

ARTICLE

Damage by frost and lower lethal temperature in field-grown cut dahlia

Dano por geada e temperatura letal crítica inferior em dália de corte cultivada a campo

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Abstract: Dahlia (*Dahlia variabilis* Desf.) is a widely cultivated ornamental crop valued for its rusticity and aesthetic appeal, but highly sensitive to thermal stress, particularly low temperatures. This study aimed to determine the lower lethal temperature (LLT) for five field-grown cut dahlia cultivars in order to support adaptive management strategies under extreme climatic events. Field experiments were conducted from January to July 2024 in Santa Maria, Jaguari, and Esteio, located in the subtropical climate zone of Rio Grande do Sul, Brazil. Daily minimum and maximum air temperatures were obtained from INMET (Santa Maria and Jaguari) and NASA POWER (Esteio). Damage symptoms, including leaf curling, wilting, necrosis, bud rot, and flower mummification, were visually assessed by independent observers and correlated with minimum temperatures and plant developmental stages. LLT was defined as the lowest temperature recorded on the day prior to the occurrence of irreversible damage in at least 50% of plants. In Santa Maria and Jaguari, minimum temperatures of 0.2 °C and 0.1 °C over two consecutive days caused severe vegetative and reproductive damage. In Esteio, a single-day minimum of 0.5 °C did not result in visible damage, highlighting the role of exposure duration and plant phenological stage in determining cold stress severity. The LLT for the tested cultivars was estimated at approximately 0 °C. Mitigation practices such as low polyethylene tunnels, floating row covers, thermal meshes, sprinkler irrigation, plastic soil mulching, selection of more cold-tolerant cultivars, and adjusted planting schedules are recommended. These findings provide valuable insights into dahlia responses to cold stress and support adaptive management strategies for ornamental crops in frost-prone regions.

Keywords: cold stress, cold injury, cut flowers, low temperatures.

Resumo: A dália (*Dahlia variabilis* Desf.) é uma cultura ornamental valorizada por sua rusticidade e apelo estético, mas altamente sensível ao estresse térmico, especialmente ao frio. Este estudo teve como objetivo determinar a temperatura letal inferior (LLT) para cinco cultivares de dalias de corte cultivadas a campo, a fim de subsidiar estratégias de manejo adaptativo frente a eventos climáticos extremos. Experimentos foram conduzidos de janeiro a julho de 2024 nos municípios de Santa Maria, Jaguari e Esteio, região de clima subtropical do Rio Grande do Sul, Brasil. As temperaturas mínimas e máximas diárias foram obtidas do INMET (Santa Maria e Jaguari) e NASA POWER (Esteio). Sintomas de dano, como enrolamento foliar, murcha, necrose, apodrecimento de botões e mumificação de flores, foram avaliados diariamente por observadores independentes e correlacionados com as temperaturas mínimas e a fase de desenvolvimento. A LLT foi definida como a temperatura mais baixa registrada no dia anterior ao aparecimento de danos irreversíveis em pelo menos 50% das plantas. Em Santa Maria e Jaguari, temperaturas de 0,2 °C e 0,1 °C durante dois dias consecutivos causaram severos danos vegetativos e reprodutivos. Em Esteio, 0,5 °C em apenas um dia não resultou em danos, evidenciando a importância da duração da exposição e da fase fenológica. A LLT para as cultivares avaliadas foi estimada em aproximadamente 0 °C. Recomenda-se adoção de práticas de mitigação como túneis baixos, coberturas flutuantes, malhas térmicas, irrigação por aspersão, uso de cultivares mais tolerantes e ajustes no calendário de plantio. Os resultados oferecem subsídios para estratégias adaptativas no cultivo de dalias em regiões sujeitas à geada.

Palavras-chave: Baixas temperaturas, estresse por frio, flores de corte, injúria por frio.

Introduction

The floriculture sector has increased in importance in Brazilian agribusiness during the last decade, particularly among small farmers, due to its high profitability and relatively low land-use requirements (Junqueira and Peetz, 2017; Streck and Uhlmann, 2021; Fonseca et al., 2024). In Brazil, the consumption of flowers and ornamental plants has peak demands on commemorative dates such as International Women's Day, Mother's Day, Valentine's Day, and All Souls' Day. This seasonal demand for flowers indicates a need for a stable and resilient production system that can withstand environmental stressors and ensure consistent flower quality and availability.

Among the wide range of ornamental species cultivated, cut dahlias (*Dahlia variabilis* Desf.) stand out for their commercial value, adaptability to open-field cultivation, and diverse flower morphology, which enhances their market appeal. Native to the mountainous regions of Mexico and belonging to the Asteraceae family, dahlias are perennial herbaceous plants that can be propagated by seeds, cuttings or tubers, and have been widely used as bedding plants, garden plants and cut flowers in subtropical and temperate regions around the world (Brondum and Heins, 1993). Their versatility and aesthetic appeal have contributed to their increasing significance in the floriculture industry worldwide. In Brazil, cut dahlias were included in 2021 in the Flowers for All project,

a nationwide initiative aimed at fostering social inclusion and income diversification among small rural producers by promoting the cultivation of resilient and easy-to-manage flower species (Streck and Uhlmann, 2021; Fonseca et al., 2024).

Dahlias have cardinal temperatures that define the range of temperatures where plants can survive and thrive, with a lower base temperature (T_b) of 5.5 °C and an upper base temperature (T_B) of 34.9 °C, depending on developmental phase (Brondum and Heins, 1993). An exposure to temperatures below T_b slows metabolism to a very low rate so that development and growth processes stop or take place at a minimum rate that can be neglected from a practical view point, and as temperatures continues to drop, cells and tissues can be damaged irreversible, achieving the so called lower lethal temperature (LLT) (Erpen et al., 2013; Munns, 2018). Fernandes et al. (2023b) characterized the main phenological stages of dahlias and quantified their phyllochron under different temperature regimes, highlighting the importance of thermal time in predicting developmental progression, particularly under field conditions.

Despite extensive research on temperature thresholds for many ornamental species, information regarding the effects of suboptimal temperatures on field-grown dahlias remains limited, particularly in subtropical and temperate regions where freezing temperatures and frosts are more frequent and LLT can be achieved. Low air temperatures

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can disrupt physiological processes in plants, with reproductive organs (buds and flowers) often being the most vulnerable. Studies on other ornamental species, such as gladiolus (*Gladiolus x grandiflorus* Hort.), indicate that extreme temperatures, both high and low, can compromise reproductive development, reducing flower quality and yield (Schwab et al., 2018; Uhlmann et al., 2017; Uhlmann et al., 2021; Becker et al. 2021). Furthermore, climate change has significantly altered temperature patterns both on a global and on a regional scale, increasing the frequency and intensity of extreme weather events, including frost episodes in temperate regions (IPCC, 2021). These climatic shifts pose a major challenge for ornamental horticulture, particularly for species sensitive to temperature fluctuations, such as dahlias. Therefore, understanding how dahlias respond to cold stress is therefore crucial for implementing adaptive management practices, including optimized planting schedules, election

of cold-tolerant cultivars, protective strategies such as frost protection nets and sprinkler irrigation.

The objective in this study was to determine the lower lethal temperature (LLT) for field-grown cut dahlias, contributing to the development of climate-adaptive management strategies that mitigate the adverse effects of low air temperatures.

Material and Methods

Locations of the experiments: field experiments were conducted in the state of Rio Grande do Sul (RS), located in Southern Brazil, from January to October 2024, covering the entire planting-to-blooming cycle of dahlias, in the municipalities of Santa Maria, Jaguari, and Esteio, situated in a subtropical climate zone in the state of Rio Grande do Sul, Brazil (Fig. 1).

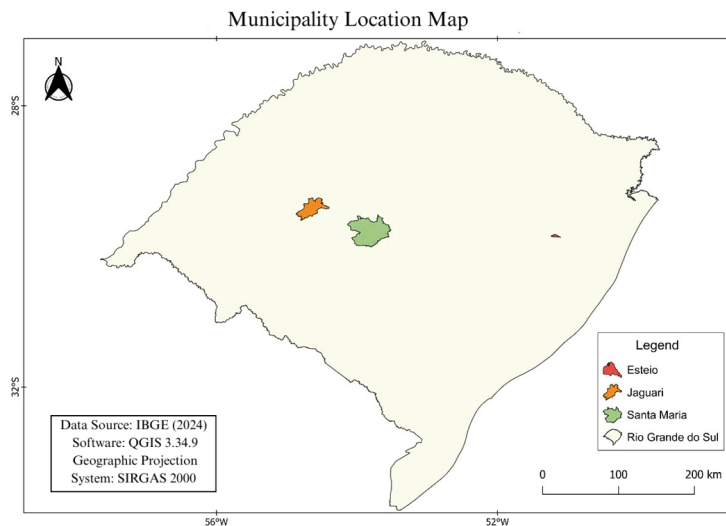


Fig. 1. Geographic location of the municipalities where field experiments with dahlia were conducted in the state of Rio Grande do Sul, Brazil.

The study was performed in Esteio (red), Jaguari (orange), and Santa Maria (green).

Map created using QGIS 3.34.9, projection system SIRGAS 2000. Source of data: IBGE (2024).

The state of Rio Grande do Sul (RS) has a humid subtropical climate (Cfa and Cfb according to the Köppen classification), with well-distributed rainfall throughout the year and well-defined seasonal variations in terms of temperature (Alvares et al., 2013). Due to its geographic location and topography, the entire state is highly susceptible to temperature extremes, including frost events in late Autumn, Winter, and early Spring. The climate is notably variable, with frequent thermal fluctuations during transitional seasons that favor unexpected frost occurrences (Fig. 1).

According to the eco-climatic division by Maluf and Caiaffo (2001), Santa Maria (95 m) and Jaguari (110 m) are located in the Central Region, whereas Esteio (25 m) is part of the Metropolitan Region of Porto Alegre. Based on historical climate normals from INMET (1991 – 2020), the

average minimum temperatures in June and July are 10.4 °C and 9.4 °C in Santa Maria, and 11.3 °C and 10.4 °C in Porto Alegre (used here as a proxy for Esteio). These data confirm a higher frost risk in Santa Maria and Jaguari, particularly in low-lying areas with cold air drainage, while Esteio, influenced by urban heat effects and slightly lower elevation, presents milder winter conditions (Maluf, 2000; Heldwein et al., 2009).

Dahlia cultivars: Five dahlia (*Dahlia variabilis* Desf) cultivars were used in the study: Carla, Marina, Vicent Vans, Rebecca's World, and Frantônio. They differ in color and number of petals, and size of the capitulum (Fig. 2).

Details about the dahlia cultivars and planting dates at each location are in Table 1.



Fig. 2. Dahlia (*Dahlia variabilis* Desf.) cultivars (A) Carla, (B) Marina, (C) Vicent Vans, (D) Rebecca's World, and (E) Frantônio used in field experiments conducted in three municipalities in the state of Rio Grande do Sul, Brazil, during 2024.

Table 1. Locations, dahlia cultivars, planting dates, during the field experiments in Southern Brazil.

Location	Cultivars	Planting Date (dd/mm/yyyy)
Santa Maria	Carla, Marina, Vicent Vans	22/02/2024
Jaguari	Frantonio, Rebecca's World	07/01/2024
Esteio	Carla	04/06/2024 11/06/2024

Field Experiments: field management practices followed a nationwide protocol of the Flowers for All project (Streck and Uhlmann, 2021; Fonseca et al., 2024). Dahlia (*Dahlia variabilis* Desf) tubers from a commercial company were planted in all sites at a depth of 5 cm in raised beds measuring 1.0 m in width and 0.2 m in height, with a plant spacing of 0.40 m × 0.40 m. No supplementary irrigation was needed, as there was abundant rainfall during the experiment on all sites. Pre-planting fertilization was performed with 50 g m⁻² of NPK (5-20-20), and soil pH correction was carried out according to the needs of each location based on soil tests. Once the first flower was harvested, top-dressing fertilization was performed with 50 g m⁻² of urea and 50 g m⁻² of potassium chloride.

Meteorological Data: Daily minimum and maximum air temperatures were obtained from meteorological stations of the Brazilian National Weather Service (INMET, 2024) for the sites of Santa Maria (automatic station located at Universidade Federal de Santa Maria) and Jaguari (data from the meteorological station at São Vicente do Sul station, situated approximately 20 km from the experimental area). For Esteio, due to the absence of a reliable local weather station after the floods that affected

much of Rio Grande do Sul in May 2024, temperature data were retrieved from the NASA POWER platform (NASA, 2024).

Plant Assessments: In order to evaluate and to identify symptoms of damage due to cold temperatures in leaves, buds, and flowers such as leaf curling, wilting, dry edges, necrosis, burns, and rotting daily observations were made on ten tagged plants per cultivar at each site, from February 22th to October 25th, 2024. The evaluation criteria included leaf curling, wilting (reversible or irreversible), dry margins, tissue necrosis, flower burns, bud rot, and flower mummification. Each symptom was visually scored on an ordinal scale (0 = no damage, 1 = mild, 2 = moderate, 3 = severe), based on methods adapted from Sakai and Larcher (1987) and Levitt (1980), which describe plant physiological responses to cold stress. Field teams underwent prior training led by the principal investigators, including theoretical sessions with reference images, joint assessments in the field during symptomatic days, and calibration of visual scores through group discussions and photographic documentation. Plant developmental stages and phases were also recorded daily and classified as vegetative, reproductive, visible bud, flowering, or floral senescence. All data were logged into digital

spreadsheets, integrating date, cultivar, location, symptoms, severity, and developmental phase, supported by georeferenced photographic records. It is important to highlight the current lack of published data on cold tolerance among commercial dahlia cultivars under field conditions, particularly in the subtropical humid climate of southern Brazil, which reinforces the importance of the findings generated by this study for both scientific and horticultural communities.

The appearance of the cold symptoms was correlated with the minimum daily air temperature recorded at each site to estimate the lower lethal temperature (LLT). The minimum temperature observed the day before visible and irreversible symptoms appeared in at least 50% of the plants was assumed as the LLT.

Results and Discussion

During the experimental period, daily minimum temperature fluctuations indicated varying degrees of cold stress across the studied locations (Fig. 3), with cold air events recorded on June 29th, June 30th, and July 1st in Santa Maria and Jaguari, and on July 1st in Esteio. These cold events were associated with minimum temperatures below 1 °C and preceded the appearance of damage symptoms in the plants. The first cold event, which affected all three locations, was more intense in Santa Maria and Jaguari (lowest recorded minimum temperature: -0.2 °C in Jaguari compared to Esteio (0.5 °C)). The green dotted line in Fig. 3 represents the base temperature of 5.5 °C for dahlia (Brundum and Heins, 1993), below which plant development rate can be neglected.

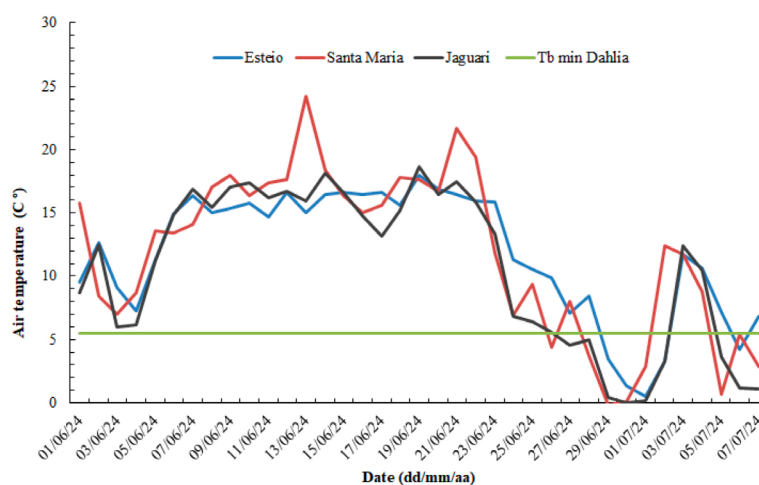


Fig. 3. Daily minimum temperature in three locations (Santa Maria, Jaguari, and Esteio, Rio Grande do Sul State) during the Winter of 2024. Frost events and cold-induced damage in Santa Maria (red arrow) and Jaguari (black arrow) are indicated. The green dotted line indicates the lower base temperature (5.5 °C) for dahlia development.

In Santa Maria and Jaguari (Fig. 4A – 4E), plants were at the reproductive phase when exposed to sub-zero temperatures and exhibited irreversible damage such as bud and leaf necrosis, mummification, and tissue discoloration. In contrast, plants in Esteio, which were still at the vegetative phase at the time of the cold event, remained visually unaffected (Fig. 4F – 4J), despite the minimum temperature reaching 0.5 °C. It was also observed that exposure periods exceeding 12-h at or near freezing temperatures notably intensified the occurrence of damage symptoms, particularly in plants in the reproductive phase. Based on these results and the analysis of daily minimum temperatures (Fig. 3), it is suggested that the lower lethal temperature (LLT) for dahlias is approximately 0 °C, with more severe damage occurring when temperatures fall below this threshold. Furthermore, our results suggest that short exposures (less than 12-h) to temperatures slightly above freezing (between 1 °C and 2 °C) may not cause visible injury, while minimum daily temperature below 0 °C for two or more consecutive days can lead to significant tissue damage. This reinforces the observation that not only the intensity of cold, but also the duration of exposure, particularly beyond 12 hours, is critical in determining the extent of injury. For example, the results obtained in this study demonstrate that not only the absolute

minimum temperature, but also the duration of exposure to cold, are decisive factors in determining the extent of frost damage in *Dahlia variabilis*. In Santa Maria and Jaguari, severe damage to vegetative and reproductive structures was observed after two consecutive days with minimum temperatures close to 0 °C, whereas in Esteio, a single occurrence of 0.5 °C did not result in visible injuries. This contrast reinforces the role of prolonged exposure in intensifying physiological stress. The symptoms documented such as necrosis, bud rot, and floral mummification, are consistent with cellular damage mechanisms reported in the literature, including increased membrane permeability, dehydration, and the formation of intracellular and extracellular ice (Krahl and Marocco, 2019). Such physiological disruptions are known to be exacerbated when low temperatures persist for extended periods, often exceeding 12-h, facilitating cumulative stress and mechanical injury. These biophysical processes disrupt membrane integrity and cellular compartmentalization, ultimately leading to tissue collapse. The different severity of symptoms among cultivars also suggests potential genotypic variation in cold tolerance, highlighting the importance of cultivar-specific assessments when designing adaptive management strategies for ornamental species under frost-prone conditions.



Fig. 4. Damage caused by cold temperatures in dahlia plants cultivated in the field in three locations in Southern Brazil after the first frost event of 2024. All plants were at the reproductive phase at the time of the event (A, B, C) in Santa Maria, showing necrosis and mummification in buds and leaves; (D, E) in Jaguari, highlighting severe necrosis and tissue discoloration; and (F, G, H, I, J) in Esteio, where the plants were at the vegetative phase remained healthy, with no visible symptoms of cold damage.

Low temperatures also trigger an increase in reactive oxygen species (ROS), which can further compromise cell integrity, requiring plants to activate antioxidant defense mechanisms to mitigate oxidative damage. Such responses have been observed in other cold-stressed species, such as *Setaria viridis*, where enhanced antioxidant activity played a crucial role in reducing cellular injury (Carvalho et al., 2022; Kolupayev et al., 2022).

Plants exposed to low temperatures undergo a complex network of transcriptional, epigenetic, and metabolic adjustments to enhance their tolerance to cold (Ding et al., 2024). Cold-responsive genes (COR genes), including C-repeat binding factors (CBFs), regulate membrane fluidity, osmoprotectant accumulation, and antioxidant defense mechanisms, thereby preventing cellular damage caused by freezing temperatures. These molecular responses have been extensively documented in various ornamental species, reinforcing the importance of selecting cold-tolerant genotypes of ornamental crop production in subtropical and temperate regions. However, research on the specific molecular responses of dahlias to cold stress remains limited, indicating the need for further studies to characterize their tolerance mechanisms (Kolupayev et al., 2023).

The response of dahlias to cold temperatures reflects a pattern of thermal sensitivity similar to that observed in previous studies related to heat stress (Fernandes et al., 2023a), indicating that the reproductive parts of plants, such as buds and flowers, show higher vulnerability to extreme temperatures, both heat or cold, compared to vegetative parts (leaves and stems). Studies on other ornamental species, such as gladiolus, corroborate with the results with dahlia in this study so that extreme temperatures, whether heat or cold, cause irreversible damage to reproductive parts, emphasizing the need for preventive management to ensure the sustainability of ornamental crops (Streck et al., 2021).

Selecting dahlia cultivars for their tolerance to cooler temperatures can significantly enhance their survival and performance in frost-prone regions. Previous studies indicate that cultivars adapted to temperate climates display greater cold resistance, attributed to physiological traits such as increased membrane fluidity and heightened antioxidant activity (Wang et al., 2018). The results of this study reinforce that dahlias (*Dahlia variabilis* Desf) are particularly sensitive to low temperatures, with more pronounced damage occurring under prolonged cold conditions. These findings are important for understanding the impacts of climate on ornamental crops and developing adaptive management practices to

ensure sustainable cultivation in subtropical and temperate regions and contributing towards a sustainable production of cut dahlias, even in climate change scenarios.

As practical applications of the results from this study, protective management practices can be adopted by farmers to minimize cold impacts in subtropical and temperate regions such as polyethylene low tunnels, covering plants during cold spells, frost protection nets, floating row covers, soil mulching with black plastic, adjustments of planting schedules to avoid the coldest period of the year, selection of cold-tolerant cultivars, proper site selection with good air circulation, and sprinkler irrigation which releases latent heat upon freezing, protecting plant tissues. Monitoring local weather forecasts and being prepared to take promptly action can further mitigate the risks associated with low-temperature exposure.

Conclusions

The lower lethal temperature (LLT) for field grown cut dahlias (*Dahlia variabilis* Desf) is approximately 0 °C, with more severe damage occurring when minimum daily temperatures fall below freezing for two or more consecutive days. Reproductive structures were the most affected, reinforcing the importance of adaptive management strategies to mitigate frost damage in dahlia cultivation. These findings contribute to sustainable management practices in ornamental horticulture, ensuring better resilience to extreme temperatures in subtropical and temperate regions.

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Author Contribution

MESF: Conceptualization, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing. **MLS:** Conceptualization, Investigation, Data Curation, Writing – Review & Editing. **LLB:** Investigation, Supervision, Writing – Review & Editing. **LOU:** Investigation, Supervision, Writing – Review & Editing. **LGOS:** Investigation, Data Curation, Formal Analysis. **TH:** Investigation, Data Curation, Formal Analysis. **LF:** Investigation, Data Curation, Formal Analysis. **NAS:** Conceptualization, Methodology, Supervision, Formal Analysis, Project Administration. Writing – Review & Editing.

Declaration of Competing Interests

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.

Data Availability Statement

Data will be made available upon request to the authors.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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