PANORAMA OF FLORICULTURE AND PHYSIOLOGICAL ASPECTS OF AMARYLLIS UNDER WATER STRESS CONDITIONS

PANORAMA DA FLORICULTURA E ASPECTOS FISIOLÓGICOS DA AMARÍLIS SOB CONDIÇÕES DE ESTRESSE HÍDRICO

PANORAMA DE LA FLORICULTURA Y ASPECTOS FISIOLÓGICOS DE LA AMARILIS BAJO CONDICIONES DE ESTRÉS HÍDRICO

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ABSTRACT

Floriculture is one of the most promising segments of global agribusiness, characterized by high profitability and continuous expansion, especially in countries such as the Netherlands, China, and the United States. In Brazil, the sector has stood out for its steady growth, even in the face of economic and climatic adversities, generating billions of reais and thousands of direct and indirect jobs. Among the species of greatest commercial relevance, amaryllis (Hippeastrum hybridum Hort.) presents significant economic and ornamental potential due to its wide diversity of cultivars, high market demand, and good adaptability to tropical and subtropical conditions. However, environmental factors, particularly water availability, significantly affect the productivity and quality of this species' flowers and bulbs. Water stress induces physiological and biochemical changes, such as stomatal closure, reduced photosynthetic rate, and accumulation of reactive oxygen species, compromising cellular metabolism and the visual appearance of the plants. To minimize these effects, amaryllis exhibits adaptive responses associated with increased activity of antioxidant enzymes and structural modifications in leaf tissues. This review presents an updated overview of the flower agribusiness, emphasizing the economic importance and edaphoclimatic requirements of amaryllis, and discusses the main physiological mechanisms involved in the response to water deficit. Understanding these responses is essential for the development of more efficient and sustainable water management practices, contributing to the production of higher-quality flowers and to strengthening the competitive performance of Brazilian floriculture.

Keywords: Water Deficit. Plant Physiology. Ornamental Flowers. Water Management.

RESUMO

A floricultura é um dos segmentos mais promissores do agronegócio mundial, caracterizado pela elevada rentabilidade e expansão contínua, especialmente em países como Holanda, China e Estados Unidos. No Brasil, o setor vem se destacando pelo crescimento constante, mesmo diante de adversidades econômicas e climáticas, movimentando bilhões de reais e gerando milhares de empregos diretos e indiretos. Dentre as espécies de maior relevância comercial, a amarílis (Hippeastrum hybridum Hort.) apresenta expressivo potencial econômico e ornamental, devido à sua ampla diversidade de cultivares, elevada demanda de mercado e boa adaptabilidade às condições tropicais e subtropicais. Entretanto, fatores ambientais, sobretudo a disponibilidade hídrica, afetam significativamente a produtividade e qualidade das flores e bulbos dessa espécie. O estresse hídrico induz alterações fisiológicas e bioquímicas, como fechamento estomático, redução da taxa fotossintética e acúmulo de espécies reativas de oxigênio, comprometendo o metabolismo celular e a aparência visual das plantas. Para minimizar esses efeitos, a amarílis apresenta respostas adaptativas associadas ao aumento da atividade de enzimas antioxidantes e à modificação estrutural dos tecidos foliares. Essa revisão apresenta um panorama atualizado do agronegócio de flores, com ênfase na importância econômica e nas exigências edafoclimáticas da amarílis, além de discutir os principais mecanismos fisiológicos de resposta ao déficit hídrico. Compreender tais respostas é essencial para o desenvolvimento de práticas de manejo hídrico mais eficientes e sustentáveis, contribuindo para a produção de flores de maior qualidade e para o fortalecimento competitivo da floricultura brasileira.

Palavras-chave: Déficit Hídrico. Fisiologia Vegetal. Flores Ornamentais. Manejo Hídrico.

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RESUMEN

La floricultura es uno de los segmentos más prometedores del agronegocio mundial, caracterizado por su alta rentabilidad y expansión continua, especialmente en países como los Países Bajos, China y Estados Unidos. En Brasil, el sector se ha destacado por su crecimiento constante, incluso frente a las adversidades económicas y climáticas, moviendo miles de millones de reales y generando miles de empleos directos e indirectos. Entre las especies de mayor relevancia comercial, la amarilis (Hippeastrum hybridum Hort.) presenta un destacado potencial económico y ornamental debido a su amplia diversidad de cultivares, elevada demanda del mercado y buena adaptabilidad a condiciones tropicales y subtropicales. Sin embargo, factores ambientales —en especial la disponibilidad hídrica— afectan significativamente la productividad y la calidad de las flores y bulbos de esta especie. El estrés hídrico induce cambios fisiológicos y bioquímicos, como el cierre estomático, la reducción de la tasa fotosintética y la acumulación de especies reactivas de oxígeno, lo que compromete el metabolismo celular y la apariencia visual de las plantas. Para minimizar estos efectos, la amarilis presenta respuestas adaptativas asociadas al aumento de la actividad de enzimas antioxidantes y a modificaciones estructurales en los tejidos foliares. Esta revisión presenta un panorama actualizado del agronegocio de flores, con énfasis en la importancia económica y en los requisitos edafoclimáticos de la amarilis, además de discutir los principales mecanismos fisiológicos de respuesta al déficit hídrico. Comprender dichas respuestas es esencial para el desarrollo de prácticas de manejo hídrico más eficientes y sostenibles, contribuyendo a la producción de flores de mayor calidad y al fortalecimiento competitivo de la floricultura brasileña.

Palabras clave: Déficit Hídrico. Fisiología Vegetal. Flores Ornamentales. Manejo Hídrico.

1 INTRODUCTION

Floriculture stands out as one of the fastest growing and most economically relevant agricultural activities on the world stage, being recognized by the Food and Agriculture Organization of the United Nations (FAO) as a strategic sector for agricultural and social development (SINGAB et al., 2016). Countries such as the Netherlands, China, the United States, and Japan lead global production, driven by the use of advanced technologies and greenhouse cultivation (BRAINER, 2018). The world flower market moves, on average, 64.5 billion euros, with emphasis on Asia and Europe, which concentrate a large part of the production and commercialization (NEWMAN, 2019; PEREIRA et al., 2021).

In Brazil, floriculture has shown continuous growth even in periods of economic instability, moving approximately R$ 8 billion in 2018, with significant generation of direct and indirect jobs (JUNQUEIRA; PEETZ, 2018; CONAB, 2021). The regional expansion and the strengthening of production poles, especially in the states of São Paulo, Pernambuco, Ceará and Bahia, have boosted the diversity and competitiveness of the sector (FREITAS; CASTRO, 2020; DE SOUZA et al., 2020). However, factors such as seasonality of demand, lack of qualified labor and vulnerability to climatic conditions still represent relevant challenges (JÚNIOR et al., 2015).

Among the ornamental species of greatest economic importance, amaryllis (*Hippeastrum hybridum* Hort.), belonging to the Amaryllidaceae family, widely cultivated in tropical and subtropical regions (DATTA, 2021), stands out. The species has high commercial value due to its diversity of colors, floral beauty, and adaptability to hot and humid climate conditions (AZIMI; ALAVIJEH, 2020; WANG et al., 2018). In Brazil, production is concentrated mainly in the states of São Paulo and Ceará, with bulb exports representing about 60% of national production (MATEUS et al., 2010; TOMBOLATO et al., 2010).

However, the production of amaryllis, as well as other ornamental flowers, is strongly affected by adverse environmental conditions, especially water availability (INKHAM; PANJAMA; RUAMRUNGSRI, 2022). Water stress can reduce the growth, photosynthesis, and commercial quality of flower stems and bulbs (ZAMPIROLLO et al., 2021; GIORDANO et al., 2021). Thus, understanding the physiological and biochemical mechanisms of amaryllis' response to water deficit is essential for the development of more efficient and sustainable management strategies (CAMPOS et al., 2019).

In view of this, the objective is to evaluate the panorama of flower agribusiness, with emphasis on the economic importance of amaryllis, and to discuss the main effects of water stress on its physiological, biochemical and productive aspects, highlighting management practices that can contribute to the maintenance of the quality and productivity of this species in adverse conditions of water availability.

GLOBAL SCENARIO OF FLOWER AGRIBUSINESS

The commercialization of floriculture products is a market in growing development, and the promotion of this segment is one of the priorities of organizations such as FAO (SINGAB et al., 2016). Floriculture is an activity that is present in almost all countries, with the Netherlands standing out as the largest producer, with the use of greenhouse crops, followed by China, the United States and Japan (BRAINER, 2018). The number of farmers who have adhered to the production of flowers leaving aside other crops has increased, an example is Punjab, Pakistan where about 37% of farmers have migrated to this branch due to the high economic returns of the commercialization of cut flowers (SINGAB et al., 2016).

Figure 1

Commercialization of floriculture products in Colorado

Source: Newman, (2019).

Worldwide, the average value of the flower market is 64.5 billion euros, in which wholesale production corresponds to 15 billion in Asia and 11 billion in Europe. The United States stands out for having floriculture as the main component of agricultural activity, with greater production of flowers in pots and plants for flower beds. The production of cut flowers is concentrated in developing countries. Brazil stands out among the South American countries with the highest production, with a cultivation area of 14.99 thousand hectares (NEWMAN, 2019). The global import of cut flowers had a significant increase in the periods from 2009 to 2018 of about 46%, where 71% of this production was destined for the European Union (EU). In addition, in 2017 the flower market generated a capital of 74 million dollars, in which the countries of Asia and Europe were the main contributors (PEREIRA et al., 2021).

2 IMPORTANCE OF BRAZILIAN FLORICULTURE

Floriculture is a sector that in Brazil, even through the crisis in the economy, has been showing exceptional growth compared to other agribusiness sectors. This sector moved R$ 6.9 billion at the level of final consumer in 2017, in 2018 the value in greens collected was about R$ 8 billion, showing a growth of 7% compared to 2017 (JUNQUEIRA; PEETZ, 2018; PAIVA et al., 2020). The increase in the productivity of flower production in Brazil is made possible by the inclusion of new regional production areas, research funding, offers of credit lines and technical assistance programs, which strengthen production (JUNQUEIRA; PEETZ, 2008). However, the production of flowers is still not enough to supply the domestic market, thus resulting in the closing of the trade balance with a negative balance in most years (JUNQUEIRA; PEETZ, 2013).

The Brazilian flower production presents challenges, mainly due to climatic instability, which leads to high production losses, due to extreme events, the need for high qualified labor, difficulties in flow, distribution and the need for a production calendar due to the seasonality of the demand for flowers, causing great variations in prices (JÚNIOR et al., 2015). The number of producers of flowers and ornamental plants in Brazil is about 8 thousand, with the cultivation of 2,500 species, 17,500 varieties. This sector generates an average of 209,000 direct jobs and 800,000 indirect jobs (CONAB, 2021).

In Brazil, the largest average area of flower production is in São Paulo with 45.7% of the national total and is also where the main marketing centers in the country are located: the units of CEAGESP (Companhia de Entreposto e Armazéns Gerais de São Paulo), Ceasa de Campinas and the Cooperativa Veiling Holambra (BRAINER, 2018; DE SOUZA et al., 2020). However, there is currently growth in the states of Rio Grande do Sul, Paraná, Santa Catarina, Minas Gerais, Rio de Janeiro, Goiás, the Federal District, and most states in the North and Northeast (CONAB, 2021). The floriculture market is quite dynamic, composed of the ornamental plants and gardening segment (42%), cut flowers and foliage sector (34%) and the flower and bottled plants market (24%) (JUNQUEIRA; PEETZ, 2017, 2018). In the

Northeast region, flower production has increased significantly in recent years, in 2006 the region contained about 2,177 production establishments in 2017, this figure increased to 6,021 establishments, currently this is in third place, with production concentrated mainly in the states of Bahia, Pernambuco and Ceará (BRAINER, 2018). The amount collected from floriculture in the northeast in 2017 was 129 million reais, of which 24 million reais came from family farming (FREITAS; CASTRO, 2020). The production of flowers in Pernambuco is distributed in three regions: Zona da Mata, Agreste and Sertão, regions with different potentialities and climatic characteristics (OLIVEIRA; BRAINER, 2007).

3 MARKETING OF AMARYLLIS

Amarillis (*Hippeastrum hybridum* Hort.) is a genus belonging to the family *Amarylidaceae*, native to Central and South America (DATTA, 2021). It is a bulbous plant which has its species widely distributed in the tropical and subtropical regions of the world, it is stipulated that there are about a thousand hybrids of *Hippeastrum* Commercially distributed (AZIMI; ALAVIJEH, 2020; XIONG et al., 2020). The ways of propagation of this species can be through seeds, compensated bulbs/bulbils, basal cuts of the bulbs, double scaling and tissue culture (DATTA, 2021). As for morphology, these plants are characterized by containing between three and six leaves with the shiny pact, similar to ribbons (600 mm long and 50 mm wide), the leaves appear simultaneously with the flowers, and a plant may have one or two inflorescences, containing two to five trumpet-shaped flowers, and can have a size of up to 550 mm with 200 mm in diameter (WANG et al., 2018). The flowers are zoomorphic and stand out due to their size and diversity of colorations which include red, white, pink, sandy, orange and/or with veins of different colors (AZIMI; ALAVIJEH, 2020).

Figure 2

Diversity of colors and shapes of amaryllis flowers

Source: Marasek-Ciolakowska; Sochacki; Marciniak, (2021).

Considered an easy plant to grow, as it has good adaptability to hot and humid environmental conditions, it has been standing out in the world market, containing more than 300 recognized cultivars, which have their varieties exported by countries such as the Netherlands, South Africa, Japan, Brazil and the United States (WANG et al., 2018). Amaryllis is among the 20 most popular flowers worldwide, and can be used as cut flowers, vase plants or in a limited way in green spaces (AZIMI; ALAVIJEH, 2020). Amaryllis has been standing out with cut flowers in recent years, in 2016 it occupied the eleventh position among the best-selling cut flowers in Dutch flower auctions. Due to the high demand, large investments have been made to obtain new varieties of amaryllis, in which in the period from 2015 to 2019 113 new varieties were registered (MARASEK-CIOLAKOWSKA; SOCHACKI; MARCINIAK, 2021). Amaryllis plants have good adaptation to cultivation in Brazil, this is due to the fact that they have a large number of native species, endemic to the Amazon region (TOMBOLATO et al., 2010). The annual production of amaryllis bulbs in the country is about three million, concentrated in greater numbers in the states of São Paulo (Holambra) and Ceará (Paraipaba), with distribution of about 60% of the total production for export and 40% for the domestic market (MATEUS et al., 2010; TOMBOLATO et al., 2010). The process of commercialization of amaryllis in Brazil occurs as vase flowers, cuts, bulbs in large quantities for export and loose bulbs. However, the commercialization as a cut flower is considered a promising novelty, information from the wholesale flower market showed that in 2010 a single producer sold 60 thousand amaryllis stems (TOMBOLATO et al., 2010). Due to the demand in the market, some commercial classification standards are established for commercialization as a vase plant and cut flowers presented in table 1.

Table 1

Commercialization standards of amaryllis as a vase flower established by the Veiling Holambra Cooperative and as a cut flower adopted by the main producer cooperatives in the market

Requirements	Vase Flower	Cut Flower
Height	A1 (23 and 46 with) A2 (13 & 22com) B (<12 with)	Minimum 40
Number of Rods	1 to 2	-
Rod Diameter (cm)	Minimum 1.5 mm	Thin (≤ 7 cm) Intermediate (8 to 10 cm) Thick (>10 cm)
Flower Bud Size (cm)	8 to 12	-
Opening Point/ Harvest	A1 (Closed buttons) A2 (Opening start)	A1 (Closed buttons)
Peak Commercialization	Mother's Day and Christmas	Spring (September)

Source: Adapted from the work of Tombolato et al. (2010).

4 EDAPHOCLIMATIC CONDITIONS FOR AMARYLLIS PRODUCTION

Amaryllis is a highly demanding crop in temperature, presenting optimal temperatures differentiated according to the stage of development, in the initial phase of growth the optimal temperature is between 18 and 20 °C, from leaf development, higher temperatures can favor the development of the bulb and emission of the flower bud (PELLEGRINI, 2007; INKHAM; PIRIYAPONGPITAK; RUAMRUNGSRI, 2019). Hertogh; Gallitano (1998) established that, during the production cycle, the ideal day and night temperatures of 22/18 ºC, which provide higher yields. Very low temperatures harm the development of the plant, while the occurrence of high temperatures (above 30/26 °C) can affect the quality of the stems, causing a reduction in plant height, leaf size and length, and a change in flower color. Inkham; Piriyapongpitak &

Ruamrungsri (2019) When evaluating the effect of storage and growth temperatures on development, flower and bulb quality of amaryllis, they obtained an ideal temperature of 25 º C, which resulted in higher plant height, flower diameter, bulb diameter, fresh and dry bulb weight.

As for luminosity, this crop is conducted in full sun conditions, or light shading. Conditions of high light restriction result in competition for photoassimilates between bulbs and leaves, being a detrimental factor for bulb production and floral scapes (BROWN; BLACK, 2007; PELLEGRINI, 2007). However, in regions with very high temperatures, the use of artificial shading is a management technique used to make it possible to produce quality flower stems during the hottest months of the year (SCHWAB et al., 2015).

The water requirement of this crop varies according to soil type, time of year, climatic conditions and stage of development (ZHENG et al., 2019), the phase with the greatest demand for water is right after planting, in which the soil must be kept moist, avoiding excess water that results in rotting of the bulbs (BROWN; BLACK, 2007). Water deficit conditions during the growth phase of the plant can result in the anticipation of flowering (PELLEGRINI, 2007). Water quality is a crucial fact for good development, since this crop is extremely sensitive to the presence of salts in the water. High salinity conditions result in marginal necrosis and tip blight on mature basal leaves, inhibition of flowering, and reduction of fresh mass of the whole plant (SHILLO et al., 2002).

The nutritional requirement for amaryllis varies according to the stage of development, the initial stages are less demanding, so it is recommended to avoid high levels of nutrients during the planting season (SILVA et al., 2014). The macronutrients most absorbed by amaryllis are potassium and nitrogen, and it is recommended to apply small amounts of nitrogen in installments to avoid nitrate losses by leaching, which should be done at the beginning and end of vegetative development, thus ensuring the availability of nitrogen during the vegetative and reproductive phase of the plant (JAMIL et al., 2016; SILVA et al., 2014).

5 PLANT PHYSIOLOGY UNDER WATER STRESS

The knowledge of the water needs of a crop is of paramount importance to obtain high yields, reduce production costs and preserve water resources (MENEGAES et al., 2017). When it comes to flower production, adequate water management is crucial, as it directly reflects on the quality of the final product, adequate water availability can result in greater photosynthetic activity, high accumulation of dry mass, adequate development of plants with well-defined phenological phases, resulting in a greater number of flower stems and high commercial value (GIRARDI et al., 2016).

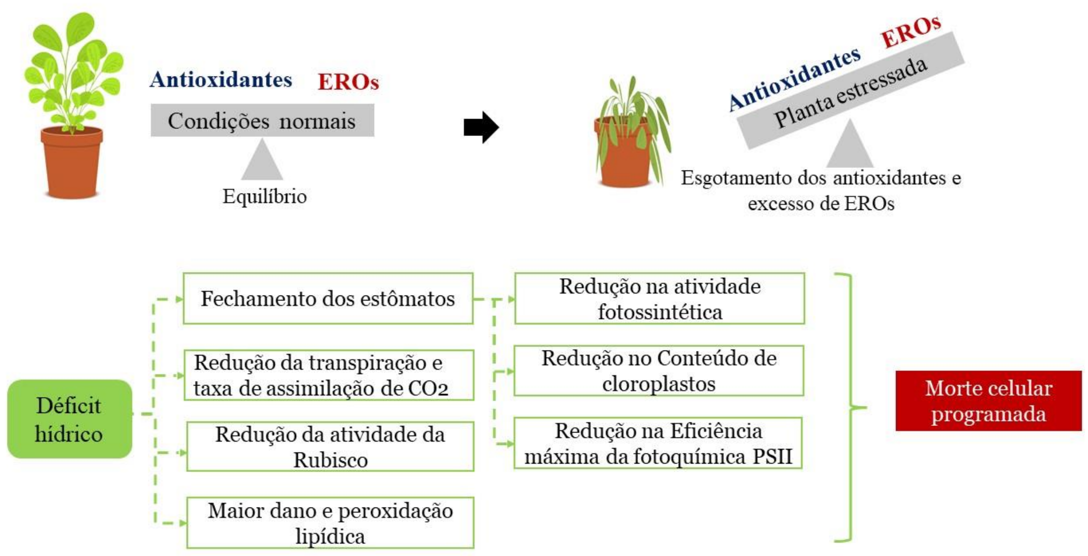
However, conditions of low water availability result in physiological changes such as less turgidity of the cells, alteration in the opening of the stomata and in the structure of the chloroplasts, reduction of transpiration and rate of assimilation of carbon dioxide (ZAMPIROLLO et al., 2021). The reduction in CO2 assimilation causes a reduction in the activity of the enzyme ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), to compensate for this reduction in carboxylation promoted by Rubisco, NAPH accumulates and the electron acceptor NADP+ becomes unavailable, resulting in the accumulation of electrons at the end of the photochemical step (CAMPOS et al., 2019). The electrons are directed to molecular oxygen giving rise to superoxide radicals, which together with other reactive species cause damage to the photosynthetic apparatus, promoting the peroxidation of lipid membranes and chlorophylls (CAMPOS et al., 2019; POLLASTRINI et al., 2017; ZAMPIROLLO et al., 2021).

To control the imbalance arising from low photosynthetic assimilation and other physiological processes that lead to the formation of reactive oxygen species (ROS), plants have an antioxidant defense system that acts by protecting cells from possible oxidative damage, this is

composed of enzymes, such as superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT) and, non-enzymatic components, such as ascorbate, glutathione, carotenoids, and phenolic compounds (CAMPOS et al., 2019; SHARMA et al., 2012).

Figure 3

Consequences caused by water deficit in plants



Source: The authors.

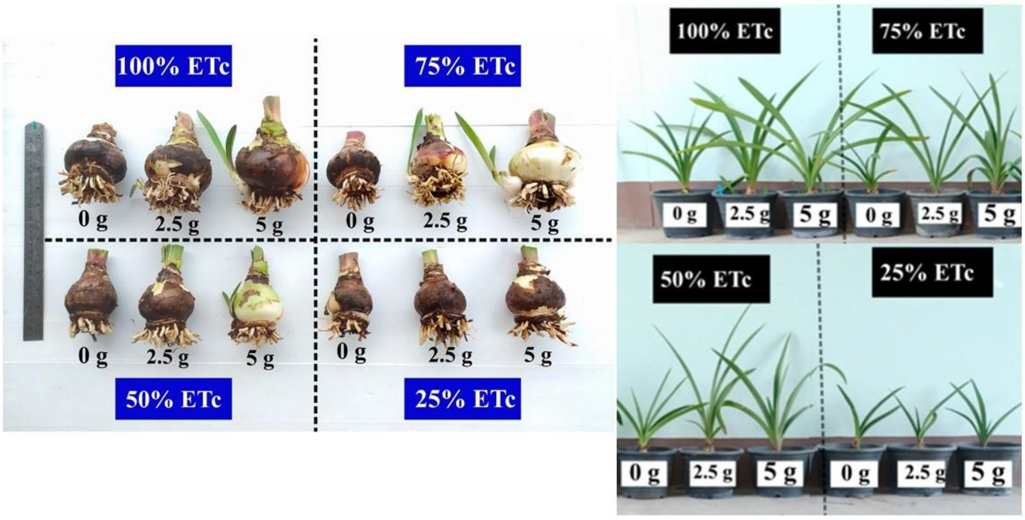
Water stress can also occur due to the use of excessive irrigation, in these conditions, the flooded soil leads to a lack of oxygen to the roots, causing the death of root tissues, favoring lactic fermentation and acidosis in the cells, and can also lead to a reduction in the absorption of nutrients and water due to lack of energy. In addition, the use of excessive irrigation is an extremely costly practice, which promotes the proliferation of diseases and leaching of fertilizers, consequently environmental pollution (NACKLEY et al., 2020).

In ornamental species, modifications due to water stress include a reduction in leaf area, accompanied by greater root development in order to maximize water absorption. In addition, there is an increase in the spongy and palisade tissues, as a strategy to increase the diffusion of CO2 to the intracellular spaces. (GIORDANO et al., 2021).

Modifications in the photosynthetic apparatus are among the main responses of plants to water restriction, the flowering of chlorophyll *the* is often used as an indirect measure of the damage caused, water stress promotes imbalance between the production and use of electrons in the PSII photosystem, altering the maximum quantum yield of the PSII reaction centers (Fv/Fm ratio), which under ideal conditions ranges from 0.78 to 0.85 (TOSCANO; FERRANTE; ROMANO, 2019). Stress-induced modifications in plants directly affect the visual appearance and coloration of leaves. The availability of energy for plants under conditions of water deficit is reduced, due to the decrease in photosynthetic activity, and carbohydrate production, altering floral production and durability (GIORDANO et al., 2021). Conditions of water deficit in amaryllis promote a reduction in photosynthetic rate, plant height, number of shoots and number of leaves. In addition, they cause a reduction in bulb quality parameters such as: fresh mass, circumference and firmness (INKHAM; PANJAMA; RUAMRUNGSRI, 2022).

Figure 4

Effect of irrigation levels on the growth and quality of Hippeastrum 'Red Lion' bulbs grown under different fertilization rates



Source: Inkham; Panjama; Ruamrungsri (2022)

6 FINAL CONSIDERATIONS

Flower agribusiness presents itself as a strategic and expanding segment in the global and national scenario, supported by the diversity of species, technological advances and appreciation of the ornamental market. Brazil occupies a prominent position in this sector, although it still faces challenges related to logistics, technical qualification and adaptation of crops to regional edaphoclimatic conditions.

Amarylllis, in turn, is a promising crop in Brazilian floriculture, due to its physiological plasticity and high commercial value. However, its productive and ornamental performance is strongly influenced by water availability, and irrigation management and understanding of the physiological mechanisms of tolerance to water stress are determining factors for the success of production. The adoption of sustainable practices and the deepening of research on the physiological behavior of amaryllis under water deficit can contribute significantly to the competitive strengthening of Brazilian floriculture and its insertion in the global market of high value-added flowers.

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