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Gladiolus production as a function of growing environment conditions: a scientometric analysis

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Abstract

Lately, an increase in the commercialization of gladiolus has been observed, making it necessary to know information that contributes to the optimization of its production. Such information can be obtained from the scientometric analysis. Thus, the objective of this work was to perform a scientometric analysis of the global scientific literature to quantify the studies on gladiolus and to specify in the Brazilian scientific literature the results of works on the cultivation environment. The scientometric analysis was performed in the Scopus database for the entire historical data series until the year 2021. A total of 1402 scientific papers published on gladiolus culture were obtained with an average publication rate equal to 0.62 papers year^{-1}. These papers were mostly published as scientific articles in English language in journals focusing on horticulture and India is the country with the highest number of publications. About the cultivation environment, the studies conducted in Brazil indicate that the production of gladiolus should be carried out in periods that do not occur frosts and also for average air temperature below 35 °C and soil humidity above 75% of field capacity. Despite the important results of these works, the global scientific literature still lacks more information that adequately assists in the increase of gladiolus production.
Keywords: agrometeorology, agricultural production, floriculture, *Gladiolus* x *grandiflorus Hort.*

Introduction

Gladiolus (*Gladiolus* x *grandiflorus* Hort.), belonging to the family Iridaceae, is a herbaceous and heliophilous plant, hybridized from various species native to southern Africa and the Mediterranean, propagated vegetatively through bulbs (Schwab et al., 2017). The currently cultivated gladiolus cultivars belong to the genus *Gladiolus*, whose florets can exhibit color variations depending on the cultivar (Ahmad et al., 2011).

In Brazil, gladiolus is one of the main commercially traded cut flowers, especially during the Day of the Dead holiday. However, in recent years, its demand has started to expand to other commercial dates, such as Mother's Day and Christmas, as well as for event decoration (Schwab et al., 2018). In order to meet the growing demand during these dates and celebratory events, gladiolus production tends to increase, necessitating an understanding of the influence of the growing environment for successful production.

Considering the climatic conditions in Brazil, gladiolus can be cultivated throughout the year (Schwab et al., 2018). However, adverse conditions in the growing environment, such as reduced light intensity, changes in air temperature and soil water availability, can result in delayed or accelerated harvesting, reduced stem height and bud number, and decreased stem quality (Becker et al., 2021a,b; Uhlmann et al., 2017), leading to reduced value in the sale of floral stems and subsequent economic losses for producers.

Given the interest in optimizing gladiolus production for the purpose of producing marketable floral stems, it becomes increasingly necessary to evaluate and understand advances in the studies of this crop through the results published in scientific literature. Researchers and public and private entities in the floriculture and ornamental plants sector have shown increasing interest

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in quantitatively analyzing scientific production to understand the dynamics of science and technology in this field of knowledge, in order to contribute to production planning and decision-making.

The study of scientometrics represents an important observation tool in the progress of science and technology, and it can contribute to optimizing planning activities involving commercial gladiolus production, enabling the producer to define the planting calendar considering the expected harvest date and local weather conditions, thereby increasing the security and profitability of the activity. Thus, the objective of this study was to perform a scientometric analysis to investigate the state of the art of research on gladiolus in international and national scientific literature, specifically focusing on the results of studies conducted in Brazil that examined the gladiolus response to the growing environment.

Materials and Methods

A scientometric analysis was conducted based on the search for scientific articles published and indexed in the Scopus database (www.scopus.com), which is a multidisciplinary database produced by Elsevier since 2004, covering literature from 1960 onwards. Scopus contains abstracts of millions of articles, references, and indexes from scientific, technical, and medical literature.

The first step of the research involved a guided survey of studies related to the research topic. Articles were selected using the combination of terms "Gladiolus" OR "gladíolo*" OR "gladiolu*" in the search field to identify articles that contained any of these words in the title, abstract, or keywords, within the historical series up to the year 2021. After analyzing the results, it was found that the search needed further filtering, as some of the initial results included studies on "gladioli," which is a bacterium. Therefore, options to exclude the word "gladioli" in the title, abstract, or keywords were applied. Manual analysis and exclusion were also performed in the search to identify studies specifically focused on the bacteria "gladioli."

The research results were tabulated for quantitative and statistical analysis, including regression analysis with estimation of the coefficient of determination (R^2) and linear correlation analysis using the Pearson correlation coefficient (r), adopting $\alpha = 0.05$ for the analyses. The following information was obtained: i) year of publication of the studies; ii) country of origin of the corresponding author; iii) language of publication; iv) type of publication; v) title of the indexing journal; and vi) research area. For studies conducted in Brazil, the following additional information was collected: i) Brazilian state where the research was conducted; and ii) research theme. For studies conducted in Brazil that examined the gladiolus response to the growing environment, information on the environmental factors influencing the development and quality of gladiolus was also gathered.

Results And Discussion

The data search in the Scopus database resulted in a total of 1402 scientific papers. (**Figure 1**) shows the relationship between the number of published papers and the year of publication. The first paper was published in 1876 (n=1). In (Figure 1A), an exponential regression fit between the number of published papers and time can be observed ($R^2 = 0.8645$; $p<0.05$). The study revealed an increase in scientific production each year ($r = 0.71$; $p<0.05$), at an average rate of approximately 0.62 papers per year compared to the subsequent year.

This increase in the number of papers indicates that over the years, there has been a growing interest among researchers in investigating and better describing the behavior and aspects of gladiolus with the aim of optimizing its commercial production. This is because gladiolus is among the most cultivated and traded cut flowers in the world (Mazzini-Guedes et al., 2017) and is also employed in landscaping and ornamentation (Tomiozzo et al., 2018). Furthermore, it can be inferred that there is a tendency for continuous growth in research and publication of papers on this flowering crop.

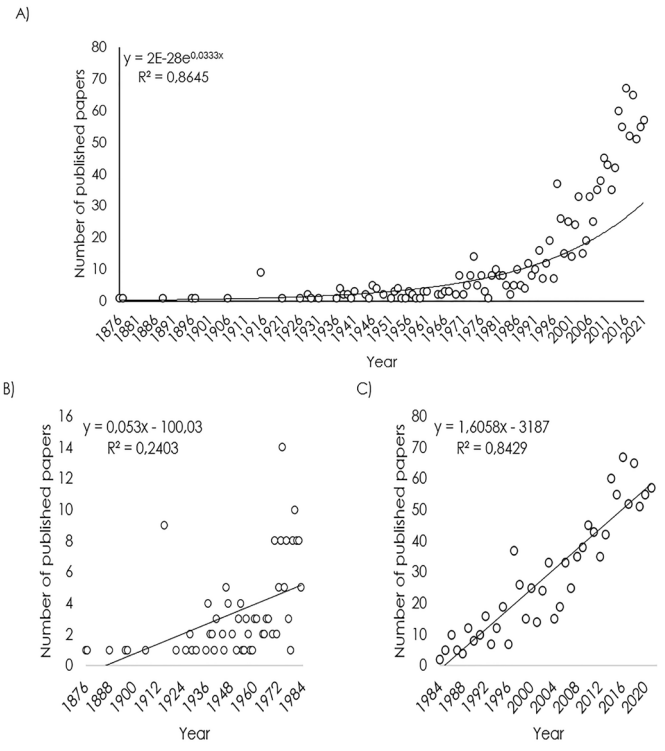

Figure 1. Number of published papers as a function of publication years, A) from 1876 to 2021, B) from 1876 to 1983, and C) from 1984 to 2021.

Until 1983, there was an increase in the number of published papers; however, this growth was not significant (R^2 = 0.2403 - Figure 1B). A significant increase in publications was observed from 1984 onwards (R^2 = 0.8429 - Figure 1C), where the growth rate of publications increased from 0.49 papers per year to 0.92 papers per year ($p<0.05$). When examining the number of papers over the years, it was found that 2016 had the highest number of papers published in a single year (n=67, 4.78% of the total papers). This increase in the number of scientific papers can be associated with the global growth of the flower market (Ibraflor, 2021). The increasing demand in the floral and ornamental plant sector and the increase in production of these crops have stimulated research development in this field of knowledge.

When examining the global distribution of the number of papers (**Figure 2**), it can be observed that India (n=255) has the highest number of publications (18.18% of the total papers), followed by the United States (n=157) and Japan (n=64). Brazil has published 62 papers on gladiolus (4.42% of the total papers), ranking as the 6th country with the highest number of publications. The prominence of India as the country with the highest number of publications can be attributed to the fact that gladiolus occupies the third position in terms of cultivated area and flower production in India, with 11,660 hectares cultivated across the states of Uttar Pradesh, West Bengal, Odisha, Chhattisgarh, Haryana, and Maharashtra (India, 2019).

The language with the highest number of publications is English (n=1128; 80.46% of the total papers). This is due to the fact that English makes the papers accessible to the entire world since it is considered a universal language, allowing the exchange of information and knowledge among native speakers from different countries. Regarding the type of publication, scientific articles stand out (n=1146; 81.74% of the total papers), followed by papers (n=94) and reviews (n=29), notes (n=31), and other forms of publication (n=102).

Analyzing the indexed journals, Acta Horticulturae had the highest number of publications (n=97), followed by Scientia Horticulturae (n=42) and Indian Journal of Horticulture (n=30). It can be inferred that the journal in which the paper is published is one of the criteria, among others, for evaluating the context in which the field of knowledge being assessed is situated. Thus, in the papers published by field (**Figure 3**), the highest number of papers was observed in the research area of "Agricultural and Biological Sciences" (n=944), representing 67.33% of the publications. It is worth noting that the scientific journals that published the most papers on gladiolus focus on publishing papers in the field of horticulture. This justifies the significant number of papers being present in the research area of "Agricultural and Biological Sciences". It is understood that other research areas also have publications on gladiolus due to the broad scope of agriculture, encompassing laboratory, social, and economic origins, demonstrating the dynamism and interconnection of these fields.

Regarding the studies conducted in Brazil, the Brazilian state with the highest number of publications was Rio Grande do Sul (n=18), followed by Minas Gerais (n=13) and São Paulo (n=11), as shown in (**Figure 4**). The other states that have published papers on gladiolus cultivation include Pernambuco, Paraíba, Mato Grosso do Sul, Mato Grosso, Rio de Janeiro, Paraná, Santa Catarina, and the Federal District. The remaining states do not have any published studies on the species. The fact that Rio Grande do Sul (n=18) had the highest number of publications among Brazilian states is related to the research results produced by the PhenoGlad team, initially composed of professors and undergraduate and graduate students from the Federal University of Santa Maria (UFSM), in Santa Maria, Rio Grande do Sul, Brazil, with the initial focus of their work being gladiolus cultivation.

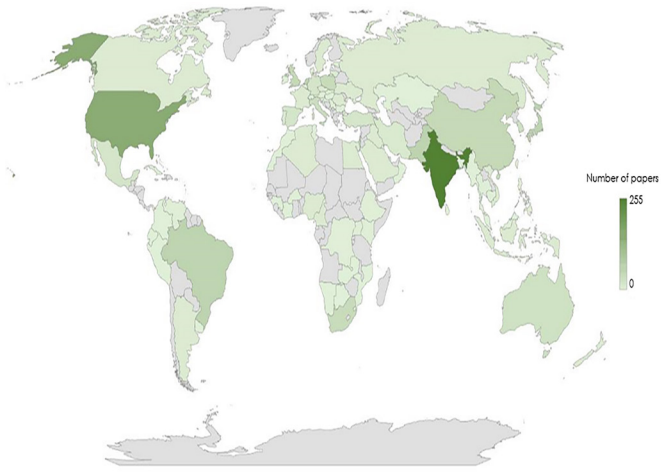

Figure 2. Graphical representation of the global distribution of the number of papers.

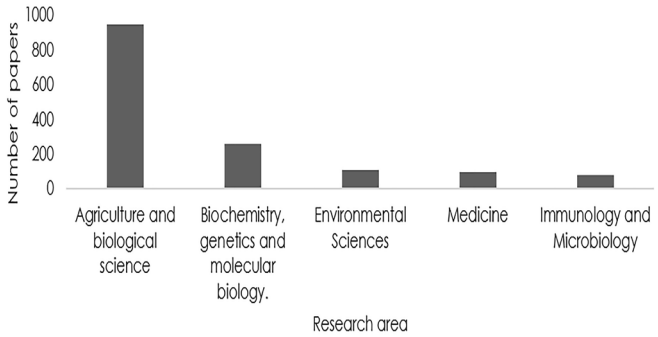

Figure 3. Distribution of the number of papers by research area.

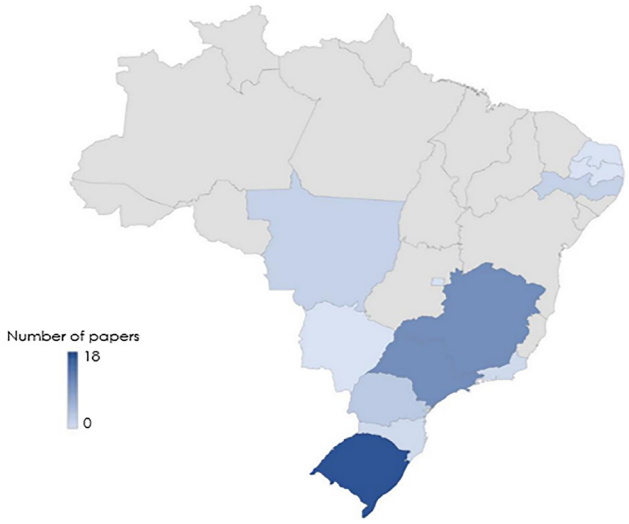

Figure 4. Number of Brazilian papers published by State.

Among the Brazilian papers, the topic with the highest number of publications was "Production/Incentive Techniques" (n=24), followed by "Environment" (n=22) and "Cultivation System" (n=5). Other themes addressed in the research included: "Diseases" (n=5), "Market Description" (n=3), "Genetic Identification" (n=2), and "Floral Properties" (n=1) (**Figure 5**). Specifically, Brazilian studies investigating the response of gladiolus to the environment considered the following environmental factors: cultivation season (n=8), soil water availability (n=7), and air temperature (n=7).

Given that, among Brazilian studies, "Environment" was the second main factor studied in Gladiolus production, it is affirmed that, as in any production process, the environment and its factors are determinants of production success. The cultivation season has been extensively studied as it directly affects local climatic conditions, resulting in variations in air temperature and soil moisture. This has led numerous researchers to investigate the optimal conditions for production, whether of bulbs or flowers, in order to optimize planting schedules for specific dates or areas.

Overall, research results indicate that local

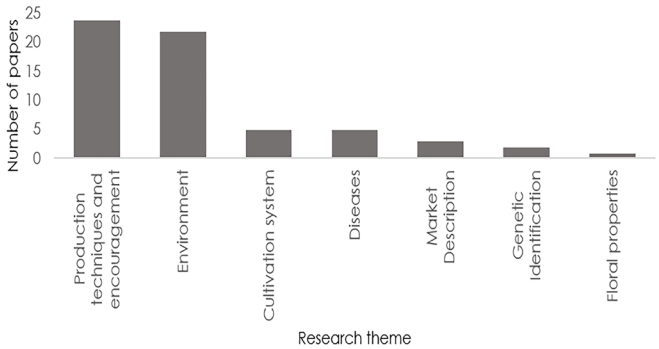

Figure 5. Number of Brazilian studies published per research theme.

weather conditions such as photoperiod, air temperature, soil moisture availability, and solar radiation directly influence the growth and development of Gladiolus, thereby affecting the duration of its phenological phases (Pereira et al., 2016a,b; Schwab et al., 2017). Considering that the Gladiolus vegetative cycle is influenced by cultivation environment conditions, which in turn affect the quality of floral stems, determining the planting date becomes a decisive factor for scheduling harvest (Schwab et al., 2017). Harvest scheduling is especially important for flower plantations that have a concentrated commercialization calendar, primarily during festive periods (Schwab et al., 2018).

Gladiolus is considered a facultative short-day plant (Shillo and Halley, 1976a). However, during summer, when the photoperiod exceeds 12 hours, the species exhibits accelerated growth and development (Paiva et al., 1999), indicating that temperature variations have a greater impact on the crop's development. Therefore, characterizing the cycle in degree-days Celsius is more appropriate. This defines a cycle elongation under low-temperature conditions and cycle shortening under higher temperature conditions (Streck et al., 2012).

The cardinal temperatures of Gladiolus vary depending on the phenological phase of the crop. Each phenological phase can be defined by descriptive morphological characteristics that subdivide each phase into stages, which can be encoded as S (dormancy and sprouting stages), V (vegetative stage), and R (reproductive stage) (Schwab et al., 2014). For these respective phenological phases (stages), the cardinal temperatures are: lower basal temperature equal to 5, 2, and 6 °C; optimum temperature equal to 25, 27, and 25 °C; and upper basal temperature equal to 35, 45, and 42 °C (Uhlmann et al., 2017).

Extreme temperatures (above 35 °C and below 0 °C) reduce the commercial quality of stems and can even cause plant death (Schwab et al., 2018). An alternative to mitigate the effects of high temperatures is cultivation under protection (shading) (Sousa et al., 2021). In shaded cultivation with 70% shading, an 84.42% increase in aboveground biomass accumulation can be observed, along with increased stem diameter and plant height by 59.57% and 50.00%, respectively, compared to cultivation under full sun. However, flower stems from bulbs produced in full sun have an additional 10 days of vase life (Sousa et al., 2021).

In Brazil, locations prone to frost have limited climatic conditions for Gladiolus production during this period (Schwab et al., 2018). This is because Gladiolus

plants are intolerant to frost, which refers to low light and low air temperatures (1 to 4 °C), which can affect the development of the floral stem. The stages most sensitive to low temperatures are primarily the early developmental stages and stages near flowering, which can compromise the number of flowers per spike (Shillo and Halevy, 1976a).

Solar radiation availability directly and positively contributes to Gladiolus development, as it is responsible for the photosynthetic energy of the crop. The demand for photosynthetic reserves is accentuated during the reproductive phase, primarily for the formation and opening of florets. Moreover, the higher the available solar radiation, the greater the amount of photosynthetic reserves available, which can be used for other plant sinks, such as the growth of daughter corms and cormels (Schwab et al., 2017). Regarding the required light intensity, Gladiolus fails to flower when exposed to low light. The end of the reproductive stage and the emergence stage of the floral spike are the most sensitive to low light, affecting the plant's inflorescence (Shillo and Halevy, 1976b). This increased flowering in response to increased light intensity justifies the predominant field planting of Gladiolus without the need for a protected environment to attenuate light.

Soil water availability is also an important factor in Gladiolus production, with the species being more sensitive to water deficit during the reproductive phase (Becker et al., 2021c). Specifically, Pereira et al. (2009) identified the spiking stage as the most critical phenological phase in terms of water deficit. The results showed a reduction of up to 61% in floral stem length and an 85% reduction in the number of flowers for a soil water tension of 60 kPa. It is recommended that during this phase, the soil water tension be close to field capacity. The authors also observed that plants subjected to treatments with water tensions of 40 and 60 kPa exhibited aerial burn and wrinkling of some leaves. Additionally, Gladiolus cultivation at 80% of soil field capacity yields better results for commercialization, generating longer floral stems (63.61 cm), a greater number of leaves (6.94) and flowers (9.28), larger diameter (1.15 cm), and reduced cultivation period (57.5 days) (Santos et al., 2020; Mazzini-Guedes et al., 2017).

Considering adequate soil water availability for Gladiolus, certain agricultural practices can be performed to optimize crop development. Maintaining soil volumetric moisture above 24% and applying vegetable ash at a rate exceeding 11 g dm-3 results in increased bulb diameter and mass. Ash can be used as both a soil amendment and a fertilizer for Gladiolus production in greenhouses, as it improves water retention capacity in the soil (Pereira et al., 2009). Under conditions of adequate soil water availability, with water depth in the soil above 75% of field capacity, nitrogen fertilization significantly favors the dry mass of Gladiolus floral stems. Under these conditions, floral stem length and the number of flowers reach a classification for commercial purposes (Porto et al., 2014).

Furthermore, regarding water in Gladiolus production, the use of treated wastewater for irrigation does not generate morphological differences in the plants. It also does not affect soil micro and macroporosity, electrical conductivity (EC), or sodicity. However, soil salinization can occur after one year of employing this practice (Cerqueira et al., 2008).

The results of these Brazilian studies contribute to optimizing Gladiolus production and management for the cultivation conditions in Brazil. Gaps in this area of knowledge have been identified, requiring further research on the influence of meteorological variables and soil water availability on Gladiolus production in different regions of Brazil, as studies are predominantly concentrated in the southern region of the country. These are important studies that provide guidance on the best agricultural cultivation practices, support proper activity planning, assist in decision-making in the production process, and contribute to other alternative applications of the crop, considering its significant growth potential in the national flower market.

Conclusions

The interest in Gladiolus research tends to grow on a global scale, with scientific papers published in various fields of knowledge, particularly in Agriculture and Biological Sciences.

The meteorological conditions of the cultivation environment, which depend on the planting season, are determining factors in the duration of the Gladiolus development cycle and the quality of floral stems and bulbs.

Regarding Brazilian agroclimatic conditions, published works indicate restrictions on Gladiolus cultivation in Brazil during periods and locations with frost coinciding with the plant's sprouting or flowering stages. In locations or times of the year with air temperatures above 35 °C, the use of shade nets can minimize crop damage. Furthermore, flower quality is superior when soil water availability is at least 75% of field capacity, and irrigation can be performed with treated wastewater.

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