatachalam K, Hanpakdeesakul S, et al. 2023. Exploring the potential of sunflowers: agronomy, applications, and opportunities within bio-circular-green economy. *Horticulturae*, **9:** 1079. https://doi.org/10.3390/horticulturae9101079

Robinson RG. 1971. Sunflower Phenology: Year, variety and date of planting effects on day and growing degree day summations. *Crop Science*, **11:** 635. https://doi.org/10.2135/cropsci1971.0011183X001100050009x

Rosa HT, Walter LC, Streck NA, Alberto CM. 2009. Métodos de soma térmica e datas de semeadura na determinação de filocrono de cultivares de trigo. *Pesquisa Agropecuária Brasileira*, **44:** 1374-1382. https://doi.org/10.1590/S0100-204X2009001100002

Roth M. 2007. Review of urban climate research in (sub)tropical regions. *International Journal of Climatology*, **27:** 1859-1873. https://doi.org/10.1002/joc.1591

Rouphael Y, Colla G, Fanasca S, Karam F. 2007. Leaf area estimation of sunflower leaves from simple linear measurements. *Photosynthetica*, **45:** 306–308. https://doi.org/10.1007/s11099-007-0051-z

Sadras VO, Hall AJ. 1988. Quantification of temperature, photoperiod and population effects on plant leaf area in sunflower crops. *Field Crops Research*, **18:** 185–196. https://doi.org/10.1016/0378-4290(88)90008-1

Sadras VO, Villalobos FJ. 1993. Floral initiation, leaf initiation and leaf appearance in sunflower. *Field Crops Research*, **33:** 449-457. https://doi.org/10.1016/0378-4290(93)90165-J

Schneiter AA, Miller JF. 1981. Description of Sunflower Growth Stages. *Crop Science*, **21:** 901–903. https://doi.org/10.2135/cropsci1981.0011183X002100060024x

Schwab NT, Streck NA, Becker CC, Langner JA, Uhlmann LO, Ribeiro BSMR. 2015. A phenological scale for the development of Gladiolus. *Annals of Applied Biology*, **166:** 496-507. https://doi.org/10.1111/aab.12198

Seiler GJ. 1997. Anatomy and Morphology of Sunflower. In Sunflower Technology and Production, A.A. Schneiter (Ed.). https://doi.org/10.2134/agronmonogr35.c3

Setiyono TD, Weiss A, Specht J, Bastidas AM, Cassman KG, Dobermann A. (2007). Understanding and modeling the effect of temperature and daylength on soybean phenology under high-yield conditions. *Field Crops Research*, **100:** 257-271. https://doi.org/10.1016/j.fcr.2006.07.011.

Shatoori MM, Saffari VR, Farahmand H. 2021. Correlation Between Vase Life and Biochemical Parameters in Ornamental Sunflower (*Helianthus annuus* L.) Affected by Spraying Chemical Materials During the Growth Stages. *Journal of Plant growth Regulation*, **40:** 179-186. https://doi.org/10.1007/s00344-020-10088-2

Silva GIN da, Jardim AM da RF, Souza M de S, et al. 2023. Combined agricultural practices in millet and cactus: phyllochron, structural characteristics and relations with yield. Scientia Agrícola, 80:e20220046. http://doi.org/10.1590/1678-992X-2022-0046

Streck NA. 2002. A generalized nonlinear air temperature response function for node appearance rate in muskmelon (*Cucumis melo* L.). *Revista Brasileira de Agrometeorologia*, **10:** 105-111.

Streck NA, Weiss A, Xue Q, Baenziger PS. 2003. Incorporating a Chronology Response into the Prediction of Leaf Appearance Rate in Winter Wheat. *Annals of Botany*, **92:** 181–190. https://doi.org/10.1093/aob/mcg121

Streck NA. 2004. A temperature response function for development of chrysanthemum (*Chrysantemum x morifolium* Ramat.). Ciência Rural, **34:** 49-54. https://doi.org/10.1590/S0103-84782004000100008

Streck NA, Bosco LC, Lago I. 2008a. Simulating Leaf Appearance in Rice. *Agronomy Journal*, **100:** 490-501. https://doi.org/10.2134/agronj2007.0156

Streck NA, Lago I, Gabriel LF, Samboranha FK. 2008b. Simulating maize phenology as a function of air temperature with a linear and a nonlinear model. *Pesquisa Agropecuária Brasileira,* **43:** 449-455. https://doi.org/10.1590/S0100-204X2008000400002

Streck NA, Lago I, Samboranha FK, Gabriel LF, Schwantes AP, Schons A. 2009a. Base temperature for leaf appearance and phyllochron of the BRS Missões maize variety. *Ciência Rural*, **39:** 224-227. https://doi.org/10.1590/S0103-84782009000100035

Streck NA, De Paula FLM, Dellai J, Bisognin DA, De Paula AL. 2009b. Phyllochron in potato affected by tuber seed-size and growing season. *Bragantia*, **68:** 137-143. https://doi.org/10.1590/S0006-87052009000100015

Streck NA, Hanauer JG, Gabriel LF, Buske TC, Langner JA. 2010. Leaf development and growth of selected sugarcane clones in a subtropical environment. *Pesquisa Agropecuária Brasileira,* **45:** 1049-1057.

Streck NA, Bellé RA, Backes FAAL, Gabriel LF, Uhlmann LO, Becker CC. 2012. Desenvolvimento vegetativo e reprodutivo em gladíolo. *Ciência rural*, **42:** 1968-1974. https://doi.org/10.1590/S0103-84782012001100010

Tenorio FM, Specht JE, Arkebauer TJ, Eskridge KM, Graef GL, Grassini P. 2017. Co-ordination between primordium formation and leaf appearance in soybean (*Glycine max*) as influenced by temperature. *Field Crops Research*, 210: 197-206. https://doi.org/10.1016/j.fcr.2017.03.015

Villalobos J, Ritchie JT. 1992. The effect of temperature on leaf emergence rates of sunflower genotypes. *Field Crops Research*, **29:** 37-46. https://doi.org/10.1016/0378-4290(92)90074-J.

Villalobos FJ, Hall AJ, Ritchie JT, Orgaz F. 1996. OILCROP-SUN: A Development, Growth, and Yield Model of the Sunflower Crop. *Agronomy Journal*, **88:** 403-415. https://doi.org/10.2134/agronj1996.00021962008800030008x

Walter LC, Streck NA, Rosa H., Alberto CM, Oliveira FB. 2009. Vegetative and reproductive development of wheat cultivars and its association with leaf appearance. *Ciência Rural*, **39:** 2320-2326. https://doi.org/10.1590/S0103-84782009005000169

Wilhelm WW, McMaster GS. 1995. Importance of the phyllochron in studying development and growth in grasses. *Crop Science*, 35, 1–3. https://doi.org/10.2135/cropsci1995.0011183X003500010001x

Xu H, Ming B, Wang K, Xue J, Hou P, Li S, Xie R. 2023. Quantitative analysis of maize leaf collar appearance rates. *Plant Physiology and Biochemistry*, **196:** 454-462. https://doi.org/10.1016/j.plaphy.2023.01.016.

Xue Q, Weiss A, Baenziger PS. 2004. Predicting leaf appearance in field-grown winter wheat: evaluating linear and non-linear models. *Ecological Modelling*, **175:** 261-270. https://doi.org/10.1016/j.ecolmodel.2003.10.018

Figures captions

Fig. 1. Geographic location of the field on farm trials with cut sunflower genotypes conducted in three regions of Brazil, South America (A): (B) Northwest, (C) Midwest and (D) South, and in (E) Tuscany, Italy, Europe. World map in panel (F).

Fig. 2. Relationship between the accumulated leaf number on the stem (ALN, leaves stem^{-1}) and accumulated thermal time (ATT, °C day) for (A, C) the cut sunflower hybrid Amalfi Orange in the 06/08/2020sowing date at Santa Maria - RS, Brazil, and (B, D) the cut sunflower hybrid Amalfi Golden in the 28/02/2023sowing date at Pescia – Tuscany, Italy. Panels A and B indicates the Single phyllochron (yellow circles), and panels C and D indicates the Early phyllochron (green circles) and Late phyllochron (red circles).

Fig. 3. Box plots demonstrating the phyllochron phases for cut sunflower, in °C day leaf^{-1}, pooling data collected in field on farm trials in Brazil (2020-2023) and Italy (2023). Solid line inside the boxes indicate the median. Different lower-case letters are different according to Post Doc Dunn Test at 5% probability.

Fig. 4. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing location for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). Locations: BVS (Boa Vista do Sul/RS), BZN (Bozano/RS), BNP (Brunópolis/RS), CNT (Canhotinho/PE), DRD (Dourados/MS), HDO (Herval D'Oeste/SC), JC (Júlio de Castilhos/RS), NX (Novo Xingú/RS), PSC (Pescia, Italy), PTR (Petrolina/PE), RS (Rio do Sul/SC), SM (Santa Maria/RS), TSN (Teresina, PI) and VCR (Vacaria/RS). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

Fig. 5. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing Seasons (Spring, Summer, Autumm, and Winter) for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

Fig. 6. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing genotypes for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

Table 1. Characterization of cut sunflower field on farm trials conducted during four years (2020 to 2023) in Brazil, South America, and during one year (2023) in Italy, Europe, that composed the dataset used in this study.

Country	Region	State	Locations	Latitude	Longitude	Year	Months of sowing dates	Genotypes	Environment
Brazil	Northeast	Piauí	Teresina	5°5’S	42°48’W	2021 and 2022	September and March	1	Tropical
		Pernambuco	Canhotinho	8°52’S	36°11’W	2022	November	1	Tropical
			Petrolina	09°23’S	40°30’W	2022	May	1	
	Midwest	Mato Grosso do Sul	Dourados	22°13’S	54°48’W	2021	October	1	Tropical
	Southern	Santa Catarina	Brunópolis	27°18’S	50°52’W	2021	March	2	Subtropical
			Herval D’Oeste	27°19’S	51°49’W	2021	January to March	7	
			Rio do Sul	27°12’S	49°38’W	2021	March	2	
		Rio Grande do Sul	Santa Maria	29°43’S	53°43’W	2020 to 2023	January to October	12	Subtropical
			Júlio de Castilhos	29°23’S	53°68’W	2021	March	2	
			Novo Xingú	27°43’S	53°3’W	2021	September and October	1	
			Boa Vista do Sul	29°21’S	51°40’W	2022	March	1	
			Bozano	28°22’S	53°46’W	2023	January and February	1	
			Vacaria	28°30’S	50°55’W	2023	April	1	
Italy	Tuscany	Pistoia	Pescia	28°30’S	50°55’W	2023	February	8	Temperate

Table 2. Minimum (TMin), maximum (TMax) and mean air temperature (Mean), and photoperiod (P) across different locations, sowing date (dd/mm/yyyy), and transplant date (dd/mm/yyyy) in the trials in Brazil, South America, from 2020 to 2023, and Italy, Europe, in 2023.

Country	Region	State	Locations	Sowing date	Transplant date	TMin (°C)	TMax (°C)	Mean (°C)	P (h)
Brazil	Northwest	Piauí	Teresina	30/09/2021	07/10/2021	11.3	30.6	20.9	13.00
		Pernambuco	Canhotinho	03/11/2022	16/11/2022	17.3	30.5	23.9	12.46
			Petrolina	26/05/2022	03/06/2022	14.5	32.2	23.4	11.46
	Midwest	Mato Grosso do Sul	Dourados	15/10/2021	25/10/2021	14.7	35.7	25.2	12.82
		Santa Catarina	Brunópolis	31/03/2021	04/14/2021	1.7	28.5	15.1	11.39
			Curitibanos	08/09/2022	05/10/2022	0.9	25.8	13.4	12.56
			Herval D'Oeste	29/01/2021	08/02/2021	9.5	33.3	21.4	12.63
				26/02/2021	06/03/2021	4.0	33.3	18.6	12.00
				22/03/2021	29/03/2021	4.0	30.5	17.2	11.31
			Rio do Sul	29/03/2021	09/04/2021	2.8	27.4	15.1	12.00
		Rio Grande do Sul	Santa Maria	06/08/2020	17/08/2020	-0.9	34.5	16.8	11.64
				22/01/2021	30/01/2021	12.7	35.0	23.8	13.09
				26/02/2021	06/03/2021	9.8	35.0	22.4	12.05
				11/05/2021	01/06/2021	-0.6	35.1	17.2	10.21
				08/06/2021	02/07/2021	-0.6	35.1	17.2	10.60
				02/07/2021	16/07/2021	-0.6	35.1	17.2	10.89
				07/09/2021	24/09/2021	-0.6	35.1	17.2	12.53
				15/10/2021	26/10/2021	6.0	37.7	21.8	13.14
				27/01/2022	04/02/2022	9.6	37.7	23.6	13.40

				08/08/2022	25/08/2022	1.2	32.3	16.8	11.90
			Júlio de Castilhos	17/03/2021	23/03/2021	0.0	30.3	15.1	11.29
				15/04/2021	25/04/2021	0.0	30.3	15.1	10.85
			Novo Xingú	23/09/2021	05/10/2021	16.0	30.0	23.0	12.81
				09/10/2021	21/10/2021	16.0	30.0	23.0	13.10
				25/10/2021	10/11/2021	16.0	30.0	23.0	13.51
				16/11/2021	30/11/2021	16.0	30.0	23.0	13.73
			Boa Vista do Sul	12/03/2022	22/03/2022	4.3	32.0	18.1	11.52
			Bozano	27/01/2023	03/02/2023	6.6	36.4	21.5	13.01
				03/02/2023	10/02/2023	6.6	36.4	21.5	12.75
				10/02/2023	17/02/2023	6.6	36.4	21.5	12.57
				17/02/2023	24/02/2023	6.6	34.3	20.4	12.30
			Vacaria	03/04/2023	13/04/2023	-2.0	27.0	12.5	10.85
Italy	Tuscany	Pistoia	Pescia	28/02/2023	17/03/2023	0.5	32.7	16.6	12.96

Table 3. Means of phyllochron (°C day leaf^{-1}) for the single factor planting methods and for the two-factor interaction genotype x phyllochron phases (from V1 to FLN ($\text{PHYL}_{\text{single}}$), phyllochron from V1 to V6 stages ($\text{PHYL}_{\text{early}}$), and phyllochron from V7 to FLN ($\text{PHYL}_{\text{late}}$)) of six cut sunflower genotypes, in planting methods trial in Santa Maria, RS, Brazil, 2020.

Single factor: planting methods			
	Direct sowing	**Transplanting**	**p-value**
Phyllochron	27.38 B	29.15 A	0.0
Two-factor interaction: genotype x phyllochron phases			
Genotype	**$\text{PHYL}_{\text{single}}$**	**$\text{PHYL}_{\text{early}}$**	**$\text{PHYL}_{\text{late}}$**
AG-01	25.93 aB*	41.76 aA	22.96 aC
AO-02	23.78 aB	37.39 bcA	22.17 abB
MO-03	25.75 aB	39.64 abA	22.39 abC
SO-06	25.07 aB	38.55 abA	23.91 aB
VO-09	23.87 aB	34.34 cA	19.36 bC
VT-11	24.49 aB	34.11 cA	23.28 aB
CV (%)**	8.3	**p-value**	0.0005

* Means followed by the same lower case letters in columns and upper case letters in rows are note different according to the Tukey test at $p < 0.05$.

** Coefficient of variation.

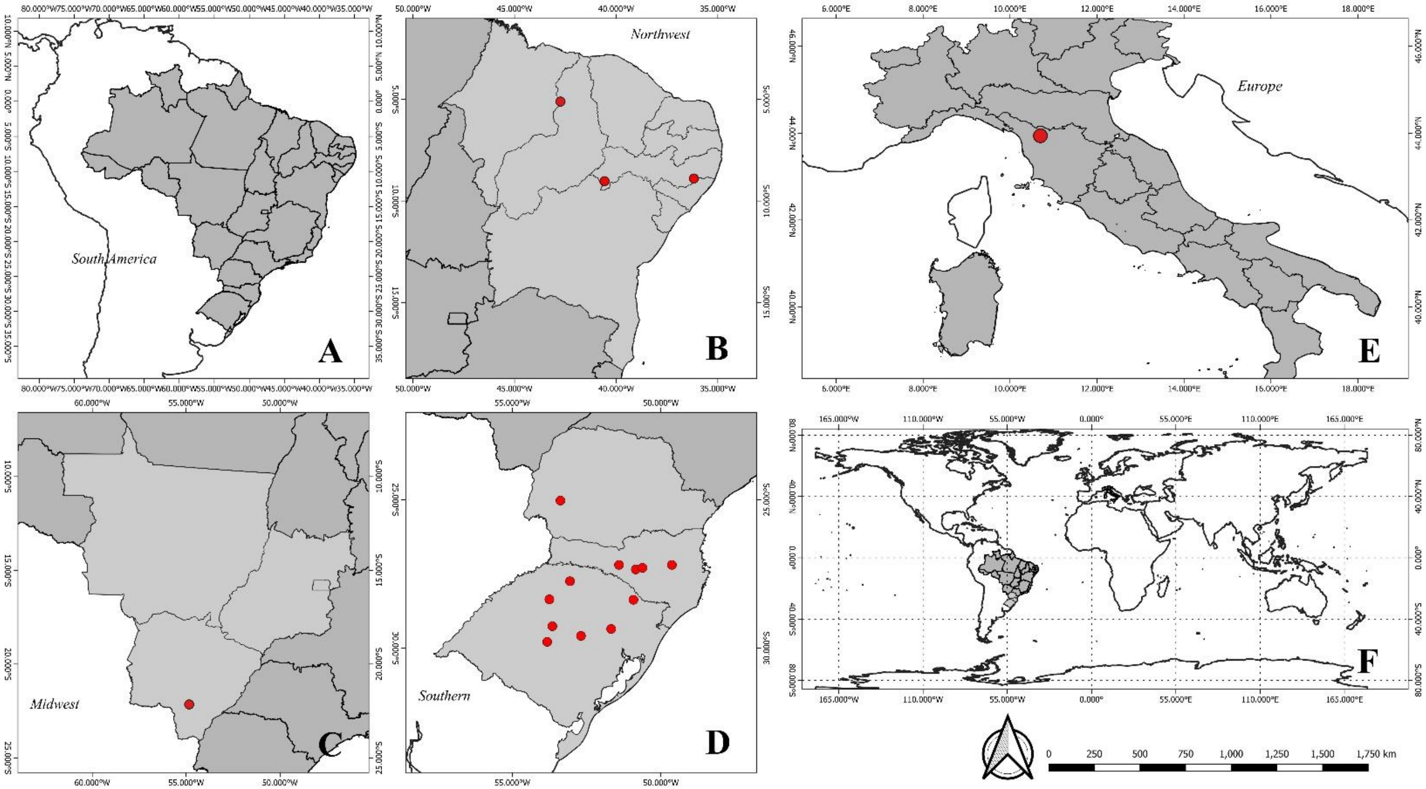


Fig. 1. Geographic location of the field on farm trials with cut sunflower genotypes conducted in three regions of Brazil, South America (A): (B) Northwest, (C) Midwest and (D) South, and in (E) Tuscany, Italy, Europe. World map in panel (F).

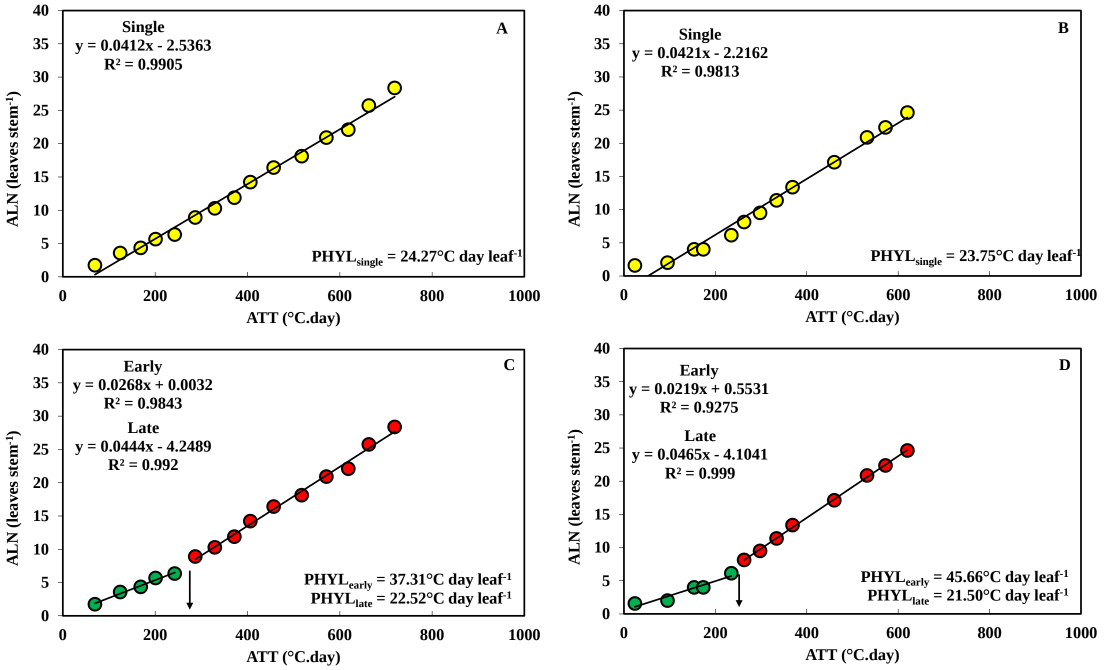


Fig. 2. Relationship between the accumulated leaf number on the stem (ALN, leaves stem^{-1}) and accumulated thermal time (ATT, °C day) for (A, C) the cut sunflower hybrid Amalfi Orange in the 06/08/2020sowing date at Santa Maria - RS, Brazil, and (B, D) the cut sunflower hybrid Amalfi Golden in the 28/02/2023sowing date at Pescia – Tuscany, Italy. Panels A and B indicates the Single phyllochron (yellow circles), and panels C and D indicates the Early phyllochron (green circles) and Late phyllochron (red circles).

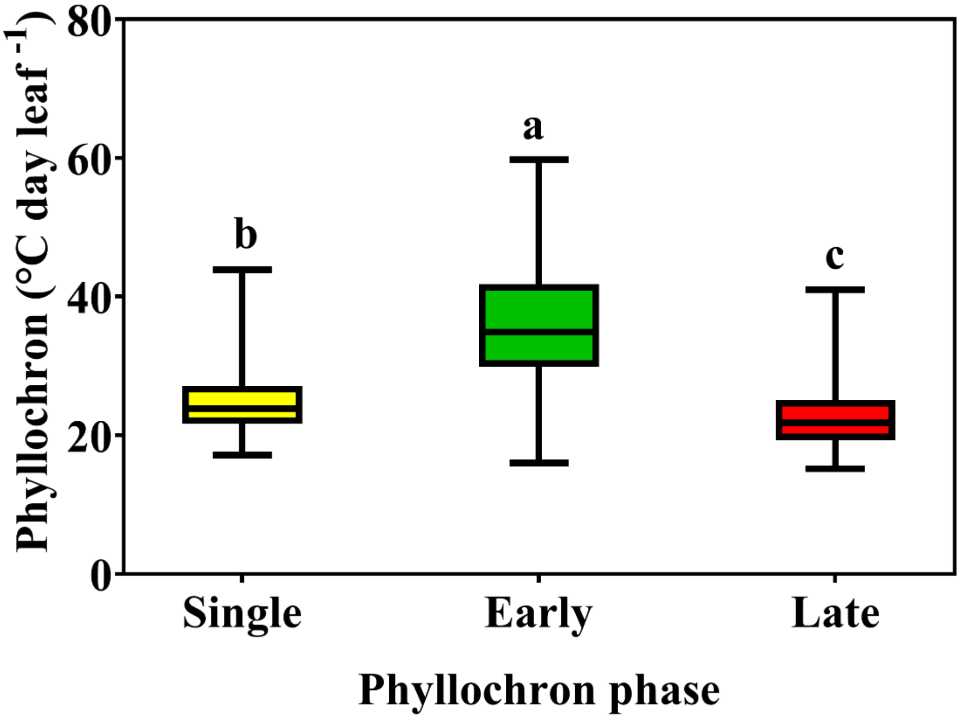


Fig. 3. Box plots demonstrating the phyllochron phases for cut sunflower, in °C day leaf^{-1}, pooling data collected in field on farm trials in Brazil (2020-2023) and Italy (2023). Solid line inside the boxes indicate the median. Different lower-case letters are different according to Post Doc Dunn Test at 5% probability.

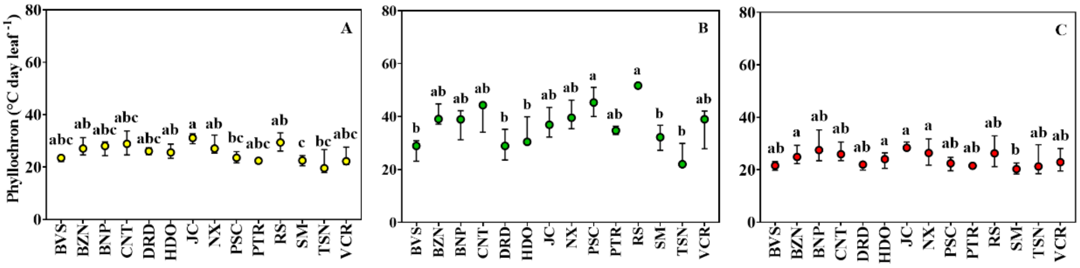


Fig. 4. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing location for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). Locations: BVS (Boa Vista do Sul/RS), BZN (Bozano/RS), BNP (Brunópolis/RS), CNT (Canhotinho/PE), DRD (Dourados/MS), HDO (Herval D'Oeste/SC), JC (Júlio de Castilhos/RS), NX (Novo Xingú/RS), PSC (Pescia, Italy), PTR (Petrolina/PE), RS (Rio do Sul/SC), SM (Santa Maria/RS), TSN (Teresina, PI) and VCR (Vacaria/RS). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

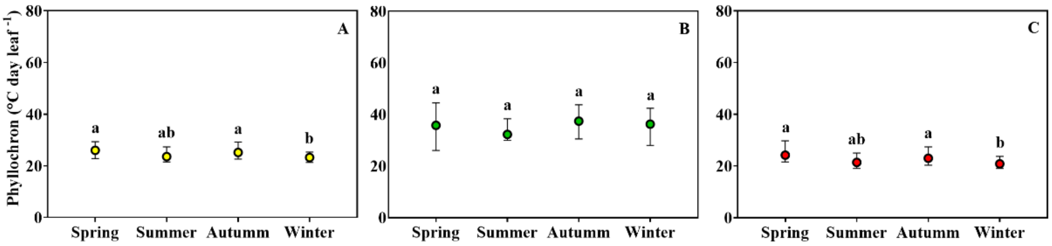


Fig. 5. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing Seasons (Spring, Summer, Autumm, and Winter) for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

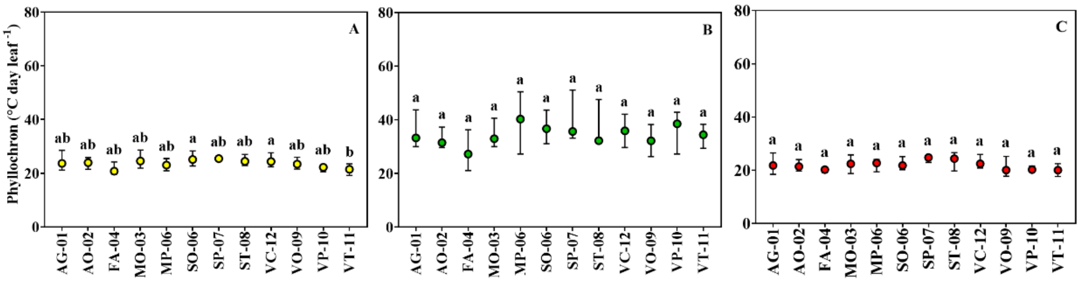


Fig. 6. Median of phyllochron with interquartile range for cut sunflower, in °C day leaf^{-1}, comparing genotypes for each phyllochron phase (A - single phyllochron, B – early phyllochron and C – late phyllochron), from data collected in field grown trials in Brazil (2020-2023) and Italy (2023). The different lower-case letters within each panel are different according to Post Doc Dunn Test at 5% probability.

3.3 CAPÍTULO 3 – FLOWER DEVELOPMENT AND YIELD OF FIELD GROWN STATICE AS A FUNCTION OF TRANSPLANTING DATE AND LOCATION IN A SUBTROPICAL ENVIRONMENT

(Será submetida à *South African Journal of Botany*, portanto as normas estão de acordo com as diretrizes exigidas)

FLOWER DEVELOPMENT AND YIELD OF FIELD GROWN STATICE AS A FUNCTION OF TRANSPLANTING DATE AND LOCATION IN A SUBTROPICAL ENVIRONMENT

Regina Tomiozzo[1], Leosane Cristina Bosco[2], Lilian Osmari Uhlmann[1], Otavio Bagiotto Rossato[3], Alexandra Goede de Souza[4], Soeni Bellé[5], Jenniffer Aparecida Schnitzer-Ribeiro[5], Cleber Maus Alberto[6], Luana Fernandes Tironi[7], Thais Pires Roso[1], Felipe Luan Port[3], Gabrieli Wasilkosky[4], Nicolly Carrazoni Tavares[6], Alencar Junior Zanon[1], Nereu Augusto Streck[1]

[1] Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brasil.
[2] Universidade Federal de Santa Catarina (UFSC), Campus Curitibanos/SC, SC, Brasil.
[3] Instituto Federal Catarinense (IFC), Campus Concórdia/SC, SC, Brasil.
[4] Instituto Federal Catarinense (IFC), Campus Rio do Sul/SC, SC, Brasil.
[5] Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul (IFRS), Campus Bento Gonçalves, RS, Brasil.
[6] Universidade Federal do Pampa (UNPAMPA), Campus Itaqui/RS, RS, Brasil.
[7] Empresa de Assistência Técnica e Extensão Rural (Emater/RS-Ascar), Santa Maria, RS, Brasil

Correspondence
Regina Tomiozzo
Email: re.tomiozzo@gmail.com
Nereu Augusto Streck
Email: nstreck2@yahoo.com.br
Departamento de Fitotecnia, Centro de Ciências Rurais, Universidade Federal de Santa Maria (UFSM), Av. Roraima, 1000, 97105-900, Santa Maria, RS, Brazil.

Abstract

Limonium sinuatum Mill., commonly known as statice or sea lavender, is widely used as cut flower, fresh or dried. Flowering in statice occurs seasonally, requiring low non-freezing temperatures for vernalization, followed by a long-day photoperiod and temperatures between 22-27°C, being improved or prejudiced by the seedlings transplant date. The objective in this study was to describe the flowering pattern of the statice crop in the subtropics of Brazil, investigating factors that influence its reproductive phase. Through field studies conducted across multiple transplant dates and locations during 2020 and 2021 in Southern Brazil, two cultivars of statice (QIS Yellow and QIS Purple) were used to evaluate reproductive phase. Harvestings at R5 stage were performed weekly and grouped per square meter by week, starting on Sundays ending on Saturdays. Stem height, stem diameter, number of branches, and number of corymbs were recorded at each harvest. Photoperiod and vernalization days (VD) for each transplant date and location were calculated. The development of statice floral stems varied among cultivars, transplant dates and locations in days to flowering (45 to 243 days), harvest period (5 to 18 weeks), yield (33 to 180 stems/m^2) and parameters of quality in each harvest week. There is a pattern in the weekly production of statice, with a peak production that can last from 2 to 4 weeks, during which the production and quality of the flowers are higher. Beyond this period, these factors begin to decline as the end of the cycle approaches. Our results demonstrate that statice flower development and yield are intrinsically linked to the species' vernalization and photoperiod requirements and help farmers to choose the best moment to cultivate statice in subtropical environment. Furthermore, they provide guidance for farmers on conducting statice harvests aimed at producing high-quality and marketable flowers.

Keywords: *Limonium sinuatum* Mill., cut flower, temperature, vernalization, flowering, harvesting.

3.3.1 Introduction

Statice (*Limonium sinuatum* Mill.) is an herbaceous plant native to the Mediterranean Region, worldwide popular as a cut flower because of its high yield with low technological inputs and the versatility of its floral stems, which can be used both as fresh or dry flower in bouquets and flower arrangements, with long shelf life after harvest (Nataraj et al., 2009; Ciotta and Nunes, 2011). Therefore, statice is an excellent flower crop for diversifying flower production, providing resilience to farmers, and resulting in a positive financial impact. For these agronomic features, statice was introduced in the "Flowers for All" Project, the largest ongoing floriculture project in Brazil, which aims to diversify crops and profit for small landholder family farmers (Streck and Uhlmann, 2021, Uhlmann et al., 2019).

Flowering is the visual expression of the reproductive phase, and in statice the reproductive phase begins at the R1 stage (Heading), emitting numerous new stems sequentially in the rosette (Buffon et al., 2022). Statice inflorescences are raceme-corymbiform type (Blas, 1992), so that the main structure is characteristic of a raceme with alternate branches on the main stem, and each branch has one or more corymbs. The corymbs are the attractive part of the statice floral stem, composed of small spikes with spikelets that support the calyxes, with a papery appearance, which can have several colors such as yellow, white, blue, pink, and purple (Paparozzi, 1986; González-Orenga et al., 2021; Xu et al., 2021).

Flowering in statice is the result of a complex interaction between temperature, photoperiod, and vernalization (Wilfret, 1976; Pareja-Bonilla et al., 2024). As a consequence, statice farmers have to choose the right time of the year for planting to ensure flowering (Proietti et al., 2022). Air temperature is the main factor for the development of statice throughout its cycle, from germination to flowering, and can affect flowering in three different ways: through vernalization for flowering induction, by accelerating flowering with increasing temperature up to the optimum temperature for this phase, and by delaying the time to flowering with supra-optimal temperatures (Chen, 2005). Vernalization is the first pathway involved in statice flowering. Vernalization is defined as a requirement of plant exposure to low nonfreezing temperatures for inducing or accelerating plants to flower (Chang et al., 2010; Kim, 2020). Usually, the vernalization requirement for statice is fulfilled by exposing the seedlings to temperatures of 11 – 13 °C for three weeks (Shillo, 1976; Shillo and Zamski, 1985).

The second pathway involved in statice flowering is photoperiod. Statice is a facultative long-day plant so that photoperiod longer than 13 hours accelerate flowering (Shillo, 1976; Mattson and Erwim, 2005; Chen et al., 2010). The role of photoperiod in inducing flowering in statice only takes place after the vernalization requirements are met. As a consequence, flowering of statice will occur in the field when air temperature and photoperiod conditions are favorable in Spring, when photoperiod is greater than 13 hours and temperatures range from 22 to 27 °C (Shillo and Zamski, 1985).

Because of the vernalization and photoperiod requirements, statice production in Southern Brazil is seasonal. Sowing takes place in the Fall, plants remain in the vegetative phase during the Winter when temperatures are low and vernalizing, and flowering takes place in Spring (Cohen et al., 1995, Chang et al., 2010; Buffon et al., 2021). If the vernalization and photoperiod requirements are not fulfilled, flowering may not occur or may be delayed until environmental conditions are favorable.

Recent studies on flower development and yield of statice were not found in the literature and detailed studies on statice floral production with practical applications to farmers and consultants are necessary. Furthermore, as a cut flower, producing high-quality floral stems is crucial. Consequently, in addition to knowing the harvesting period of statice floral stems, it is essential to understand whether the stems produced during this period maintain a standard of quality or undergo changes throughout the harvest period that may decrease their aesthetic value. Thus, the objective in this study was to describe the flowering pattern of the statice cultivars in the subtropics of Brazil, investigating factors that influence its reproductive phase.

3.3.2 Material and Methods

3.3.2.1 Field studies

Two field trials were conducted during 2020 and 2021 in eight locations in Rio Grande do Sul (RS) and Santa Catarina (SC) States, Southern Brazil (Figure 1A). The sites represent the main area of statice production in open field in Brazil and have subtropical climates (Cfa and Cfb according to the Köppen climate classification) that provide the necessary temperature and photoperiod conditions for flowering induction.

Seeds of *Limonium sinuatum* from Pan American Seeds® of two cultivars, QIS Yellow and QIS Purple, were sown in 128-cell plastic trays containing commercial substrate. After sowing the trays were kept in a protected and dark environment until seedlings emerged (cotyledons were above the substrate surface) and afterwards were transferred to a greenhouse covered with transparent plastic and open sides, where they remained until transplanting. The seedlings were regularly irrigated and fertilized with $NP_2O_5K_2O$ 13-40-13 (1 g L^{-1} of water) once a week.

The area for growing the statice in each location was previously prepared with pH correction and beds of 1m wide, 9 m long and 0.25 m height were built. Seedlings were transplanted to open field beds when they had 8 leaves and a well-structured root system. Plant spacing was 0.5 m between rows and 0.3 m among plants within rows, with two rows per bed and a plant density of 6.7 plants m^{-2}. On the day of transplanting, fertilization was applied with $NP_2O_5K_2O$ 05-20-20 at a rate of 250 kg ha^{-1} and urea at a rate of 100 kg ha^{-1}. Irrigation was done by drip and management practices such as pest, disease, and weed control were carried out as needed to keep plants free of biotic and abiotic factors. The experimental design was a randomized complete block design with three replications and two cultivars. Each replicate was a plot of 1.5 m in length with ten plants.

Trial 1 was conducted during 2020 – 2021 at the Federal University of Santa Maria located in Santa Maria/RS, Brazil, with 12 monthly sowing and transplanting dates, from August 2020 until August 2021 (Table 1). The sowing was done 30 to 60 days before the desired transplant date. The experimental design was a randomized complete block design with three replications in a bifactorial scheme (twelve transplanting dates and two cultivars).

Trial 2 was a multilocation trial conducted in eight locations distributed across the states of Santa Catarina and Rio Grande do Sul, in Southern Brazil (Figure 1). The seedlings for this trial were produced in Santa Maria/RS, with sowing on May 29th, 2020. When the seedlings reached 6 – 10 true leaves, approximately 60 days after sowing, they were sent to each location where the transplanting was carried out. Transplanting dates are presented in Table 1. In Dilermando de Aguiar/RS, cultivation was conducted in two different farms. In Itaqui/RS, a trial was conducted with supplemental irrigation and without irrigation, using the same experimental design, but in a bifactorial scheme (water regime and cultivars).

3.3.2.2 Data collecting and statistical analysis

Six plants were tagged in each plot and the date of the phenological stages R1.1 (first floral stem visible on the center of the rosette, Buffon et al., 2022) and R5.1 (all flowers opened on the first floral stem, Buffon et al., 2022) were collected on the tagged plants. The percentage of plants that initiated the reproductive phase (%R1.1) was calculated based on the total number of tagged plants. This percentage was divided into two periods: plants that initiated the reproductive phase until March 20, 2021, and plants that initiated the reproductive phase after March 20, 2021. After, the total This date was chosen because is the beginning of the Autumn Equinox in the Southern Hemisphere when temperatures and photoperiod begin to decrease and are not favorable for statice flowering.

Floral stems were harvested when they reached the R5 stage (100% of the flowers on the corymb are open, Buffon et al., (2022)). Harvests were carried out once or twice a week depending upon the location and week of the year. Harvestings were grouped by week, starting on Sundays ending on Saturdays. The amount of floral stems harvested per week was accumulated and flower production was presented both as weekly number of floral stems per square meter and accumulated number of floral stems per square meter. Week of harvest was positioned as week of the year from 1 to 52 (2020) and 53 (2021). The harvests of *Trial 1* were all concluded in December 2021. In Júlio de Castilhos/RS, only phenological data were collected and harvestings were not recorded.

At each harvest, flower production components such as the stem length, stem diameter at 1 centimeter from the cutting, number of branches, and number of corymbs were recorded. Figure 2 illustrates what was considered a corymb and a branch on the statice floral stem. The flower production components were also assessed weekly to demonstrate their variation throughout the harvests and in each transplanting date and location. The harvest period was positioned from 1 to the last week of harvesting, independent of the week of the year. Error bars were included for each harvest week. Linear regression was applied at 5% of probability by Test F, to assess the relationship between the flower production components.

At the end of the harvest period, the yield per square meter (stems/m2) was calculated. Likewise, the yield per plant (stems/plant) was also calculated and assessed by ANOVA and compared using Tukey’s test, at a 5% probability of error, using SAS Analytics Software.

3.3.2.3 Photoperiod and vernalization

Statice is a species dependent on photoperiod and vernalization for flowering. Daily photoperiod was calculated using the approach by Keisling (1982) with a twilight of 6°. The photoperiod was calculated for each location throughout the entire period in which the statice plants remained in the field. Additionally, the effective vernalization days (VD) accumulated for each transplant date and location was calculated. VD indicates the duration of exposure to vernalizing temperatures starting from the optimal vernalization temperature, accumulating only a fraction of VD on a calendar day. For the calculation of VD, the daily vernalization rate [fvn(T)] was calculated using a beta function (Wang & Engel, 1998; Streck, 2003; Streck et al., 2003a; Alberto et al., 2009):

$$fvn(T) = [2(T-T_n)^{\alpha} (T_{ot} - T_n)^{\alpha} - (T-T_n)^{2\alpha}]/(T_{ot} - T_n)^{2\alpha} \text{ for } T_n, T, T_x$$

$$fvn(T) = 0 \text{ for } T < T_n \text{ or } T > T_x$$

$$\alpha = \ln 2/\ln [(T_x - T_n) / (T_{op} - T_n)]$$

where Tn, Tot, and Tx are the minimum, optimum, and maximum cardinal vernalization temperatures, T is the daily average temperature at which vernalization was performed, and ln is the natural logarithm. Since there is no information available on the cardinal vernalization temperatures for statice in the literature, the cardinal vernalization temperatures for lily cultivation were considered, which are Tb = -1.5°C, Tot = 5°C, and TB = 21°C (Streck 2002, Streck and Schuh, 2005). The VD was calculated by accumulating the daily vernalization rates.

VD was calculated for three different periods during statice development. First, VD was calculated from the day after sowing until the day of transplanting [VD(SO-TP)]. The statice seedlings for *Trial 2* were produced in Santa Maria and VD (SO-TP) was calculated using the meteorological data from this location. From transplanting onwards, data from the corresponding location of cultivation were used. Then, VD was calculated from the day after transplant until the occurrence date of the R1 stage [VD(TP-R1)]. Finally, the total VD was calculated from the day after sowing until the occurrence date of the R1 stage [VD(SO-R1)]. Standard deviation (SD) and coefficient of variation (%) were calculated for VD values.

The maximum and minimum air temperature data used for VD calculation were collected from May 2020 to December 2021 (*Trial 1*) and July 2020 to January 2021 (*Trial 2*), from the automatic weather stations of the National Institute of Meteorology (INMET) in Santa Maria/RS, Bento Gonçalves/RS, Uruguaiana/RS, Joaçaba/SC, Curitibanos/SC, and Ituporanga/SC. Meteorological station located in Santa Maria, represented the climate for *Trial 1* at Santa Maria and *Trial 2* at Santa Maria/RS and Dilermando de Aguiar/RS farms. Bento Gonçalves represents the climate in Pinto Bandeira/RS, and Uruguaiana represents the climate of Itaqui/RS. Joaçaba, Curitibanos/SC and Ituporanga represent the climates in Concórdia/SC, Curitibanos/SC and Rio do Sul/SC, respectively. Daily precipitation was also registered for each transplanting date and location. Accumulated precipitation was calculated through the sum of daily precipitation from transplanting date to the last harvest week.

3.3.3 Results

3.3.3.1 Meteorological data

The two field trials in different locations and transplanting dates exposed statice plants to a wide range of temperature, precipitation, and photoperiod (Figure 3). In Santa Maria/RS during *Trial 1* air temperature varied from -1.8 to 38.8°C, and photoperiod varied from 10h to 14h during Winter and Summer, respectively (Figure 3A). In *Trial 2* air temperature ranged from -0.9 to 38.8°C in Santa Maria/RS and Dilermando de Aguiar/RS (Figure3B), from -2.4 to 38.8°C in Júlio de Castilhos/RS (Figure 3C), from -0.6 to 38.3°C in Itaqui/RS (Figure3D), from -1.3 to 35.3°C in Pinto Bandeira/RS (Figure 3E), from 1.1 to 36.8°C in Concórdia/SC (Figure 3F), from 1.1 to 33.2°C in Curitibanos/SC (Figure 3G), and from -2 to 34.5°C in Rio do Sul/SC (Figure 3H). Since cultivation occurred with plantings at the end of July or early August 2020 in all locations, the same trend of increasing both average air temperature and photoperiod was observed in all locations. This is the time of year when conditions are favorable for statice flowering in Southern Brazil.

Precipitation also plays an important role in statice production, so that three or more rainy days in a row may decrease flower quality and favor diseases like Botrytis. Accumulated precipitation in *Trial 1* varied among transplanting dates. In August/2020, September/2020, and October/2020 the precipitation was 263.3 mm, 189.8 mm, and 175.83, respectively. November/2020 and December/2020 accumulated 126.0 mm and 284.9 until the last harvest of the cultivar QIS Yellow, and 898.9 mm and 776.9 until the last harvest of the cultivar QIS Purple, respectively. From January/2021 to August/2021, the precipitation decreased steadily as 1271.8 mm, 1062.2 mm, 1016.8 mm, 921.2 mm, 694.2 mm, 565.2 mm, and 531.6 mm. In *Trial 2,* the meteorological station that represents Santa Maria/RS and Dilermando de Aguiar/RS registered an accumulated precipitation of 629.3 mm. In Júlio de Castilhos/RS, 632 mm was registered and 674.8 mm in Pinto Bandeira/RS. Itaqui/RS registered the lowest precipitation, with 579.4 mm. Locations in Santa Catarina state registered the highest precipitation, with 950.4 mm, 945.4 mm, and 881.0 mm for Concórdia/SC, Rio do Sul/SC e Curitibanos/SC, respectively.

3.3.3.2 Vernalization days

In *Trial 1* there was a reduction in vernalization days (VD) from the sowing to the transplanting (SO-TP) phase from August/2020 (34.57 VD) to March/2021 (6.55 VD) and an increase from March/2021 to August/2021 (48.82), with coefficient of variation equal to 67.76% (Table 2). The VD from the transplanting to R1 phase [VD(TP-R1)] decreased from August/2020 (9.95 VD) to November/2020 (1.91 VC) for the cultivar QIS Yellow and from August/2020 (22.19 VD) to October/2020 (11.85 VD) for the cultivar QIS Purple. This occurred because statice was cultivated during a transition period from Winter to Spring (August and September) and subsequently from Spring to Summer (October, November, and December). In Spring, air temperature began to rise, accumulating fewer days with vernalizing temperatures towards the end of each crop cycle. In December/2020 (3.94 VD), there was a slight increase in VD(TP-R1) compared to November/2020 (1.91 VD) for QIS Yellow.

Sowing and transplanting of statice in November/2020, December/2020, and January/2021, February/2021 were considered "off-season" as the air temperature was high, not providing temperatures low enough for vernalizing statice plants, and the photoperiod was already inductive (higher than or equal to 13 hours). Therefore, plants transplanted during these months required a longer period to accumulate the necessary vernalization days to enter the reproductive phase, thus extending the developmental cycle. March/2021 and April/2021 are again positioned in a transition period, this time from Summer to Autumn. This is a time of the year when conditions in Southern Brazil reverse so that photoperiod and temperature begin to decrease, providing the necessary conditions for vernalization.

Transplanting during the "off-season" exhibited high VD(SO-R1), such as 94.29 VD for QIS Purple in November/2020.

In *Trial 2*, VD(SO-TP) varied among locations, from 31.54 to 36.20 VD (CV = 4.60%), due to the different transplanting dates. After transplanting, VD(TP-R1) presented the highest variations, from 10.36 to 19.86 for QIS Yellow (CV = 25.92%) and from 18.09 to 25.99 for QIS Purple (CV = 12.40%). Thus, VD(SO-R1) varied from 43.73 to 52.48 VD for QIS Yellow (CV = 6.81%) and 52.44 to 59.93 VD for QIS Purple (CV = 5.17%). In general, QIS Purple demonstrated higher vernalization requirements compared to QIS Yellow, except for January/2021 (50.73 VD) and March/2021 (54.76 VD). This indicates that the QIS Purple cultivar is more demanding in vernalization compared to the QIS Yellow cultivar.

3.3.3.3 Days to flowering

Time from transplanting to flowering varied between transplanting dates (Figure 4A) and locations (Figure 4B). Transplanting during “off-season” had a longer vegetative phase compared to the transplanting during Autumm-Winter season. Consequently, more days until the first harvest were observed. Variations across cultivars were also verified, especially on November/2020 and December/2020 transplanting, when time to flowering was 45 and 50 days for QIS Yellow and, 260 and 191 days for QIS Purple, respectively. Variations were also observed between locations and cultivars (*Trial 2*) so that QIS Purple presented need longer time to flowering than QIS Yellow in Rio do Sul/SC, Curitibanos/SC, Júlio de Castilhos/RS, and Itaqui/RS – Irrigated.

3.3.3.4 Percentage of plants reaching R1 Stage

Table 3 presents the percentage of plants that reached the reproductive phase (%R1) at two times of the year: until March 20 and after March 20. The %R1 in *Trial 1* varied between cultivars and transplanting date. In transplantings during the months of August/2020, September/2020, October/2020, and June/2021, July/2021 and August/2021, 100% of the plants of both cultivars reached the reproductive phase. However, plants transplanted from November/2020 to February/2021 did not reach 100% R1 until March 20th. All QIS Yellow plants from November/2020 and December/2020 flowered by March 20th, indicating that the vernalization requirements were met for these plants. However, for QIS Purple plants, only 16.6% in November/2020 and 33.3% in December/2020 reached the reproductive phase until March 20th. The highest percentage of flowering for this cultivar occurred after March 20th, totaling 72.2% and 61.1%, respectively.

The low %R1 for "off-season" crops occurred due to the extended period that the plants remained in the field. The statice plants underwent senescence, primarily due to the heat in the early days after transplanting during the Summer months. Therefore, the low %R1 percentage is more related to plant survival than to vernalization itself. The QIS Yellow cultivar was the most affected by plant loss, indicating its greater sensitivity compared to QIS Purple. In *Trial 2*, 100% of the plants entered the R1 stage at all sites. In Itaqui/RS, in the non-irrigated cultivation, the percentage of plants in R1 was 88.9% for QIS Yellow and 94.4% for QIS Purple, due to plant mortality. In Santa Maria/RS, there was a loss of only one QIS Purple plant.

3.3.3.5 Statice flowers development

Morphologically, a statice plant presents several axillary buds that will give rise to floral stems, which develop successively, alternating at the center of the rosette (Buffon et al., 2021a). Thus, floral stems reach the harvest point (R5 stage) at different times during flowering, which can last for several weeks. This period is referred to as the "harvest period", which is depicted for different transplant dates in Figure 5. The duration of this period will depend on the transplant date and the number of floral stems emitted by the plant.

Harvest period for August/2020, September/2020 and October 2020 started at the week 43, 45, 47 of the year 2020 and last 14 and 15, 13 and 13, 13 and 10 weeks, respectively, for QIS Yellow and QIS Purple (Figure 5A, 5B and 5C). Transplanting in November/2020 and December 2020 presented two harvest periods (Figure 5D and 5E). The first one started right after transplanting QIS Yellow, at the week 51 of 2020 for November/2020, lasting 15 weeks, and at the week 5 of 2021 for December/2020, lasting 12 weeks. The second one started at week 35 and 36 for the QIS Purple cultivar, lasting 18 and 18 weeks, respectively. This division in the harvest period during these two times of the year occurred due to the vernalization requirement of each cultivar and whether it was met or not. Additionally, the weekly production was lower than in the initial three months of cultivation.

The next months synchronized the flowering period after winter. Harvests from transplants in January/2021 (Figure 5F), February/2021 (Figure 5G), March 2021 (Figure

5H) began only at weeks 36, 35, 35 of the year 2021, remaining 9 and 17, 9 and 17, 12 and 18 weeks for QIS Yellow and QIS Purple, respectively. Throughout the period, the plants remained vegetative and excessively increased the number of leaves (data not shown). Harvests of April/2021 began at week 36 and lasts 13 weeks for QIS Yellow (Figure 5I). June (Figure 5J) and July/2021 (Figure 5K) harvesting started at week 39 and 40, remaining 12 and 11 weeks for QIS Yellow and 14 and 13 weeks for QIS Purple. Agosto/2021 (Figure 5L) was less productive and with a shorter harvest period than August/2020. Therefore, it is observed that the main effect in the production of statice floral stems is the distribution of production. Weekly production starts small, increasing until it reaches a peak, and then gradually decreases until floral stem production completely ceases.

The same response was observed in the trials conducted during 2020 in seven locations of *Trial 2* (Figure 6). In Júlio de Castilhos/RS, data about harvesting was not recorded. In the on-farm trial conducted Itaqui/RS with irrigation (Figure 6A) and without irrigation (Figure 6B), the harvest period started at week 42 and lasted for eight weeks for irrigated statice and started at week 43 and lasted for seven weeks for non-irrigated, with a reduction in production from the fourth week onwards. Curiously, the harvest period also starts at week 43, from 18 to 24 October/2021, for all other locations. Dilermando de Aguiar/RS, Pinto Bandeira/RS, and Santa Maria/RS, the experiments were conducted on-farm, with the first location on two different farms. At Farmer 01 (Figure 6C) in Dilermando de Aguiar/RS, the harvest period lasted for 10 weeks, unlike Farmer 02 (Figure 6D), where this period lasted only seven weeks.

Pinto Bandeira/RS presented a reduced harvest period (Figure 6E), with only five weeks. However, in this location, harvests were conducted every two weeks, justifying the reduction in the harvest period. Figure 6F demonstrates that in Santa Maria/RS, the harvest period was eleven weeks. Despite the difference in the harvest period among locations in Rio Grande do Sul, the same peak and decline production behavior can be observed throughout the weeks. The harvest period in the trials conducted in Santa Catarina are presented in Figures 6G, 6H and 6I. Concórdia/SC showed eight weeks of harvest (Figure 6G) and Curitibanos/SC, eleven weeks (Figure 6H). In Rio do Sul/SC statice flowers were harvested during seven weeks (Figure 6I). Similar to Rio Grande do Sul, the peak and decline production behavior in Santa Catarina followed the same pattern.

3.3.3.6 Yield

Just as the %R1 and VD decreased with the increase in mean air temperature, a reduction in the production of statice flowers was also observed (Figure 7A). To identify the occurrence of this reduction, only harvests conducted until March 20 were considered. For QIS Yellow, there was a reduction from 176 stems/m² to 18 stems/m², and for QIS Purple, from 146 stems/m² to 4 stems/m² for the August/2020 and December/2020 periods, respectively. The slope of the linear regression shows that for each month the transplant date is delayed, there may be a reduction of 43.18 stems/m² for QIS Yellow and 38.56 stems/m² for QIS Purple. This reduction in stem production is related to the reduction in VD for each period; thus, the lower the VD, the lower the production of floral stems in the crop. An important observation is that even if 100% of the plants in the August/2020, September/2020, and October/2020 periods initiated the reproductive phase, the production differed in these three periods.

On the other hand, an increase in productivity was identified starting from March 20 in the off-season plantings, from November/2020 to March/2021 (Figure 7B). Productivity increased from 5 to 85.33 stems/m² for QIS Yellow and from 60 to 175.67 stems/m² for QIS Purple. The angular coefficient of the linear regression shows that for each month the transplant date advance, there may be an increase of 17.87 stems/m² for QIS Yellow and 28.2 stems/m² for QIS Purple. This increase in production occurred because the plants that remained in the field only entered the reproductive phase after the passage of winter, during which the remaining plants naturally underwent vernalization, producing floral stems starting from week 35 of 2021.

The yield of statice (stems/m²) varied significantly among transplant date and locations (Figure 8). ANOVA analysis showed significative interaction between transplant dates x cultivars (p = 0.044) and locations x cultivars (p = 0.0039). QIS Yellow yield for August 2020 (176 stems/m²) and QIS Purple yield for March 2021 (179 stems/m²), demonstrate to be significantly superior compared to the others transplant dates carried out. Yield during off-season was the lowest, in November/2020 and December/2020. Tukey's test also demonstrated that the highest productivities in Rio Grande do Sul were Santa Maria/RS and in Santa Catarina, in Concórdia/SC. In Dilermando de Aguiar/RS, differences in the harvest period were observed between Farmer 01 and Farmer 02, but yields were similar for QIS Yellow and differ for QIS Purple. The lowest yield was verified in Rio do Sul/SC for both cultivars. Yield did not differ statistically between irrigated and non-irrigated field grown in Itaqui/RS. Thus, a longer harvest period may not necessarily be synonymous with higher yield. Among yield per plant, significative interaction between transplanting dates x cultivars (p = 0.0223) and locations x cultivars (p = 0.0234) was founded by ANOVA. The number of stems per plant showed differences through Tukey's test, varying from 6.63 stems and 30.52 stems/plant for QIS Yellow and 11.76 stems to 35.67 stems/plant in *Trial 1.* As expected, locations in *Trial 2,* also demonstrated differences significantly. The lowest yield was calculated in Rio do Sul/SC (9.73 and 5.20 stems/plant) and the highest yield in Santa Maria/RS (31.60 and 26.04 stems/plant) for both cultivars studied.

3.3.3.7 Flower production components

The flower production components studied are presented heatmaps demonstrating their variation along the harvest weeks for *Trial 1* (Figure 9) and *Trial 2* (Figure 10). Just as there is variation in production throughout the harvest period, flower production components also varied. The highest values of production components are observed during the period considered as the peak of production. During this peak, the production components are potentialized, but the timing of this peak differs between transplant dates, cultivars, and locations. For example, stem length for August/2020, September/2020, October/2020, this moment occurs during the 3rd to 6th harvest weeks for both QIS Yellow (Figure 9A) and QIS Purple (Figure 9B). However, for other transplant dates such as March/2021 and April/2021, this peak was later, occurring between 3rd to 8th harvest weeks for QIS Purple. Production peaks also occurred between locations, with higher values of stem length, stem diameter, number of branches, and number of corymbs mostly during the 2nd to 6th harvest weeks (Figure 10), varying with the number of harvest weeks. As the harvest period progresses, these values begin to decrease until the latest harvest.

The relationship between flower production components is presented in Figure 11, When relating production components, it is observed that there is a significant positive linear relation between stem diameter and stem length, despite the low coefficient of determination (QIS Yellow = 0.545, Figure 11A and QIS Purple = 0.4396, Figure 11B). The same significant result was also verified among the other relationships tested, as: number of branches and stem length (QIS Yellow = 0.4151, Figure 11C and QIS Purple = 0.3779, Figure 11D), number of corymbs and number of branches on the floral stem (QIS Yellow =

0.7506, Figure 11E and QIS Purple = 0.8044, Figure 11F) and between number of branches and stem diameter (QIS Yellow = 0.4519, Figure 11G and QIS Purple = 0.4683, Figure 11F).

3.3.4 Discussion

Brazil is a country with a wide territorial extension, and statice can only be field-grown in the Southern region or in areas with altitudes above 1000 m, where nighttime temperatures are lower than or equal to 15°C, meeting the vernalization requirements of statice. The different transplanting dates provided a wide variation of temperature and photoperiod throughout the years 2020 and 2021, both during the "off-season" and during the optimal season for producing statice in the Subtropics of Brazil. Our results confirm that long days and cool night temperatures, by vernalization, play an important role in regulating the flowering process in statice (Semeniuk and Krizek, 1972). There was a penalty in the percentage of flowering plants, due to factors such as delayed flowering and plant death.

According to our outcomes, vernalization requirements of statice cultivar are established and demonstrate the differences between cultivars. QIS Yellow require less vernalization days than QIS Purple to flowering, been able to flower at high temperatures contrasting with the QIS Purple cultivar that requires more vernalization days to flower, as demonstrate by the November/2020 and December/2020 transplanting dates. Different colored cultivars of statice differ in vernalization requirements: yellow and white cultivars can flower at high temperatures while pink, lavender and blue cultivars require greatest vernalization period, as stated by Shillo and Zamski (1985).

Days to flowering are variable depending on cultivars and growing conditions, along with temperature increases during growth, a delay in the time to flowering occurs. (Wilfret et al., 1973; Semeniuk and Krizek, 1973). Yellow cultivars demonstrated to need less time for the first harvest. Transplanting in “off-season,” from November/2020 to February/2021, prolonged the vegetative phase due to temperature increase, delaying the flowering. Growing statice during this period was demonstrated to be not recommended, because developmental cycle is prolonged and there was a decrease in flowers production components and yield. High day/night temperatures inhibited or greatly reduce flowering while cool/night temperature promote flowering in statice (Krizek and Semeniuk, 1972). Cold requirement is one of the greatest challenges faced in tropical climate countries, and in Brazil, only Southern region have conditions, due to the subtropical climate, to naturally meet this demand. One option for this time of year is to provide vernalization artificially, as indicated by Buffon et al. (2021).

Yield demonstrated to be affected by environmental conditions, decreasing with exposure to high temperatures and increasing again after being appropriately vernalized with the onset of winter. Thus, off-season statice crops synchronize the flowering with in-season crops, with flowering in Spring. Synchronous flowering in all individual plants of a population at the same time of each year is controlled mostly by photoperiodic conditions, which is independent of seasonal and inter-annual variations in climate, and by vernalization response, a form of biological ensuring that flowering is repressed until the end of the winter months (Corbesier et al., 1996; Samach and Coupland, 2000; Borchert et al., 2005). Exposure to low temperatures not only promotes flowering through vernalization but also increases flower production as a consequence of a greater number of floral primordia being initiated (Semeniuk and Krizek, 1973), confirmed with our findings about yield per plant. A high number of floral primordia also contributes to the extension of the harvest period, as the onset of the R5 stage in each stem does not occur simultaneously, but rather sequentially (Buffon et al., 2022).

The low yield in transplanting in June/2021, July/2021, and August/2021 was related to the high accumulated precipitation during the harvest period in 2021 compared to the same period in 2020. For field grown statice, large amount of precipitation during the harvest period is the biggest problem associated with low yields and flower production components. Statice floral stems are extremely sensitive from the R4 stage (First flowers are open, Buffon et al., 2022) onwards. Due to the calyxes papery appearance, high humidity hinders the flower opening and reduces the production of marketable floral stems. Low plastic tunnels with metal-conduit hoops tall enough to cover the plant canopy and plastic-film possible to lift and clip the sides to venting, enable farmers to protect the statice flowers during this period for a low-cost investment (Rauter et al., 2021).

The flower production components are important in statice to define the quality of the marketable floral stems. A high or low floral stems quality depends on these components, varying throughout the harvest weeks and cultivars were found. In general, QIS Yellow has the longest stems than QIS Purple. Similar variations among cultivars were found by Whipker and Hammer (1994), Nataraj (2009) and Basumatary and Hatibarua (2023). A peak of production was observed, where in addition to producing more floral stems, stem length is also higher, as well as other production components such as stem diameter, number of branches, and number of corymbs. As demonstrated in Figs. 9 and 10, the stems meet Brazilian market standards for length, ranging from 40 cm to 90 cm (Veiling Holambra, 2020). This relationship is confirmed by the results presented in Figure 11. After this peak in production, there is a decrease in weekly production as well as a reduction in flower production components. Thus, statice floral stems harvested late have lower quality, corroborating with the results found by Whipker and Hammer (1994). This reduction in flower production components in later harvestings is associated with the natural life cycle of statice. Later harvestings occur at the end of the cycle, a moment when the number of leaves decreases significantly, reducing the leaf area for intercepting solar radiation, triggering a sequence of effects that will reduce the photosynthetic capacity of statice plants, resulting in lower yield and quality (Pettigrew, 2008). The exhaustion of nutrients available in the soil at the end of the harvest period also can be one factor that is interfering with the flower production components. When adequate nutrients, as phosphorus, are not provided, stem length is severely affected (Verdelin and McDonald, 2007), and consequently the other production components dependent on stem length, such as stem diameter and number of branches.

The findings from our study indicate practical results about flowering pattern of statice crop that can be applied to various realities of worldwide statice farmers, especially in Brazil. Brazilian flower market requires statice floral stems that meet the commercial quality standards (Ciotta and Nunes, 2007). These standards consider mainly stem length and number of branches for selecting the floral stems, by color or mixed, to compose the package for selling. Number of branches demonstrate to be dependent on stem length. Thus, stems with greater length have greater diameter, as well as stems with a greater number of branches have a greater number of corymbs, regardless of the cultivar. In general, larger stems with a higher ratio of branching to corymbs are desired, for improving the quality of the marketable stems. To meet these demands, the floral stems produced during the peak of production are better suited attending the commercial standards.

On the other hand, farmers from Southern Brazil, specially of Rio Grande do Sul and Santa Catarina states, produce field-grown statice and commercialize flowers locally, in floricultures, fairs or small markets. The distance and transportation costs to send their production to the major cooperatives are not viable for Southern producers, who are mostly small-scale family farmers with limited production areas. Therefore, the flowering pattern of statice and the versatility of its floral stems make its production a profitable business for these farmers. Local markets often do not require a specific commercial quality standard, and both shorter and longer stems can be marketed, of course maintaining the aesthetic quality and uniformity of these floral stems. In this way, the entire production can be utilized, from the first to the last harvest. The ability to use dried statice floral stems allows farmers to store them for a longer period, reducing losses if they are not sold quickly. Furthermore, shorter stems that are grown in the lasts weeks of harvesting can offer farmer other possibilities to supplement income, as the composing floral arrangements with dry flowers, opening up another business opportunity to sell the production and generate more profits for the family. For these reasons, statice has been a huge success in the "Flowers For All Project" (Streck and Uhlmann, 2021).

3.3.5 Conclusion

Challenges for statice flower production posed by subtropical climates, especially during the "off-season" were found. The development of statice floral stems varied among cultivars, transplanting dates, and locations. Harvest period revealed a peak in production that can last from 2 to 4 weeks, characterized by higher yield and production components, followed by a decline in later harvests. Overall, This study highlights the flowering pattern of the statice crop and underscores the importance of considering environmental factors in maximizing the statice production. It also provides guidance for farmers on choosing the best moment to cultivate statice in subtropical environment, facilitating statice harvests aimed at producing high-quality and marketable flowers.

Acknowledgements

The authors thank farmers for allowing measurements and observations on their statice crops. Authors thank The PhenoGlad Teams for helping in collecting data. Special thanks to CAPES – Ministry of Education and CNPQ – Ministry of Science and Technology (Proc. No. 308942/2020-5) for financial support.

Conflict of interest statement

The authors declare no conflicts of interest.

ORCID

Regina Tomiozzo: https://orcid.org/0000-0001-5498-3645
Leosane Cristina Bosco: https://orcid.org/0000-0003-2623-2590
Otavio Bagiotto Rossato: https://orcid.org/0000-0003-4877-9255
Alexandra Goede de Souza: https://orcid.org/0000-0002-0572-0205
Soeni Bellé: https://orcid.org/0000-0002-0704-7712
Cleber Maus Alberto: https://orcid.org/0000-0003-2496-5272
Lilian Osmari Uhlmann: https://orcid.org/0000-0001-9142-4201
Thais Pires Roso: https://orcid.org/0000-0002-4191-8681
Felipe Luan Port: https://orcid.org/0009-0009-2277-3657
Gabrieli Wasilkosky https://orcid.org/0000-0001-7217-8789
Nicolly Carrazoni Tavares: https://orcid.org/0009-0002-0638-4458
Nereu Augusto Streck: https://orcid.org/0000-0002-2495-0823

3.3.6 References

Alberto, C. M., Streck, N. A., Walter, L. C., Rosa, H. T., Brackmann, A., Oliveira, F. B., Zanon, A. J. & Fagundes, L. K. (2009) Resposta à vernalização de cultivares brasileiras de trigo. Bragantia, Campinas, 68(2), 535-543. https://doi.org/10.1590/S0006-87052009000200029

Basumatary, P. & Hatibarua, P. (2023) Characterization And Evaluation Of Few Genotypes From The Composite Population Of *Limonium Sinuatum*. Plant Archives, 23(1), 67-69. https://doi.org/10.51470/PLANTARCHIVES.2023.v23.no1.011

Blas, I. O. de. (1992) Morfología de *Limonium sinuatum* (L.) Miller (Plumbaginaceae). Revista de Biologia Tropical, 40(1), 11-17.

Borchert, R., Renner, S., Calle, Z., Navarrete, D., Tye, A., Gautier, L. & Spichiger, R. (2005) Photoperiodic induction of synchronous flowering near the Equator. Nature, 433, 627–629. https://doi.org/10.1038/nature03259

Buffon, P. A., Schwab, N. T., Streck, N. A., Uhlmann, L. O., Lima, E. F., Marks, P. & Tomiozzo, R., (2021) Transforming a home refrigerator into a BOD prototype for statice vernalization, Ornamental Horticulture, 27(4) https://doi.org/10.1590/2447-536X.v27i4.2401

Buffon, P. A., Streck, N. A., Schwab, N. T., Uhlmann, L. O., Tomiozzo, R., Lima, E. F., Netto, J. F. & Guarienti, V. F. (2022) A phenological scale of statice. Annals of Applied Biology, 181, 275-287. https://doi.org/10.1111/aab.12765

Chang, Y., Yeh, D. & Yang, W. (2010) 'Tainan No. 1'Statice: An Early Flowering Limonium Cultivar. HortScience, 45(12), 1897-1898. https://doi.org/10.21273/HORTSCI.45.12.1897

Chen, J., Funnell, K. A. & Morgan, E. R. (2010) A model for scheduling flowering of a *Limonium sinuatum x Limonium perezii* hybrid. HortScience, 45(10), 1441-1446. https://doi.org/10.21273/HORTSCI.45.10.1441

Ciotta, M. N. & Nunes, E. da C. (2011) Tratamento pós-colheita e qualidade de hastes florais de *Limonium sinuatum*. Revista Brasileira de Horticultura Ornamental, 17(2), 159-166.

Cohen, A., Harazy, A., Rabinowith, H. & Stav, R. (1995) Selection for earl flowering in Blue Statice (*Limonium sinuatum* Mill.). Acta Horticulturae, 420, 118-124. https://doi.org/10.17660/ActaHortic.1995.420.33

Corbesier, L., Gadisseur, I., Silvestre, G., Jacqmard, A. & Bernier, G. (1996) Design in *Arabidopsis thaliana* of a synchronous system of floral induction by one long day. The Plant Journal, 9, 947-952. https://doi.org/10.1046/j.1365-313X.1996.9060947.x

González-Orenga, S., Grigore, M.-N., Boscaiu, M. & Vicente, O. (2021) Constitutive and Induced Salt Tolerance Mechanisms and Potential Uses of Limonium Mill. Species. Agronomy, 11, 413. https://doi.org/10.3390/agronomy11030413

Keisling, T.C. (1982) Calculation of length of day. Agronomy Journal, 74, 758-759.

Kim, D. H. (2020) Current understanding of flowering pathways in plants: focusing on the vernalization pathway in Arabidopsis and several vegetable crop plants. *Hortic. Environ. Biotechnology*, 61, 209–227. https://doi.org/10.1007/s13580-019-00218-5

Mattson, N. S. & Erwin, J. E. (2005) The impact of photoperiod and irradiance on flowering of several herbaceous ornamentals. Scientia Horticulturae, 104, 275-292. https://doi.org/10.1016/j.scienta.2004.08.018

Nataraj, S. K., Gangadharappa, P. M., Reddy, B. S., Naik, K.B., Prashanth, S.J. & Prakash, D.P. (2009) Evaluation of annual statice (*Limonium sinuatum* L.) cultivars. J. Hortl. Sci., 4(2), 184-186. https://doi.org/10.24154/jhs.v4i2.543

Paparozzi, E. T. (1986) Annual statice in Nebraska (Research Bulletin No. 308). Historical Research Bulletins of the Nebraska Agricultural Experiment Station (1913-1993). 15. http://digitalcommons.unl.edu/ardhistrb/15

Pareja-Bonilla, D., Arista, M., Morellato, L. P. C. & Ortiz, P. L. (2024) Better soon than never: climate change induces strong phenological reassembly in the flowering of a Mediterranean shrub community. Annals of Botany, 1-15. https://doi.org/10.1093/aob/mcad193

Pettigrew, W.T. (2008) Potassium influences on yield and quality production for maize, wheat, soybean and cotton. Physiologia Plantarum, 133, 670-681. https://doi.org/10.1111/j.1399-3054.2008.01073.x

Proietti, S., Scariot, V., Da Pascale, S. & Paradiso, R. (2022) Flowering mechanisms and environmental stimuli for flower transition: bases for production scheduling in greenhouse floriculture. Plants, 11(3), 432. https://doi.org/10.3390/plants11030432

Samach, A. & Coupland, G. (2000) Time measurement and the control of flowering in plants. Bioessays, 22, 38-47. https://doi.org/10.1002/(SICI)1521-1878(200001)22:1<38::AID-BIES8>3.0.CO;2-L

Semeniuk, P. & Krizek, D. T. (1972). Long Days and Cool Night Temperature Increase Flowering of Greenhouse Grown Limonium Cultivars. HortScience, *7*(3), 293-293. https://doi.org/10.21273/HORTSCI.7.3.293

Semeniuk, P. & Krizek, D.T. (1973) Influence of germination and growing temperature on flowering of six cultivars of annual statice (*Limonium* cv.). Journal American Society for Horticultural Science, 98(2), 140–142. https://doi.org/10.21273/JASHS.98.2.140

Shillo, R. (1976) Control of flower inanition and development of statice (*Limonium sinuatum*) by temperature and daylength. Acta horticulturae, 64, 197-204. https://doi.org/10.17660/ActaHortic.1976.64.25

Shillo, R. & E. Zamski (1985) *Limonium sinuatum*. In: Halevy, A.H. (ed.). RC Handbook of Flowering. CRC Press, Boca Raton, FL, 293-301.

Streck, N. A., Weiss, A., Xue, Q. & Baenziger, P. S. (2003a) Improving predictions of developmental stages in winter wheat: a modified Wang and Engel model. Agricultural and Forest Meteorology, 115 (3/4), 139-150. https://doi.org/10.1016/S0168-1923(02)00228-9

Streck, N.A., Weiss, A. & Baenziger, P. S. (2003b) A generalized vernalization response function for winter wheat. Agronomy Journal, 95, 155-159. https://doi.org/10.2134/agronj2003.1550a

Streck, N. A. (2002) A generalized vernalization response function for lily (*Lilium* spp.). Revista Brasileira de Agrometeorologia, 10(2), 21-228.

Streck, N. A. & Schuh, M. (2005) Simulating the vernalization response of the “Snow Queen” lily (*Lilium longiflorum* Thunb.) Scientia Agricola, 62(2), 117-121. https://doi.org/10.1590/S0103-90162005000200004

Streck, N. A. & Uhlmann, L. O. (2021) Flowers for all: bridging the gap between science and society. Chronica Horticulturae, 61(3), 32-34.

Uhlmann, L.O, Becker, C.C., Tomiozzo, R., Streck, N.A., Schons, A., Balest, D.S., Braga, M.S., Schwab, N.T. & Langner, J.A. (2019) Gladiolus as an alternative for diversification and profit in small rural property. Ornamental Horticulture, 25, 200-208. https://doi.org/10.14295/oh.v25i2.1541

Wang, E. & Engel, T. (1998) Simulation of phenological development of wheat crops. Agricultural Systems, 58(1), 1-24. https://doi.org/10.1016/S0308-521X(98)00028-6

Wilfret, G. J., Raulston, J. C., Poe, S. L., & Engelhard, A. W. (1973). Cultural techniques for the commercial production of annual statice (*Limonium* spp. mill.) in Florida. Proceedings of the Florida State Horticultural Society, 86, 399-403.

Wilfret, G. J. (1976) Statice (*Limonium sinuatum* Mill.) seed selection for earliness and increased yield. Acta Horticulturae, 63, 113-120. https://doi.org/10.17660/ActaHortic.1976.63.14

Whipker, B. E. & Hammer, P. A. (1994). Growth and Yield Characteristics of Field-grown *Limonium sinuatum* (L.). HortScience, 29(6), 638-640. https://doi.org/10.21273/HORTSCI.29.6.638

Xu, X., Zhou, Y., Mi, P., Wang, B. & Yuan, F. (2021) Salt-tolerance screening in *Limonium sinuatum* varieties with different flower colors. Nature Scientific Reports, 11:14562. https://doi.org/10.1038/s41598-021-93974-3

Tables

Table 1. Location and their respective characteristics of biome, latitude, longitude, altitude, sowing date (dd/mm/yyyy), transplant date (dd/mm/yyyy), and institution.

Trial	Location	Biome	Latitude	Longitude	Altitude	Sowing date	Transplant date	Institution
1	Santa Maria, RS	Atlantic Forest/Pampa	29°43’ S	53°43’W	95 m	25/05/2020	05/08/2020	UFSM
						06/07/2020	10/09/2020	
						04/08/2020	05/10/2020	
						17/09/2020	06/11/2020	
						21/10/2020	16/12/2020	
						26/11/2020	13/01/2021	
						17/12/2020	08/02/2021	
						21/01/2021	10/03/2021	
						03/03/2021[a]	14/04/2021	
						08/04/2021	17/06/2021	
						26/04/2021	08/07/2021	
						12/05/2021	04/08/2021	
2	Concórdia, SC	Atlantic Forest	27°14’ S	52°1’W	578 m	25/05/2020	07/08/2020	IFC
	Curitibanos, SC	Atlantic Forest	27°16’ S	50°30’W	992 m	25/05/2020	08/08/2020	UFSC
	Rio do Sul, SC	Atlantic Forest	27°12’ S	49°38’W	332 m	25/05/2020	10/08/2020	IFC
		Pampa		54°12’W	133 m	25/05/2020	03/08/2020	On farm

	Dilermando de Aguiar, RS		29°42’ S			25/05/2020	03/08/2020	On farm
	Itaqui, RS	Pampa	29°16’ S	59°51’W	57 m	25/05/2020	31/07/2020	On farm
	Júlio de Castilhos, RS	Atlantic Forest/Pampa	29°23’ S	53°68’W	529 m	25/05/2020	29/07/2020	On farm
	Pinto Bandeira, RS	Atlantic Forest	29°05’ S	51°27’W	638 m	25/05/2020	30/07/2020	On farm
	Santa Maria, RS	Atlantic Forest/Pampa	29°43’ S	53°43’W	95 m	25/05/2020	01/08/2020	On farm

[a] Only cultivar QIS Yellow cultivated.

Table 2. Sowing date (mm/dd/yyy), transplanting date (mm/dd/yyyy), vernalization days (VD, days) from the sowing to transplanting phase [VD(SO-TP)], VD from the transplanting to R1 phase [VD(TP-R1)], and VD from the sowing to R1 phase [VD(SO-R1)] of field trials with two statice cultivars QIS Yellow and QIS Purple in the *Trial 1* and *2* during 2020-2021 in eight locations in Southern Brazil.

Trial	**Locations**	**Sowing date**	**Transplanting date**	**VD(SO-TP)**	**VD(TP – R1)**		**VD(SO-R1)**	
					QIS Yellow	**QIS Purple**	**QIS Yellow**	**QIS Purple**
1	Santa Maria	25/05/2020	05/08/2020	34.57	9.95	22.19	44.52	56.76
		06/07/2020	10/09/2020	32.06	8.38	13.64	40.44	45.70
		04/08/2020	05/10/2020	26.81	5.48	11.85	32.29	38.66
		17/09/2020	06/11/2020	17.61	1.91	76.68	19.52	94.29
		21/10/2020	16/12/2020	10.2	3.94	39.57	14.14	49.77
		26/11/2020	13/01/2021	5.85	53.40	44.88	59.25	50.73
		17/12/2020	08/02/2021	6.57	51.46	70.07	58.03	76.64
		21/01/2021	10/03/2021	6.55	57.35	48.21	63.9	54.76
		03/03/2021	14/04/2021	7.90	47.53	-	55.43	-
		08/04/2021	17/06/2021	31.23	27.47	33.37	58.7	64.6
		26/04/2021	08/07/2021	41.05	16.68	24.26	57.73	65.31
		12/05/2021	04/08/2021	48.82	11.44	16.24	60.26	65.06
			CV%	**67.76%**	**88.26%**	**60.50%**	**36.03%**	**25.81%**
			SD	**15.20**	**21.70**	**22.05**	**16.94**	**15.54**
2	Concórdia/SC	25/05/2020	07/08/2020	35.18	12.45	18.09	47.63	53.27
	Curitibanos/SC	25/05/2020	08/08/2020	35.49	10.76	24.16	46.25	59.65
	Rio do Sul/SC	25/05/2020	10/08/2020	36.20	15.18	23.73	51.38	59.93
	Dilermando de Aguiar/RS – Farmer 01	25/05/2020	03/08/2020	33.83	10.36	21.28	44.19	55.11

Dilermando de Aguiar/RS – Farmer 02	25/05/2020	03/08/2020	33.83	10.69	19.96	44.52	53.79
Itaqui/RS - Irrigated	25/05/2020	31/07/2020	32.62	19.86	24.34	52.48	56.96
Itaqui/RS – Non-irrigated	25/05/2020	31/07/2020	32.62	18.79	25.99	51.41	58.61
Júlio de Castilhos/RS	25/05/2020	29/07/2020	31.54	15.28	21.39	46.82	52.93
Pinto Bandeira/RS	25/05/2020	30/07/2020	32.11	17.65	25.91	49.76	58.02
Santa Maria/RS	25/05/2020	01/08/2020	33.04	10.69	19.40	43.73	52.44
		CV%	**4.61%**	**25.92%**	**12.40%**	**6.81%**	**5.17%**
		SD	**1.55**	**3.67**	**2.78**	**3.26**	**2.90**

CV (%) = coefficient of variation, SD = standard deviation

Table 3. Percentage of field grown statice plants that reached the reproductive phase (%R1) until March 20, after March 20 for QIS Yellow and QIS Purple in the *Trial 1* and *2* during 2020-2021 in eight locations in Southern Brazil.

Trial	Location	Transplanting date	%R1 until March 20		%R1 after March 20	
			QIS Yellow	QIS Purple	QIS Yellow	QIS Purple
1	Santa Maria	05/08/2020	100	100	0	0
		10/09/2020	100	100	0	0
		05/10/2020	100	100	0	0
		06/11/2020	66.7	16.7	0	72.2
		16/12/2020	66.7	33.3	0	61.1
		13/01/2021	0	5.6	66.7	94.4
		08/02/2021	0	0	44.4	61.6
		10/03/2021	0	0	61.1	77.8
		14/04/2021[a]	0	-	88.1	-
		17/06/2021	0	0	100	100
		08/07/2021	0	0	100	100
		04/08/2021	0	0	100	100
2	Concórdia/SC	07/08/2020	100	100	0	0
	Curitibanos/SC	08/08/2020	100	100	0	0
	Rio do Sul/SC	10/08/2020	100	100	0	0
	Dilermando de Aguiar/RS – Farmer 01	03/08/2020	100	100	0	0
	Dilermando de Aguiar/RS – Farmer 02	03/08/2020	100	100	0	0
	Itaqui/RS - Irrigated	31/07/2020	100	100	0	0
	Itaqui/RS – Non-irrigated	31/07/2020	89.9	94.4	0	0
	Júlio de Castilhos/RS	29/07/2020	100	100	0	0

	Pinto Bandeira/RS	30/07/2020	100	100	0	0
	Santa Maria/RS	01/08/2020	100	94.4	0	0

[a] Only cultivar QIS Yellow cultivated.

Table 4. Yield per plant (stems/plant) for QIS Yellow and QIS Purple in the *Trial 1* and *2* during 2020-2021 in eight locations in Southern Brazil.

Trial 1		
Transplant date	**QIS Yellow**	**QIS Purple**
05/08/2020	30.52 a	24.56 abc
10/09/2020	28.10 ab	18.12 abc
05/10/2020	21.11 abc	11.76 c
06/11/2020	13.00 bc	12.21 c
16/12/2020	6.63 c	12.55 c
13/01/2021	17.83 abc	15.11 bc
08/02/2021	20.83 abc	35.67 A
10/03/2021	23.88 abc	32.4 ab
14/04/2021	21.86 abc	-
17/06/2021	17.72 abc	21.83 abc
08/07/2021	16.31 abc	21.16 abc
04/08/2021	16.01 abc	15.89 bc
Trial 2		
Location	**QIS Yellow**	**QIS Purple**
Concórdia/SC	26.00 abA	14.70 bB
Curitibanos/SC	20.77 bcA	15.23 bA
Rio do Sul/SC	9.73 dA	5.20 cA
Dilermando de Aguiar/RS – Farmer 01	15.83 cdA	17.50 bA
Dilermando de Aguiar/RS – Farmer 02	15.13 cdA	10.37 bcA
Itaqui/RS - Irrigated	15.03 cdA	9.93 bcA
Itaqui/RS – Non-irrigated	15.73 cdA	11.20 bcA
Pinto Bandeira/RS	18.50 bcA	18.27 abA
Santa Maria/RS	31.60 aA	26.07 aA

Lowercase letters in columns compare one cultivar between transplant dates or locations and uppercase letters in lines compare cultivars in the same location, according to Tukey's test ($p < 0.05$).

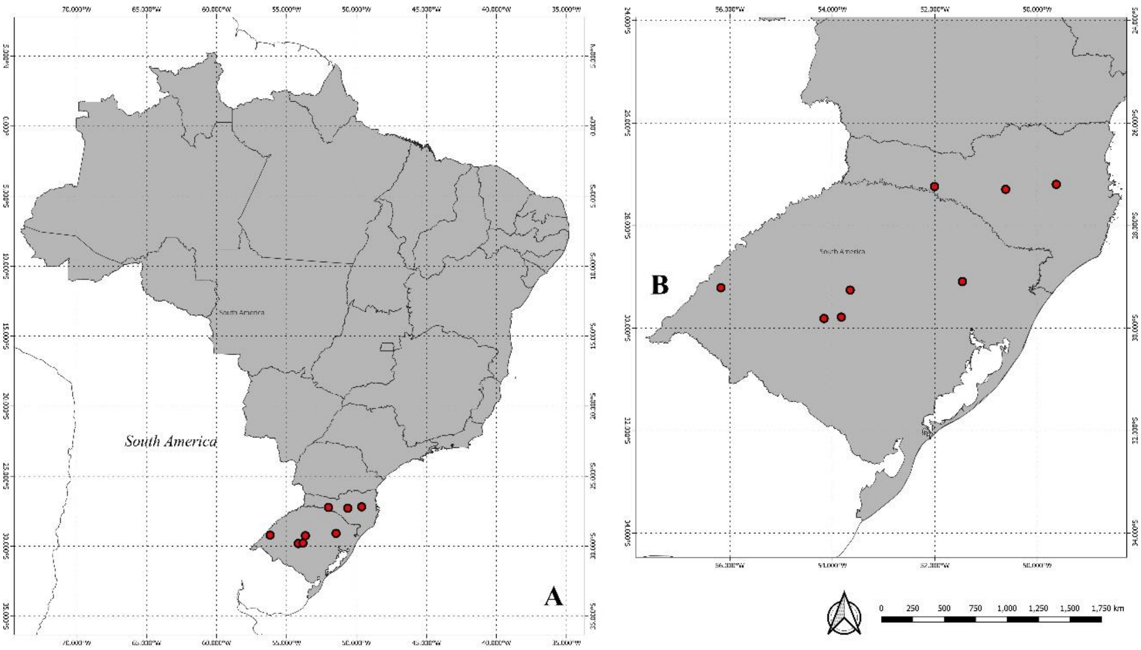


Figure 1. Geographic location of the field trials with statice conducted in eight locations in Rio Grande do Sul and Santa Catarina States, Southern Brazil, during 2020 and 2021. Locations are presented from the point of view of Brazil (A) and Southern Brazil (B).

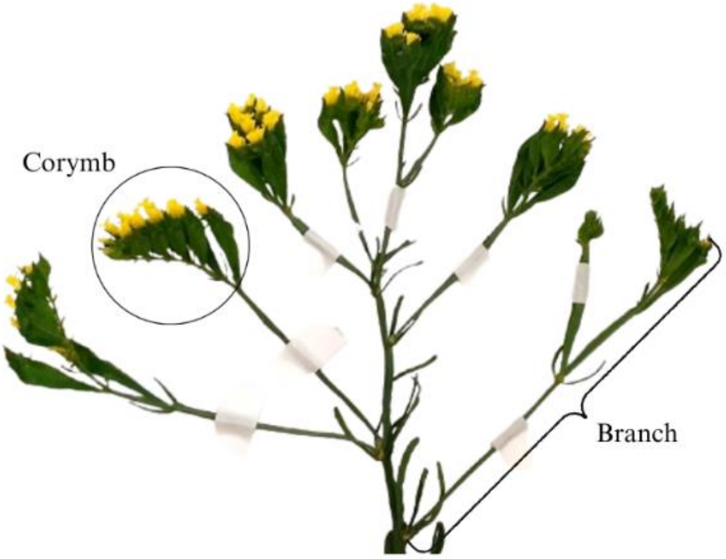


Figure 2. Illustration of the composition of a statice floral stem with corymbs and branching.

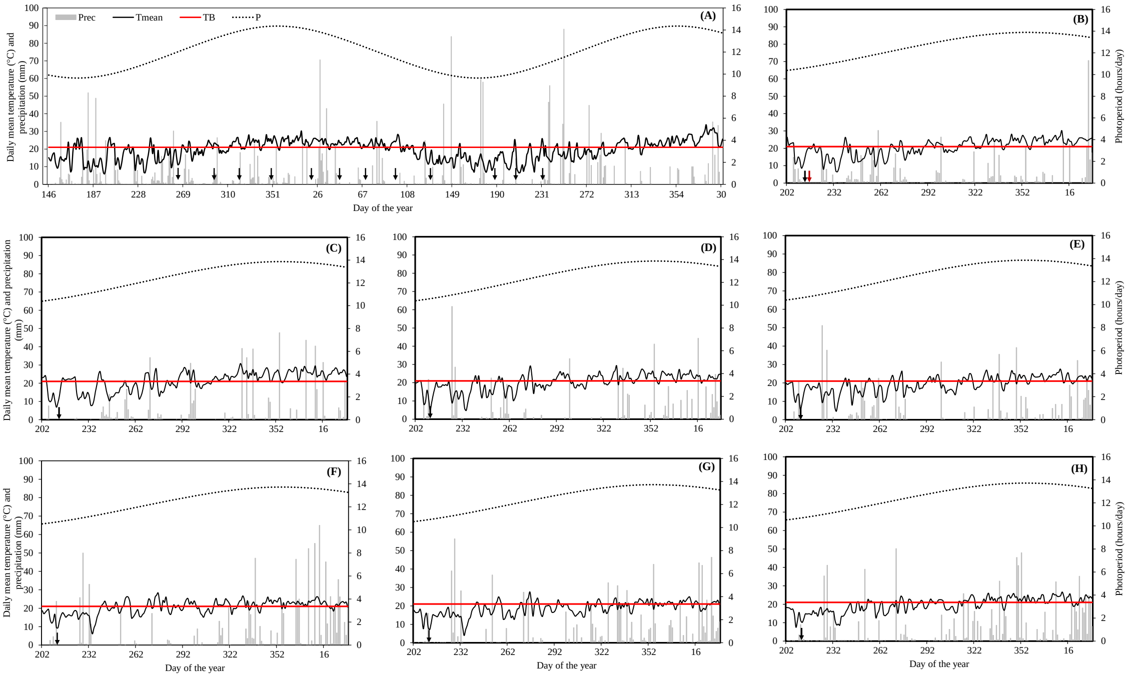


Figure 3. Daily variation of the mean air temperature (Tmean), precipitation (Prec) and photoperiod (P) during field trials with statice conducted in eight locations in |Rio Grande do Sul and Santa Catarina States, Southern Brazil, during 2020 and 2021: (A) *Trial 1* conducted in Santa Maria/RS. Each arrow indicates a transplanting date: August/2020, September/2020, October/2020, November/2020, December/2020, January/2021, February/2021, March/2021, April/2021, June/2021, July/2021, and August/2021; (B) *Trial 2* in Santa Maria/RS and Dilermando de Aguiar/RS (indicated by arrow red), (C) Júlio de Castilhos/RS, (D) Itaqui/RS, (E) Pinto Bandeira/RS, (F) Concórdia/SC, (G) Curitibanos/SC and (H) Rio do Sul/SC. Each arrow indicates a transplanting date in each location. The horizontal red line indicates the upper base cardinal temperature for vernalization (21°C).

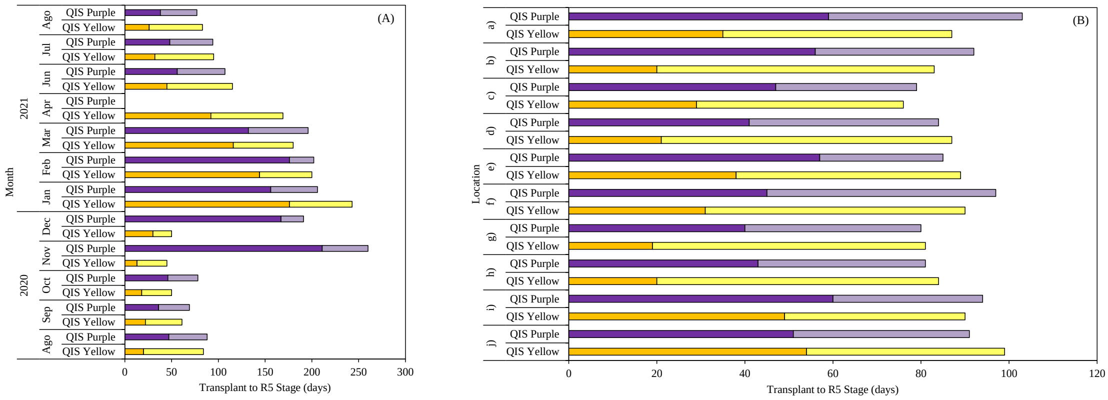


Figure 4. Days from transplanting to flowering (R5 stage) (bars) divided into vegetative phase (TP-R1, left end of the bars) and reproductive phase (R1-R5, right end of the bars) of field grown statice in Trial 1 (A) and Trial 2 (B) in eight locations in Rio Grande do Sul and Santa Catarina States, Southern Brazil, during 2020 and 2021. Locations in panel (B) are represented by letters as follows: a) Rio do Sul/SC, b) Curitibanos/SC, c) Concórdia/SC, d) Santa Maria/RS, e) Pinto Bandeira/RS, f) Júlio de Castilhos/RS, g) Dilermando de Aguiar/RS – Farmer 1, h) Dilermando de Aguiar/RS – Farmer 2, i) Itaqui/RS – Non irrigated, and j) Itaqui/RS – Irrigated.

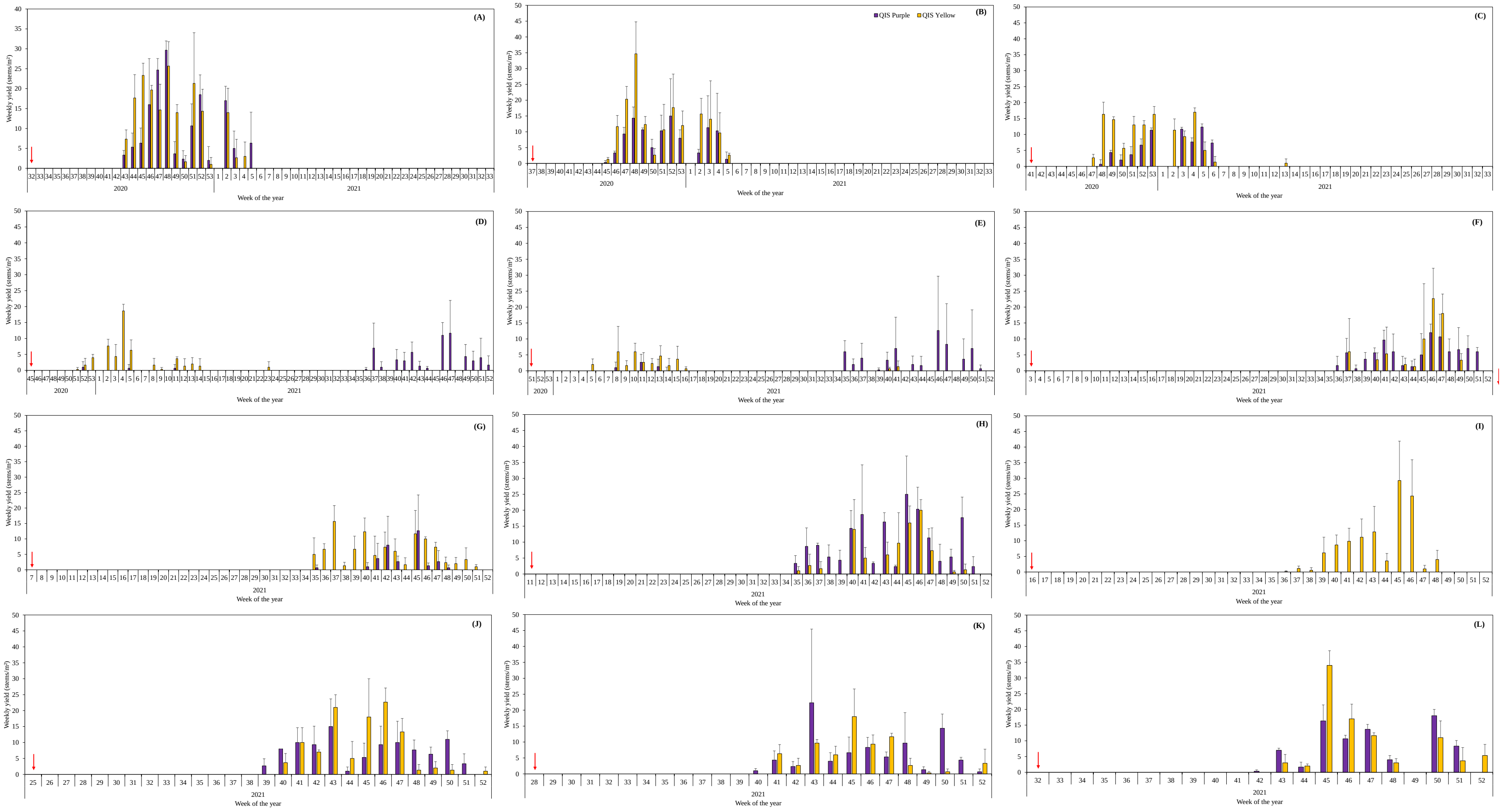


Figure 5. Weekly yield during the harvest period of field grown statice for each transplanting date in Santa Maria, RS, Brazil during 2020 and 2021: (A) August/2020, (B) September/2020, (C) October/2020, (D) November/2020, (E) December/2020, (F) January/2021, (G) February/2021, (H) March/2021, (I) April/2021, (J) June/2021, (K) July/2021, and (L) August/2021. Error bars were included for each harvest. Each arrow indicates the week of transplanting in each month.

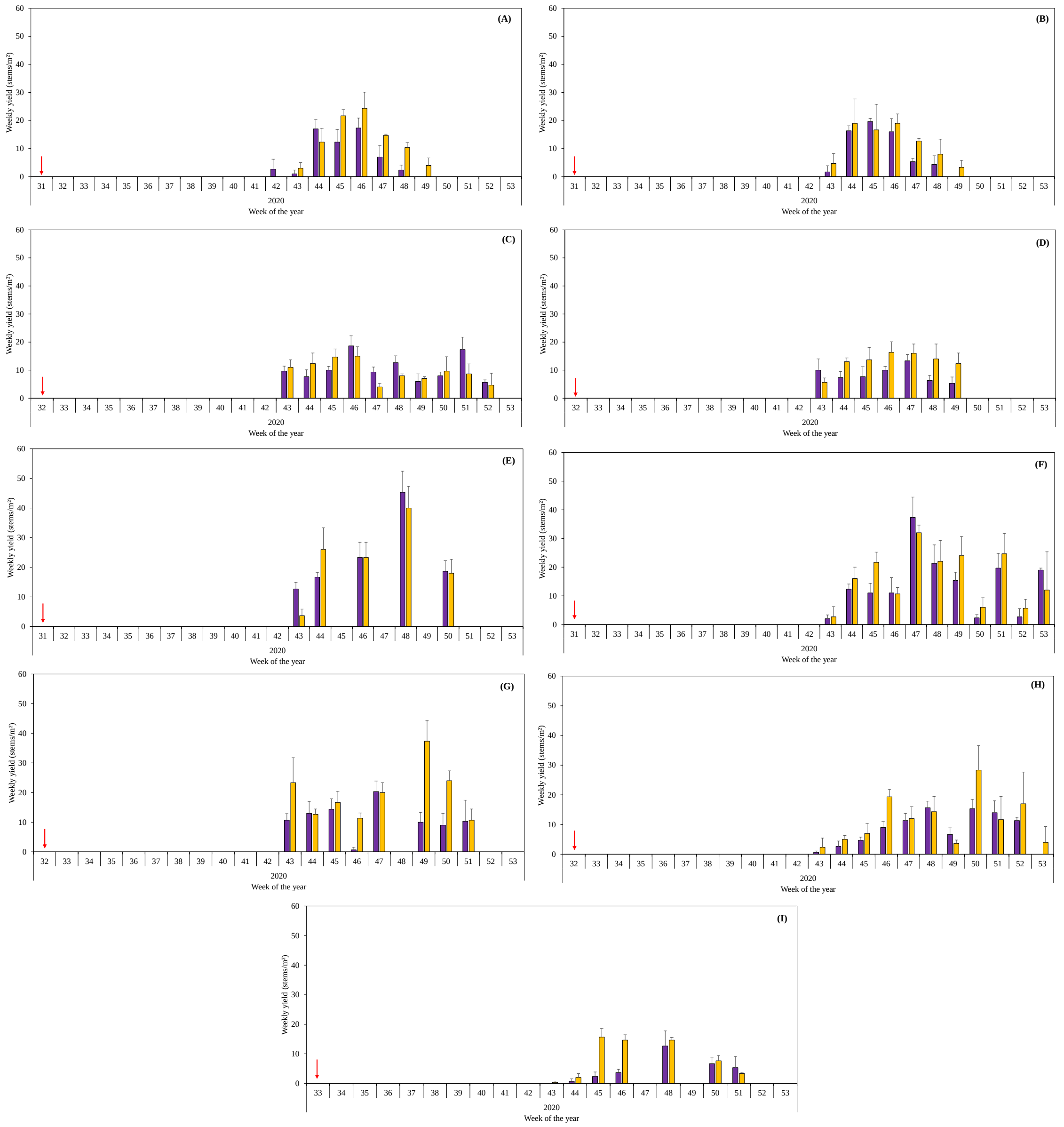


Figure 6. Weekly yield during the harvest period of field grown statice in seven locations in Southern Brazil in 2020: (A) Itaqui/RS – Irrigated, (B) Itaqui/RS – Non irrigated, (C) Dilermando de Aguiar/RS – Farmer 1, (D) Dilermando de Aguiar/RS – Farmer 2, (E) Pinto Bandeira/RS, (F) Santa Maria/RS, (G) Concórdia/SC, (H) Curitibanos/SC, and (I) Rio do Sul/SC. Error bars were included for each harvest. Each arrow indicates the week of transplanting in each location.

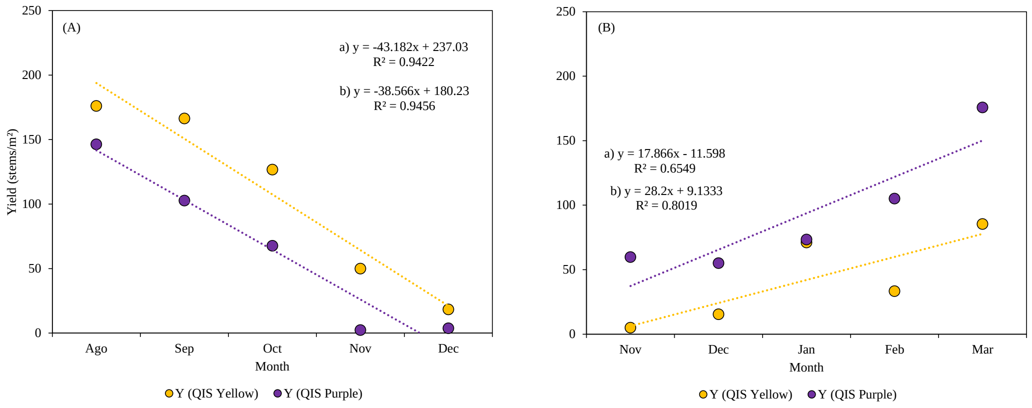


Figure 7. Floral stems yield (stems/m^2) of field grown statice as a function of the transplanting date until March 20 (A) and after March 20 (B) in Santa Maria/RS, Brazil for *Trial 1* during 2020 and 2021. Equation a) corresponds to QIS Yellow and b) QIS Purple cultivars.

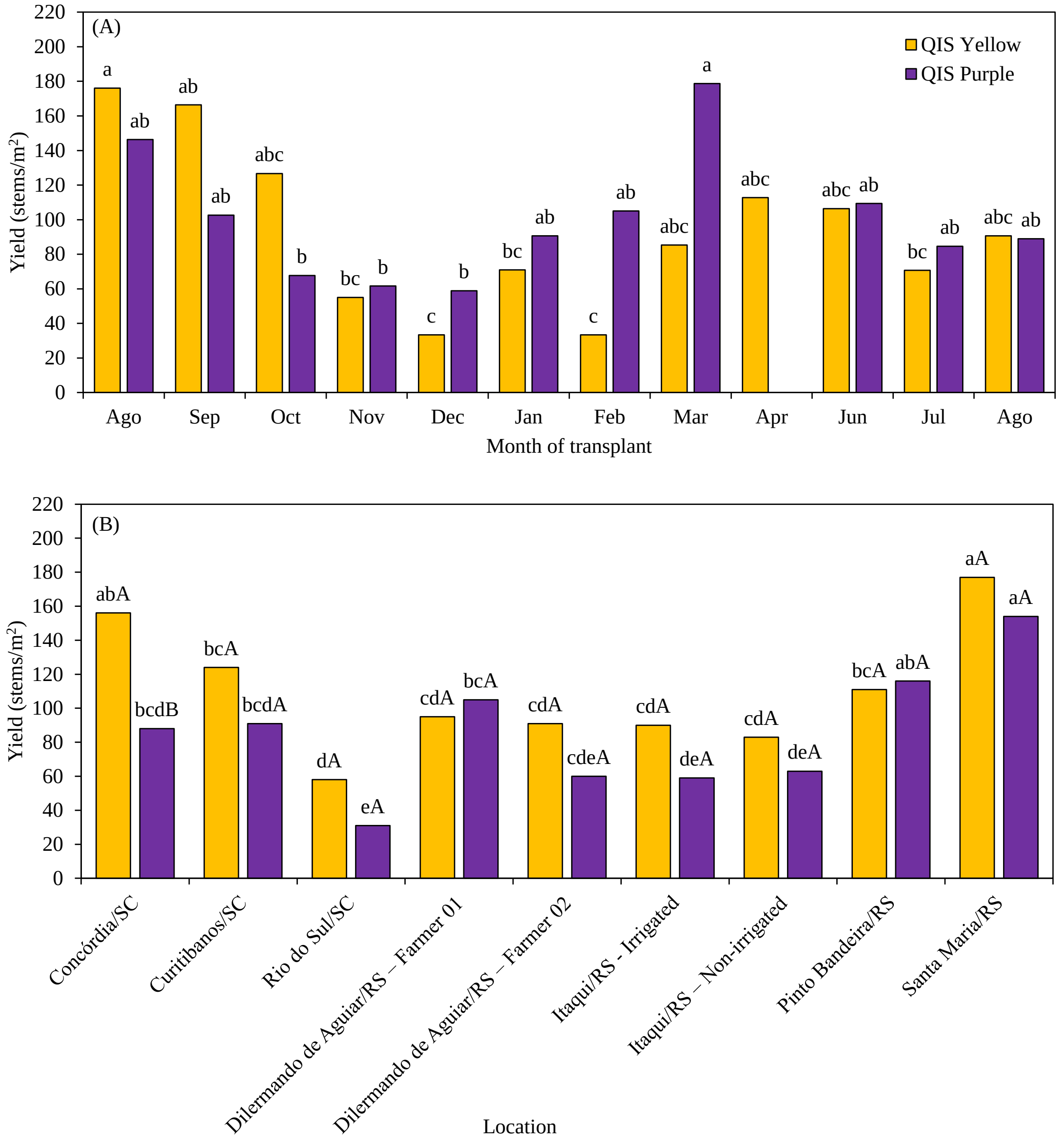


Figure 8. Floral stems yield (stems/m²) of field grown statice in different (A) transplanting dates for *Trial 1* and (B) locations for *Trial 2* in Southern Brazil during 2020-2021. Lowercase letters compare the same cultivar between transplanting dates or locations and uppercase letters compare cultivars in the same location, according to Tukey's test ($p < 0.05$).

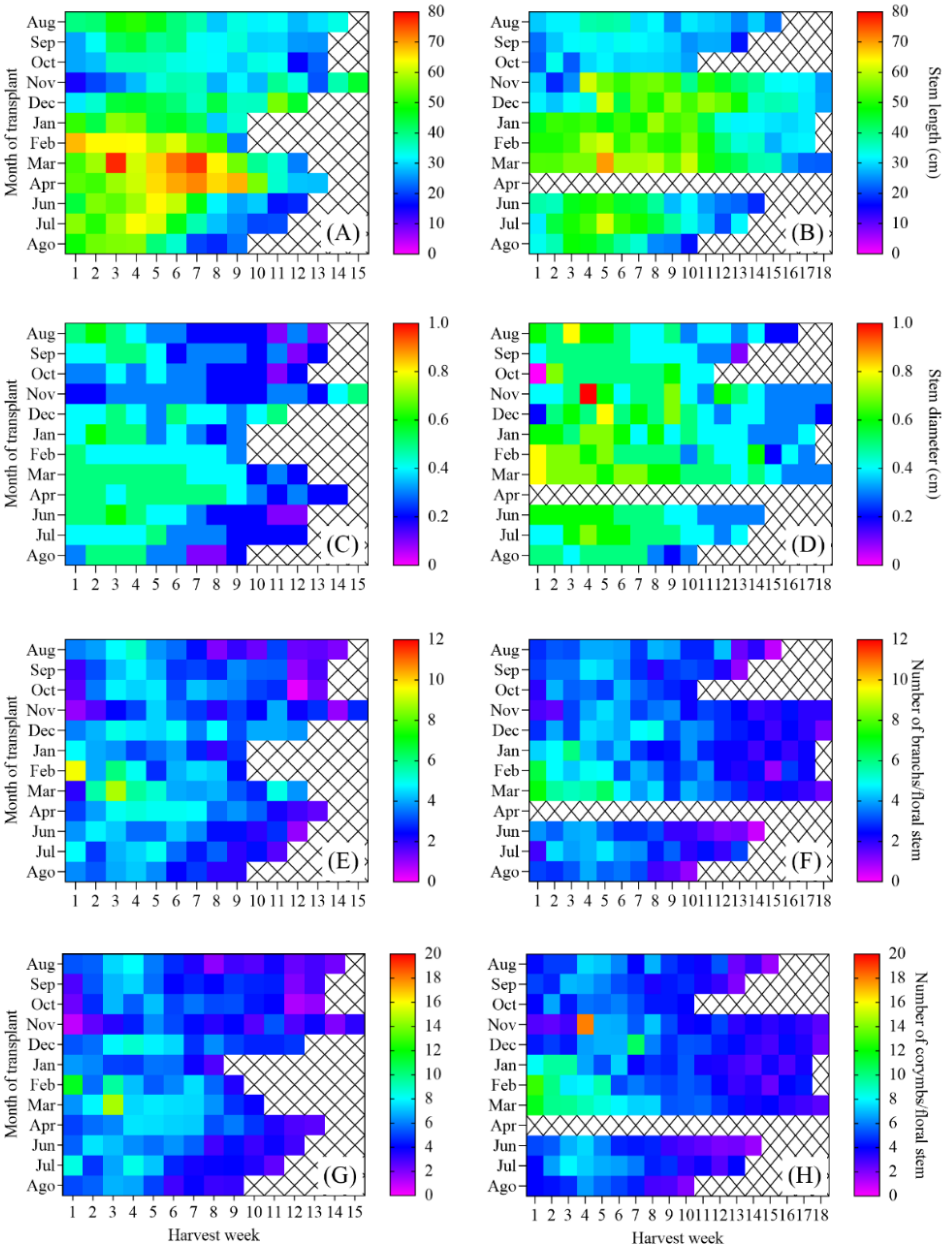


Figure 9. Flower production components of field grown statice floral stem throughout the harvest period for *Trial 1* in Santa Maria/RS, Brazil, during 2020-2021. Graphics (A, C, E, G) correspond to QIS Yellow, and Graphics (B, D, F, H) correspond to QIS Purple. The flower production components presented are (A, B) stem length (cm), (C, D) stem diameter, (E, F) number of branches/floral stem and (G, H) number of corymbs/floral. Color gradient in a heatmap goes from cold colors, representing low values, to hot colors, representing high values.

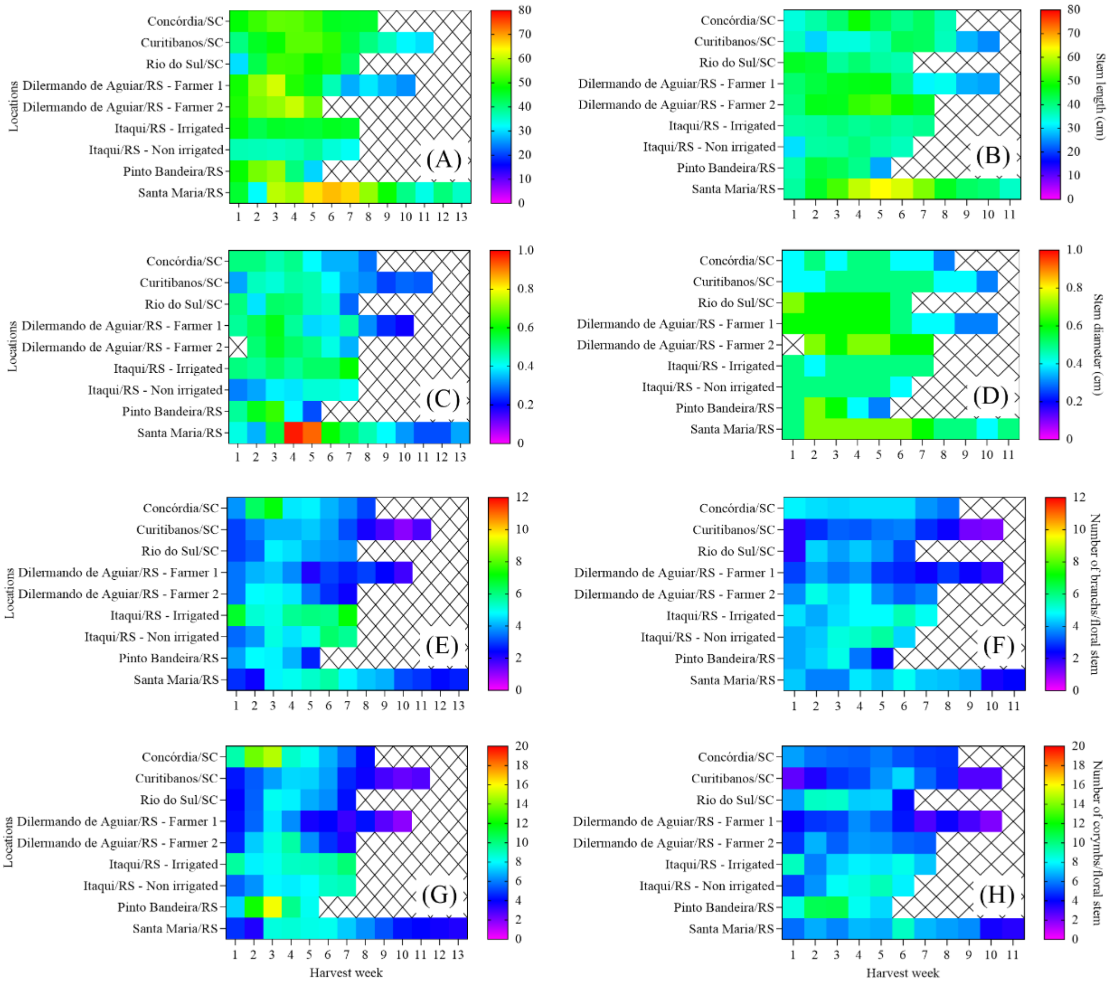


Figure 10. Flower production components of field grown statice floral stems throughout the harvest period for *Trial 2* in seven locations in Rio Grande do Sul and Santa Catarina States, Southern Brazil, during 2020. Graphics (A, C, E, G) correspond to QIS Yellow, and Graphics (B, D, F, H) correspond to QIS Purple. The flower production components presented are (A, B) stem length (cm), (C, D) stem diameter, (E, F) number of branches/floral stem and (G, H) number of corymbs/floral. Color gradient in a heatmap goes from cold colors, representing low values, to hot colors, representing high values.

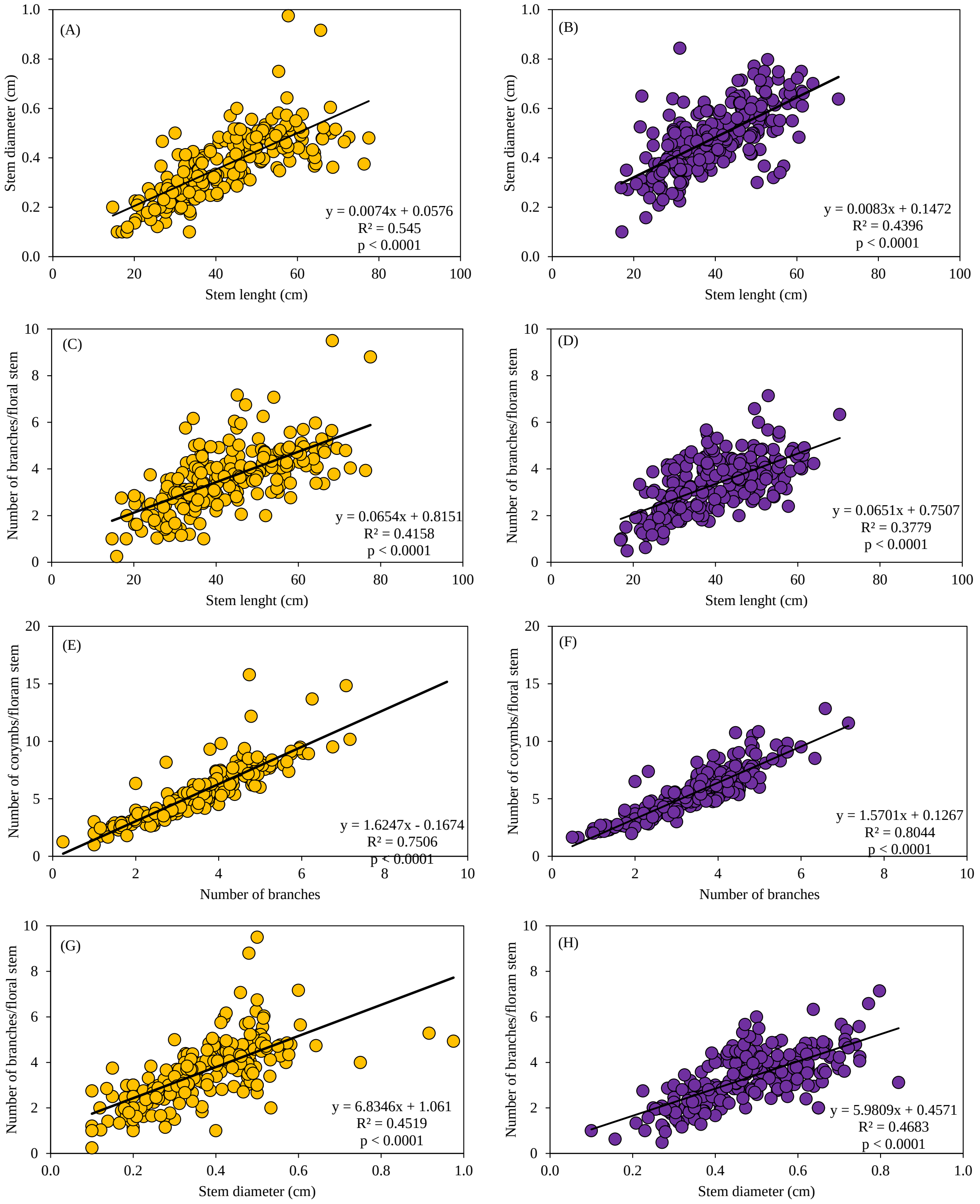
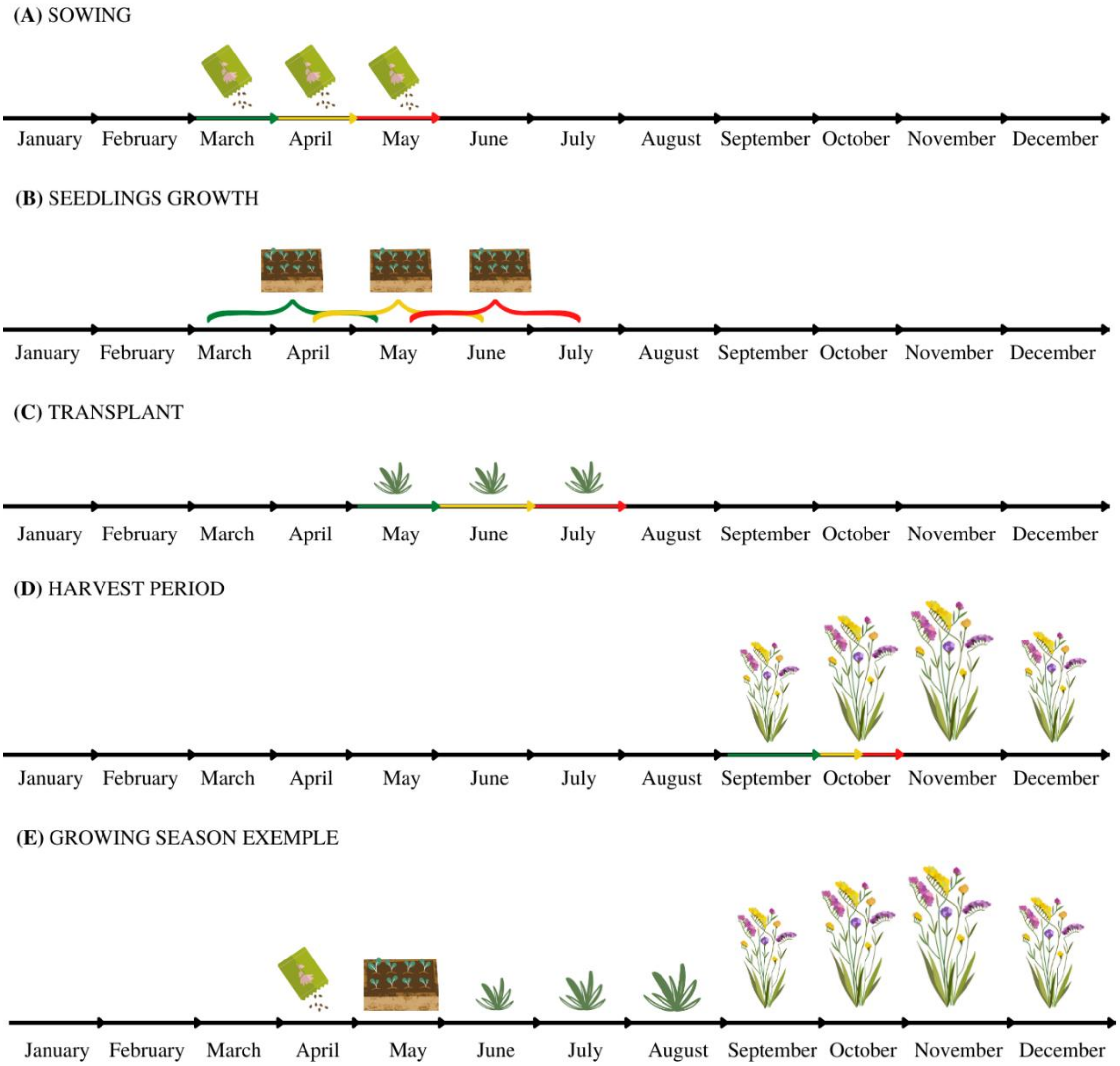


Figure 11. Linear regression between floral stem diameter (cm) and stem length (cm), number of branches/floral stem and stem length (cm), number of corymbs/floral stem and number of branches /floral stem, number of branches/floral stem and stem diameter (cm) for QIS Yellow (A, C, E, G) and QIS Purple (B, D, F, H), respectively. Data of field grown statice floral stems in *Trial 1 and 2* in seven locations in Rio Grande do Sul and Santa Catarina States, Southern Brazil, during 2020 and 2021.

Graphical abstract



This study investigated the flowering of statice in subtropical environment with practical applications to the farmers. The harvest period can vary from 5 to 18 weeks depending on cultivar, transplant date and location. Among harvest weeks, the highest values of yield and flowers quality is achieved during about 3 to 5 weeks. Transplants during the off-season prolong the developmental cycle and reduce yield due to the vernalization requirements.

4 DISCUSSÃO

Demonstramos que ensaios de campo realizados multi-anos e multi-locais proporcionam uma melhor compreensão da interação entre espécies e ambientes. A colaboração estabelecida entre as diferentes instituições de ensino e pesquisa espalhadas pelo Brazil em pesquisas com o girassol de corte e statice, e com o Centro de Pesquisa em Horticultura e Floricultura (CREA) na Itália, com o girassol de corte, proporcionaram um banco de dados robusto para compreensão da interação genótipo x ambiente x manejo e produtor. Raros são os trabalhos na área da floricultura que conseguem atingir esse patamar de conexão entre instituições em prol de um mesmo objetivo: avançar na barreira do conhecimento para gerar resultados práticos e aplicados às reais demandas do produtor de flores. A riqueza dos resultados gerados nesta tese graças a essa imensa colaboração é notória.

No Capítulo 1, foi possível estabelecer relações ecofisiológicas entre variáveis dependentes e independentes, como por exemplo: ciclo de desenvolvimento em função da duração da fase vegetativa e reprodutiva em tempo térmico (°C dia), número de folhas no estágio R1 em função do número final de folhas e componentes de produtividade (comprimento da planta, espessura da haste e espessura do capítulo) em função do índice de área foliar. Poucos estudos sobre a espécie *Helianthus annuus L.* e principalmente para genótipos com finalidade ornamental abordam este nível de informações complexas e de grande relevância para a compreensão dos fatores ecofisiológicos que influenciam o crescimento, desenvolvimento e produção de hastes florais de girassol de corte.

Os resultados evidenciam que os genótipos de girassol de corte utilizados para este estudo são bem adaptados nos ambientes tropical, subtropical e temperado, apesar das variações proporcionadas pelas diferentes condições ambientais. Ademais, um grande avanço a partir deste primeiro capítulo é o estudo com genótipos de origem italiana que ainda não estão disponíveis para cultivo comercial no Brazil, mas que apresentam grande potencial para serem introduzidas no mercado brasileiro de flores.

No Capítulo 2, aprofundou-se a discussão sobre o desenvolvimento foliar em genótipos de girassol de corte, através do filocrono, variável também abordada no Capítulo 1, mas de forma simplificada. Observou-se que ocorre uma “quebra” na emissão de folhas entre os estágios V6 (seis folhas) e V7 (sete folhas), dividindo-a em duas fases. Com isso, a relação entre a emissão de folhas e o tempo térmico não pode ser mais considerada linear, exigindo uma bi-linearidade entre as fases. Ao aplicar duas regressões lineares, foi possível determinar dois valores de filocrono, um para cada fase. O filocrono da fase "*early*" é maior (34.87°C dia folha^{-1}) do que o filocrono na fase "late" (21.82°C dia folha^{-1}), ou seja, até a sexta folhas a velocidade de emissão de folhas é menor do que a partir da sétima folha.

Em um primeiro momento, levantou-se a hipótese de que o método de plantio (semeadura direta ou transplante) poderia influenciar nessa mudança. O método mais utilizado por produtores e pelos participantes do Projeto Flores para Todos, é o transplante das mudas. As sementes são semeadas em bandejas com substratos e transplantadas apenas quando as folhas cotiledonares apresentam uma abertura de 180° e o primeiro par de folhas verdadeiras já está visível entre as folhas cotiledonares. Ao utilizar mudas transplantadas, quaisquer limitações no desenvolvimento das mudas e um possível estresse no transplante, pode prejudicar o estabelecimento inicial do stand. No entanto, os resultados demonstram que nem a semeadura direta nem o transplante são capazes de causar este retardamento no início do desenvolvimento foliar.

Descartada essa hipótese, observou-se clinicamente como ocorre a emissão de folhas em girassol de corte e sua morfologia. Constatou-se que essa mudança na velocidade de emissão de folhas está principalmente relacionada com a ontogenia da planta de girassol, visto que a quebra na emissão de folhas ocorre exatamente quando a filotaxia foliar se altera, de folhas opostas para folhas alternadas e o elongamento do caule se torna mais proeminente. Mudanças na velocidade de emissão de folhas relacionadas com a ontogenia também foi verificada para gramíneas, como o trigo (BAUMONT et al., 2019). O estudo do desenvolvimento foliar e a identificação de particularidades como essa, são de extrema importância para a calibração de modelos de simulação do desenvolvimento baseados em processos. Considerar essa mudança na velocidade de emissão de folhas no girassol de corte indica a necessidade da inclusão de uma função de resposta à cronologia no modelo de emissão de folhas para aumentar o desempenho do modelo em simular a emissão de folhas de girassol de corte.

Outra espécie de grande importância na floricultura brasileira e mundial é a statice. Esta espécie foi introduzida no Projeto Flores Para Todos em 2020 e tem grande aceitabilidade entre os produtores rurais, principalmente pela sua versatilidade e alta produtividade. Por isso, no Capítulo 3 abordou-se especificamente a produção de hastes florais de statice. Um dos grandes problemas enfrentados pelos produtores é o local de cultivo e a sazonalidade da produção. No Brasil, o cultivo limita-se na Região Sul com transplantes a partir de maio e colheitas a partir de setembro, devido aos requerimentos de vernalização e fotoperíodo longo da espécie.

Os resultados demonstraram que a statice pode ser muito produtiva quando respeitada a sua época de cultivo e que em períodos de entressafra, a produção de flores atrasará e reduzirá significativamente. O florescimento da statice segue um padrão, no qual durante o período de colheita há uma janela de duas a quatro semanas em que a produtividade em hastes por metro quadrado é maior, bem como há um incremento nos componentes de produtividade (comprimento da haste, diâmetro da haste, número de ramificações por haste e número de corimbos por haste). Posteriormente a esta janela, estes parâmetros começam a cessar, reduzindo constantemente até o final do ciclo.

Estes resultados fornecem diretrizes para produtores de flores de statice para o planejamento da comercialização das hastes florais de statice em função da produtividade ao longo do período de produção. Por exemplo, sabendo que no plantio realizado no mês de Agosto a primeira colheita ocorrerá a partir da semana 43 do ano, e que o período de colheita pode durar onze semanas consecutivas, com a maior produtividade e qualidade das flores a partir da segunda ou terceira semana de colheita, o produtor pode agendar a entrega das flores para seus clientes para depois desta janela. Dada a possibilidade do uso da statice como flor seca, não havendo a venda do produto fresco, esta pode ser armazenada e comercializada posteriormente, diminuindo as perdas na produção. Este estudo preliminar sobre o padrão de florescimento da statice poderá servir se base a construção de um modelo que além de simular o desenvolvimento da planta, indicando a ocorrência dos estágios fenológicos, poderá simular o período de colheita das hastes florais de statice em resposta à vernalização e ao fotoperíodo e a frequência com que podem ser realizadas as colheitas das hastes florais. Esta funcionalidade em um modelo de simulação permitirá ao usuário realizar o planejamento da produção de statice com maior regularidade, precisão e praticidade.

Do ponto de vista da modelagem, espera-se que os resultados desta tese forneçam uma base sólida para o desenvolvimento de tecnologias na área da floricultura, como modelos de simulação do desenvolvimento baseados em processos para as culturas do girassol de corte e da statice. Para desenvolver um modelo com boas funcionalidades e alta taxa de acerto, estudos preliminares como esse são necessários, demandando tempo, recursos humanos e financeiros. Na área da floricultura, o uso de modelos ainda é muito limitado em função da grande diversidade de espécies e genótipos. No entanto, tecnologias como essa tem ganhado espaço a cada dia, tornando-se importantes e indispensáveis ferramentas de gestão, auxiliando os produtores de flores na tomada de decisão para escolha de cultivares, época de cultivo, realização de práticas culturais e planejamento da colheita. Um excelente exemplo do uso de modelos na área da floricultura é o Aplicativo PhenoGlad Mobile, principal ferramenta de gestão utilizada no Projeto Flores Pata Todos para o cultivo de gladíolos (UHLMANN, 2017; UHLMANN, 2019).

Sobretudo, espera-se que estes resultados forneçam informações importantes aos produtores de flores sobre ambiente e seus efeitos nos processos ecofisiológicos no cultivo de girassol de corte e statice. Apesar de utilizar como exemplo o Projeto Flores Para Todos, devido a sua importante abrangência nacional, os impasses relacionados à produção de cada uma das espécies estudadas vão além, e são realidade para a grande maioria dos produtores de flores no Brasil e ao redor do mundo. O setor de flores e plantas ornamentais brasileiro só progredirá, principalmente na diversidade de produtos ofertados (diferentes espécies), com o aumento de estudos como este, com aplicação prática que atendam as demandas de quem produz e que contribuam efetivamente para a resolução dos reais problemas enfrentados em todas as camadas do setor. Pesquisas na área da floricultura estão aumentando a cada dia, mas ainda há muito para avançar no conhecimento sobre flores e plantas ornamentais, dada a vasta diversidade de biomas existentes em solo brasileiro. Espera-se que esses resultados sirvam de embasamento para pesquisas futuras na área da floricultura, não apenas sobre *Helianthus annus* L. e *Limonium sinuatum* Mill., mas entre outras espécies exóticas e nativas.

5 CONCLUSÕES

Há um impacto significativo dos ambientes tropicais, subtropicais e temperados no desenvolvimento, crescimento e produção de flores do girassol de corte. A duração da fase vegetativa tem uma relação linear positiva com o ciclo de desenvolvimento, assim como a fase reprodutiva, e é determinada pelo número final de folhas. Por outro lado, o índice de área foliar tem uma relação linear negativa com as datas de semeadura, assim como o filocrono e o número final de folhas. Os componentes de produção de flores são definidos pelo índice de área foliar e pelo número final de folhas. Em resumo, cultivares com ciclo de desenvolvimento mais longo têm alto número final de folhas, baixo filocrono e maior altura de planta do que cultivares com ciclo mais curto.

Há um ponto de quebra entre os estágios V6 e V7, evidenciado pela regressão bi-linear entre o número de folhas e o tempo térmico (°C dias). Duas fases distintas de filocrono foram identificadas: uma inicial, a 34,87°C dia folha-^{1}, e uma tardia, a 21,82°C dia folha^{-1}. As fases do filocrono apresentam consistência entre os genótipos e são influenciadas pelo ambiente, como variabilidade de local de cultivo. Essas descobertas não apenas aprimoram nossa compreensão sobre o filocrono, mas também representam um avanço substancial, fornecendo uma base sólida para incluir uma função de resposta de cronologia no desenvolvimento de futuros modelos baseados em processos para o girassol de corte.

Há uma forte dependência da época de cultivo de statice às condições flutuantes de vernalização, fotoperíodo e temperatura. O desenvolvimento das hastes florais de statice variou entre cultivares, datas de transplante e locais nos dias até o início da fase reprodutiva (45 a 243 dias), no período de colheita (5 a 18 semanas), no rendimento (33 a 180 hastes/m2) e componentes de produção de flores em cada semana de colheita. O período de colheita revelou um pico na produção que pode durar de 2 a 4 semanas, caracterizado por um maior rendimento e componentes de produção, seguido por uma diminuição em colheitas posteriores, caracterizando um padrão no florescimento da cultura de statice.

REFERÊNCIAS

AIPH. International statistics flowers and plants. International Association of Horticultural Producers, v. 69, 2021.

AIPH. International statistics flowers and plants. International Association of Horticultural Producers, v. 70, 2022.

ALBERIO, C.; IZQUIERDO, N. G.; AGUIRREZÁBAL, L. A., N. Sunflower crop physiology and agronomy. In: Sunflower: Chemistry, production, processing and utilization (Editors: MARTÍNEZ-FORCE, E.; DUNFORD, N. T.; SALAS, J. J.). AOCS Press, 2015. https://doi.org/10.1016/B978-1-893997-94-3.50001-5

ANACLETO, A. et al. Between flowers and fears: the new coronavirus pandemic (COVID-19) and the flowers retail trade. Ornamental Horticulture, v.27, p.26-32, 2021. https://doi.org/10.1590/2447-536X.v27i1.2232

ARMITAGE, A.M.; J.M. LAUSHMAN. Specialty cut flowers, 2nd ed. Timber Press, Portland, OR, 2003.

BARROSO, G. M.; GUIMARÃES, E. F.; ICHASO, C. L. F.; COSTA, C. G.; PEIXOTO, A. L. Sistemática de angiospermas do Brasil. Editora UFV: Viçosa, MG, v. 1, ed. 2, 2004. 309p.

BLAS, I. O. de. Morfología de *Limonium sinuatum* (L.) Miller (Plumbaginaceae). Revista de Biologia Tropical, v.40, e.1, p.11-17, 1992.

BAUMONT, M. ET al. Experimental and modeling evidence of carbon limitation of leaf appearance rate for spring and winter wheat. Journal of Experimental Botany, v. 70, e. 9, p. 2449–2462, 2019. https://doi.org/10.1093/jxb/erz012

CASADEBAIG, P. et al. SUNFLO, a model to simulate genotype-specific performance of the sunflower crop in contrasting environments. Agricultural and Forest Meteorology, v. 151, 2011.

CAVALCANTE, M. Z. B. Floriculture and Covid-19. Ornamental Horticulture, v.27, n.1, p. 6-7, 2021. https://doi.org/10.1590/2447-536X.v27i1.2284

CASTRO, A. C. R.; CORREIA, D.; SOUZA, F. V. D.; SOUZA, E. H.; FRANCO, J.; CAVALCANTI, T. B. Brazilian ornamental phytogenetic resources in Embrapa germplasm banks: obstacles and opportunities v. 28, n. 4, 2022 p. 396-406. https://doi.org/10.1590/2447-536X.v28i4.2549

CAVALCANTE, M. Z. B. Soiless cultivation means advance in flower production. Ornamental Horticulture, v.23, n.3, 2017. https://doi.org/10.14295/oh.v23i2.1037

IBRAFLOR. O mercado de flores no Brasil. 2022, 4p. Disponível em: https://www.ibraflor.com.br/_files/ugd/b3d028_2ca7dd85f28f4add9c4eda570adc369f.pdf

CHANG, Y.; YEH, D.; YANG, W.. 'Tainan No. 1'Statice: An Early Flowering Limonium Cultivar. HortScience, v. 45, n. 12, p. 1897-1898, 2010.

CHEN, J.; FUNNELL, K. A.; MORGAN, E. R. A model for scheduling flowering of a *Limonium sinatum* x *Limonium perezii* hybrid. HortScience, v. 45, n. 10, p. 1441-1446, 2010.

CIOTTA, M. N.; NUNES, E. da C. Tratamento pós-colheita e qualidade de hastes florais de *Limonium sinuatum*. Revista Brasileira de Horticultura Ornamental, v. 17, n. 2, p. 159-166, 2011.

CURTI, G. L.; MARTIN, T. N.; FERRONATO, M. de L.; BENIN, G. Girassol ornamental: caracterização, pós-colheita e escala de senescência. Revista de Ciências Agrárias, v. 35, p. 240-250, 2012.

DARRAS, A. Overview of the Dynamic Role of Specialty Cut Flowers in the International Cut Flower Market" *Horticulturae*, v. 7, 51, 2021. https://doi.org/10.3390/horticulturae7030051

DIÁRIO OFICIAL DA UNIÃO. Lei n° 14.673 de 25 de julho de 2023. Disponível em: https://pesquisa.in.gov.br/imprensa/jsp/visualiza/index.jsp?data=26/07/2023&jornal=515&pagina=14

GONZÁLES, M. R.; RE, F. T. G. Statice de meristemo para producción invernal. Programa de Innovación Tecnológica, 2003.

IBRAFLOR (2024) O mercado de flores no Brasil (01/2024). Disponível em: https://www.ibraflor.com.br/_files/ugd/5bcab9_1de516ce08144d058bd8167c5db12ca8.pdf

JUNQUEIRA, A. H.; PEETZ, M. da S. Sustainability in Brazilian floriculture: introductory notes to a systemic approach. Ornamental Horticulture, Campinas, v. 24, n. 2, p. 155-162, 2018. 10.14295/oh.v24i2.1253

JUNQUEIRA, A. H.; PEETZ, M. da S. Mercado interno para os produtos da floricultura brasileira: características, tendências e importância socioeconômica recente. Ornamental Horticulture, v.14, p.37-52, 2008. https://doi.org/10.14295/rbho.v14i1.230

JUNQUEIRA, A. H.; PEETZ, M. da S. Intellectual property rights in Brazilian floriculture: innovations for the growth and development of the market. Ornamental Horticulture, v.23, p.296-306, 2017. http://dx.doi.org/10.14295/oh.v23i3.1071

KAYA, Y.; JOCIC, S.; MILADINOVIC, D. Sunflower. In: Gupta S. (eds) Technological Innovations in Major World Oil Crops, Volume 1. Springer, New York, NY., 2012. https://doi.org/10.1007/978-1-4614-0356-2_4

LORENZI, H.; SOUZA, H. M. de. Plantas ornamentais no Brasil: arbustivas, herbáceas e trepadeiras. Instituto Plantarum de Estudos da Flora, 3ed, 2001. 1087p.

MLADENOVIĆ, E., CVEJIĆ, S., JOCIĆ, S., ĆUK, N., ČUKANOVIĆ, J., JOCKOVIĆ, M., MARJANOVIĆ-JEROMELA, A. Effect of plant density on stem and flower quality of single-stem ornamental sunflower genotypes. Horticultural Science, 47, 45-52, 2020. https://doi.org/10.17221/10/2019-HORTSCI

NATARAJ, S. K.; GANGADHARAPPA, P. M.; REDDY, B. S.; NAIK, K.B.; PRASHANTH, S.J.; PRAKASH, D.P. Evaluation of annual statice (*Limonium sinuatum* L.) cultivars. J. Hortl. Sci., v. 4, n. 2, p. 184-186, 2009.

NEVES, M. B.; BUZETTI, S.; CASTILHO, R. M. M. de; BOARO, C. S. F. Development of ornamental sunflower plants (*Helianthus annuus* L.) in flowerpots, two substrata with nutritive solution and in soil. Científica, Jaboticabal, v.33, n.2, p. 127-133, 2005.

NERY, F. C. How can biotechnology improve floriculture? Ornamental Horticulture, v.27, n.2, p.115-116, 2021. https://doi.org/10.1590/2447-536X.v27i2.2319

PUTTHA, R., VENKATACHALAM, K., HANPAKDEESAKUL, S., WONGSA, J., PARAMETTHANUWAT, T., SREAN, P., PAKEECHAI; K., CHAROENPHUN, N. Exploring the potential of sunflowers: agronomy, applications, and opportunities within bio-circular-green economy. Horticulturae, 9, 1079, 2023. https://doi.org/10.3390/horticulturae9101079

REIS, M.V.; SANT'ANA, G. S.; PAIVA, P. D. O.; BONIFÁCIO, F. L.; GUIMARÃES, P. H. Profile of producer and retailer of flower and ornamental plant. Ornamental Horticulture, v. 26, n. 3., 2020. https://doi.org/10.1590/2447-536X.v26i3.2164

RINALDI, M.; LOSAVIO, N.; FLAGELLA, Z. Evaluation and application of the OILCROP-SUN model for sunflower in southern Italy. Agricultural Systems, v.78, 2003.

SCHWAB, N. T. et al. Aplicabilidade do termo antocrono para representar a velocidade de abertura de flores em inflorescência. Pesquisa Agropecuária Brasileira, v. 49, n. 9, p. 657-664, 2014.

SEMENIUK, P.; KRIZEK, D.T. Influence of germination and growing temperature on flowering of six cultivars of annual statice (Limonium cv.). J. Amer. American Society for Horticultural Science, v. 98, p.140–142, 1973.

SHATOORI, M. M.; SAFFARI, V. R.; FARAHMAND, H. Correlation Between Vase Life and Biochemical Parameters in Ornamental Sunflower (*Helianthus annuus* L.) Affected by Spraying Chemical Materials During the Growth Stages. Journal of Plant growth Regulation, v. 40, p. 179-186, 2021. https://doi.org/10.1007/s00344-020-10088-2

SHILLO, R. Control of flower inanition and development of statice (Limonium sinuatum) by temperature and daylength. Acta horticulturae, v. 64, 1976.

SHILLO, R.; E. ZAMSKI. Limonium sinuatum. In: Halevy, A.H. (ed.). RC handbook of flowering. CRC Press, Boca Raton, FL, p. 293-301, 1985.

STRECK, S. A.; UHLMANN, L. O. 2021. Flowers for all; brinding the gap between science and society. Chronica Horticulturae, v. 61, p 32-34.

TOMBOLATO, A.F.C. et al. Bulbosas ornamentais no Brasil. Revista Brasileira de Horticultura Ornamental, v.16, p.127-138, 2010.

UHLLMANN, L. O. et al. PhenoGlad: A model for simulating development in Gladiolus**.** European Journal of Agronomy, v. 82, p. 33-49, 2017.

UHLMANN, L.O; BECKER, C.C.; TOMIOZZO, R.; STRECK, N.A.; SCHONS, A.; BALEST, D.S.; BRAGA, M.S.; SCHWAB, N.T.; LANGNER, J.A. Gladiolus as an alternative for diversification and profit in small rural property. Ornamental Horticulture, v. 25, p. 200-208, 2019.

VILLALOBOS, F. J. et al. OILCROP-SUN: A Development, Growth, and Yield Model of the Sunflower Crop. Agronomy Journal, v.88, 1996.

WHIPKER, B. E.; HAMMER, P. A. Características de crescimento e produção de *Limonium sinuatum* cultivado em campo (L.). HortScience , v. 29, n. 6, p. 638-640, 1994.

APÊNDICES

APÊNDICE A

Supplementary 1. Exploratory analysis of developmental cycle, phyllochron, final leaf number, plant height, stem diameter and capitulum diameter for tropical, subtropical and temperate environments for cut sunflower in 4 trials in Brazil and 1 in Italy.

Environment	**Variable**	**Descriptive statistics**									
		Min	**Max**	**$\bar{x}$**	**Med**	**Q1**	**Q3**	**SD**	**Skew**	**Kurt**	**CV%**
Tropical	Dev. Cycle (°C day)	792.8	1431.0	1067.0	1042.0	936.80	1179.0	152.7	0.26	-0.60	14.31%
	Dev. Cycle (days)	43.0	78.20	54.26	52.40	48.85	58.18	8.202	0.95	0.38	15.12%
	Phyllochron	20.00	37.70	27.60	26.30	23.90	31.30	5.07	0.40	-0.89	18.39%
	FLN	15.60	32.50	24.69	24.70	22.80	28.20	4.35	-0.59	-0.19	17.63%
	LN at R1	7.80	26.90	18.21	18.80	14.80	21.60	4.77	-0.41	-0.75	26.20%
	FLN – LN at R1	2.20	15.20	7.29	7.40	5.30	8.80	3.03	0.60	0.12	41.53%
	Plant Height	72.40	217.1	140.3	140.90	119.10	162.50	28.82	0.05	-0.19	20.54%
	Stem diameter	0.60	1.70	1.18	1.10	0.60	1.30	0.19	0.43	0.60	16.90%
	Capitulum diameter	3.50	8.90	5.29	5.20	4.70	5.78	0.98	0.92	2.21	18.44%
Subtropical	Dev. Cycle (°C day)	714.7	1457.0	1003.0	999.0	911.1	1075.0	142.5	0.66	0.86	14.21%
	Dev. Cycle (days)	40.0	110.8	66.90	63.70	54.20	76.65	15.61	0.86	0.07	23.34%
	Phyllochron	18.60	38.50	26.65	26.25	23.00	29.65	4.47	0.50	-0.27	16.75%
	FLN	13.0	40.40	24.45	24.65	20.30	28.13	5.42	0.27	-0.12	22.14%
	LN at R1	6.80	30.70	17.02	16.75	13.53	20.98	4.93	0.11	-0.57	28.94%
	FLN – LN at R1	0.90	14.00	6.80	6.70	4.70	8.80	2.78	0.23	-0.39	40.93%

Cont. **Supplementary 1**

	Plant Height	54.5	217.4	127.2	126.0	101.40	151.70	36.70	0.23	-0.31	28.85%
	Stem diameter	0.60	2.8	1.36	1.30	1.13	1.50	0.34	1.16	3.68	28.14%
	Capitulum diameter	2.80	10.30	5.81	5.60	5.00	6.60	1.27	0.69	0.86	21.88%
Temperate	Dev. Cycle (°C day)	903.5	1383.0	1140.0	1131.0	1050.0	1247.0	140.60	0.40	-0.25	12.34%
	Dev. Cycle (days)	81.00	108.0	94.96	94.40	90.20	101.2	7.86	0.27	-0.19	8.27%
	Phyllochron	23.80	31.30	26.68	26.40	25.35	27.75	2.03	0.75	1.02	7.62%
	FLN	17.50	32.30	26.25	26.10	23.60	30.60	4.55	-0.47	-0.39	17.33%
	LN at R1	12.40	25.50	18.25	18.00	14.65	21.35	4.06	0.45	-0.77	22.24%
	FLN – LN at R1	5.00	13.20	8.04	7.40	5.10	13.20	2.96	0.39	-1.43	36.84%
	Plant Height	113.8	195.70	158.50	159.40	146.50	172.50	20.60	-0.43	1.04	12.99%
	Stem diameter	1.20	1.80	1.44	1.40	1.35	1.50	0.15	0.96	1.97	10.44%
	Capitulum diameter	4.90	7.40	6.16	6.20	5.65	6.70	0.71	0.06	-0.26	11.49%

Min = minimum value; Max = maximum value, $\overline{x}$ = mean, Med = median, Q1 = first quartile, Q3 = third quartile, SD = standard deviation, Skew = coefficient of Skewness, Kurt = coefficient of kurtosis, CV (%) = coefficient of variation.

APÊNDICE B

Supplementary 2. Minimum, maximum and mean temperature across different locations, sowing (mm/dd/yyyy), transplant date (mm/dd/yyyy) for each trial.

Trial	Location	Sowing date	Transplant date	TMin (°C)	TMax (°C)	Tmean (°C)
1	Santa Maria, RS, Brazil	08/06/2020	08/17/2020	-0.9	34.5	16.8
2	Santa Maria, RS, Brazil	01/22/2021	01/30/2021	12.7	35.0	23.8
		02/26/2021	03/06/2021	9.8	35.0	22.4
	Júlio de Castilhos, RS, Brazil	2/25/2021	03/06/2021	0.0	30.3	15.1
	Herval D'Oeste, SC, Brazil	1/29/2021	02/08/2021	9.5	33.3	21.4
		2/26/2021	03/06/2021	4.0	33.3	18.6
3	Cáceres, MT, Brazil	09/02/2022	09/12/2022	13.4	41.5	27.4
	Capanema, PA, Brazil	09/10/2022	09/17/2022	21.4	34.4	27.9
	Curitibanos, SC, Brazil	09/16/2022	10/17/2022	1.0	34.6	17.8
	Dois Vizinhos, PR, Brazil	01/27/2023	02/04/2023	10.8	33.8	22.3
	Dourados, MS, Brazil	01/19/2023	01/27/2023	13.7	35.7	24.7
	Petrolina, PE, Brazil	08/08/2022	08/16/2022	14.7	37.1	25.9
	Santa Maria, RS, Brazil	08/08/2022	08/25/2022[a]	1.2	32.3	16.8
	São João Del Rei, MG, Brazil	09/13/2022	09/23/2022	8.0	33.5	20.8
4	Pescia, PT, Italy	02/28/2023	03/17/2023	0.5	32.7	16.6
5	Morro do Chapéu, BA, Brazil	04/17/2023	04/25/2023	16.6	33.9	25.2
	Dourados, MS, Brazil	10/15/2021	10/15/2021	14.7	35.7	25.2
	Teresina, PI, Brazil	16/08/2021	08/25/2021	16.8	39.5	28.1
		09/30/2021	10/07/2021	11.3	30.6	20.9
		03/09/2022	03/22/2022	21.7	33.8	27.7
	Areia, PB, Brazil	09/11/2022	09/22/2022	17.5	30.0	23.7
	Solânea, PB, Brazil	09/11/2022	09/22/2022	17.5	30.0	23.7

Canhotinho, PE, Brazil	11/03/2022	11/16/2022	17.3	30.5	23.9
Garanhuns, PE, Brazil	04/03/2023	04/12/2023	18.5	34.5	26.5
Jupí, PE, Brazil	04/05/2023	04/15/2023	18.5	34.5	26.5
Petrolina, PE, Brazil	02/03/2022	02/11/2022	19.1	34.9	27.0
	05/26/2022	06/03/2022	14.5	32.2	23.3
Cascavel, PR, Brazil	09/29/2021	10/12/2021	12.5	33.8	23.1
Santa Tereza do Oeste, PR, Brazil	03/17/2022	03/28/2022	13.7	27.1	20.4
Aurora, SC, Brazil	10/05/2021	10/15/2021	11.3	32.9	22.1
Brunópolis, SC, Brazil	03/17/2021	03/31/2021	1.7	28.5	15.1
	03/31/2021	04/14/2021	1.7	28.5	15.1
Concórdia, SC, Brazil	10/06/2021	10/25/2021	9.6	32.5	21.0
Curitibanos, SC, Brazil	09/08/2022	10/05/2022	0.9	25.8	13.4
Ituporanga, SC, Brazil	10/18/2021	10/27/2021	10.0	32.9	21.4
Herval D’Oeste, SC, Brazil	03/22/2021	03/29/2021	4.0	30.5	17.2
Rio do Sul, SC, Brazil	03/29/2021	04/09/2021	2.8	27.4	15.1
	10/05/2021	10/15/2021	11.3	32.9	22.1
Seara, SC, Brazil	09/26/2022	10/13/2022	4.4	29.6	17.0
Trombudo Central, SC, Brazil	10/18/2021	10/26/2021	10.0	32.9	21.4
Cachoeira do Sul, RS, Brazil	03/20/2021	03/29/2021	2.7	36.0	19.3
	04/13/2021	04/27/2021	2.7	33.9	18.3
Júlio de Castilhos, RS, Brazil	04/15/2021	04/25/2021	0.0	30.3	15.1
	10/13/2021	10/22/2021	9.1	35.8	22.4
	11/04/2021	11/16/2021	11.3	39.0	24.1
	01/08/2022	01/20/2022	11.2	31.3	25.1
	04/12/2022	04/26/2022	-1.0	31.3	15.1
Dilermando de Aguiar, RS, Brazil	03/15/2021	03/24/2021	5.6	33.8	19.7
	10/07/2022	10/25/2022	9.4	37.7	23.5
	10/24/2022	11/04/2022	9.6	37.7	23.6
Santa Maria, RS, Brazil	03/05/2021	03/13/2021	3.2	35.0	19.1

Cont. **Supplementary 2**

	03/05/2021	03/16/2021	3.2	35.0	19.1
	03/16/2021	03/23/2021	3.2	35.0	19.1
	05/11/2021	06/01/2021	-0.6	35.1	17.2
	06/08/2021	07/02/2021	-0.6	35.1	17.2
	07/02/2021	07/16/2021	-0.6	35.1	17.2
	07/13/2021	08/10/2021	-0.6	35.1	17.2
	09/07/2021	09/24/2021	6.0	37.7	21.8
	10/15/2021	10/26/2021	9.6	37.7	23.6
	01/27/2022	02/04/2022	10.4	37.7	24.0
	04/20/2022	04/29/2022	1.1	33.2	17.1
	09/16/2022	09/29/2022	4.6	34.9	19.7
Caiçara, RS, Brazil	09/27/2021	10/08/2021	15.8	27.4	21.6
Venâncio Aires, RS, Brazil	03/15/2021	03/23/2021	3.2	35.0	19.1
	04/05/2021	04/13/2021	1.3	34.6	17.9
Novo Xingú, RS, Brazil	09/23/2021	10/05/2021	16.0	30.0	23.0
	10/09/2021	10/21/2021	16.0	30.0	23.0
	10/25/2021	11/10/2021	16.0	30.0	23.0
	11/16/2021	11/30/2021	16.0	30.0	23.0
Seberi, RS, Brazil	09/27/2021	10/08/2021	7.8	33.9	20.8
	10/22/2021	11/04/2021	7.8	36.0	21.9
	10/21/2021	11/04/2021	7.8	36.0	21.9
Vale do Sol, RS, Brazil	10/20/2021	11/12/2021	9.1	36.9	23.0
Boa Vista do Sul, RS, Brazil	03/12/2022	03/22/2022	4.3	32.0	18.1
Novo Cabrais, RS, Brazil	02/22/2022	03/02/2022	6.4	37.7	22.0
	03/11/2022	03/19/2022	6.4	34.4	20.4
Picada Café, RS, Brazil	03/12/2022	03/28/2022	6.3	35.4	20.8
Santa Bárbara do Sul, RS, Brazil	03/14/2022	03/26/2022	2.9	33.8	18.3
Teutônia, RS, Brazil	03/14/2022	03/23/2022	6.7	34.9	20.8
Piratini, Brazil	03/11/2022	03/24/2022	6.5	31.6	19.0

Cont. **Supplementary 2**

	Rio Pardo, RS, Brazil	02/04/2022	02/14/2022	12.3	38.0	25.1
		02/14/2022	02/24/2022	8.0	38.0	23.0
	Bom Princípio, RS	02/22/2022	03/02/2022	6.3	37.8	22.0
	Cândido Godói, RS	03/11/2022	03/21/2022	6.0	36.2	21.1
	Maçambará, RS, Brazil	03/10/2022	03/20/2022	7.1	35.2	21.1
	Estrela Velha, RS, Brazil	03/10/2022	03/31/2022	1.2	34.4	17.8
	São Marcos, RS, Brazil	09/15/2022	10/07/2022	4.2	30.1	17.1
	Lajeado, RS, Brazil	09/10/2022	10/01/2022	6.0	33.6	19.8
	Faxinalzinho, RS, Brazil	09/29/2022	10/17/2022	3.6	29.8	16.7
	Barra do Ribeiro, RS, Brazil	10/17/2022	10/28/2022	9.3	35.6	22.4
	Colinas, RS, Brazil	09/20/2022	10/03/2022	7.2	35.7	21.4
	Santa Rosa, RS, Brazil	09/17/2022	09/27/2022	3.4	35.0	19.2
	Alegrete, RS, Brazil	02/23/2023	03/02/2023	11.2	36.4	23.8
		03/02/2023	03/09/2023	6.1	35.4	20.7
		03/09/2023	03/16/2023	6.1	35.4	20.7
		03/16/2023	03/23/2023	6.1	35.1	20.6
	Bozano, RS, Brazil	01/27/2023	02/03/2023	6.6	36.4	21.5
		02/03/2023	02/10/2023	6.6	36.4	21.5
		02/10/2023	02/17/2023	6.6	36.4	21.5
		02/17/2023	02/24/2023	6.6	34.3	20.4
	Vila Flores, RS, Brazil	04/03/2023	04/18/2023	3.2	28.8	16.0
	Vacaria, RS, Brazil	04/03/2023	04/13/2023	-2.0	27.0	12.5
	Nova Petrópolis, RS, Brazil	04/03/2023	04/14/2023	6.4	35.3	20.8
	Bento Gonçalves, RS, Brazil	04/04/2023	04/22/2023	6.4	28.8	17.6
	Sapiranga, RS, Brazil	04/05/2023	04/21/2023	1.9	34.7	18.3
	São Borja, RS, Brazil	04/01/2023	04/14/2023	6.9	32.5	19.7