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ARTICLE

Physiological and agronomic characters of commercial cultivars heliconias (*Heliconia sp.*) in Veracruz, Mexico

Caracteres fisiológicos e agronômicos de cultivares comerciais de helicônias (*Heliconia* sp.) em Veracruz, Méxicoen'

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Abstract: Heliconias belong to the group of tropical flowers, which generate economic benefits in the agricultural sector with their agronomic peculiarities. Besides providing the social actors involved with benefits aimed at sustainability in different tropical areas. Therefore, the objective of this study was to compare the physiological and agronomic characteristics of three commercial cultivars of Heliconias in three locations of a community in the municipality of Fortín, in the state of Veracruz, Mexico. Three sites were identified based on the type of agriculture: agroforestry system with Heliconias (site 1), agroforestry system - monoculture, with Heliconias (site 2) and monoculture (only Heliconias, site 3). A randomised complete block design with a split-plot arrangement (A x B) and six replications was used. Factors were: A) *In situ* cultivation sites, corresponding to three plots (sites) in the municipality of Coapichapan, Mexico, and B) Heliconias cultivars (*Heliconia psittacorum, Heliconia wagneriana* and *H. bihai*). The variables evaluated were tillers traits and inflorescence traits. The results show that in an agroforestry system with Heliconia, *Heliconia bihai* showed better performance in eight variables except for inflorescence number and bract number. In an agroforestry and monoculture system with Heliconia, *Heliconia bihai* shows better results in leaf length and inflorescence length. In an agroforestry system and monoculture with Heliconia, *Heliconia wagneriana* performed better in bract number, pseudostem width and leaf length. In monoculture, *Heliconia bihai* responded best to inflorescence length. Due to the tropical nature of this ornamental, the best growing conditions for Heliconia are in agroforestry systems. Due to its physiological characteristics, *Heliconia bihai* shows its agronomic potential in this type of agriculture even under monoculture conditions. Therefore, the conditions offered by an agroforestry system have a positive effect on the cultivation of Heliconia.
Keywords: agroforestry systems, commercial potential, environmental potential, ornamental plants, subgenus heliconia, tropical flowers.

Resumo: As helicônias pertencem ao grupo das flores tropicais, que geram benefícios econômicos no setor agrícola com suas peculiaridades agronômicas. Além de proporcionar aos atores sociais envolvidos benefícios voltados à sustentabilidade em diferentes áreas tropicais. Portanto, o objetivo deste estudo foi comparar as características fisiológicas e agronômicas de três cultivares comerciais de Heliconias em três locais de uma comunidade no município de Fortín, no estado de Veracruz, México. Três locais foram identificados com base no tipo de agricultura: sistema agroflorestal com Heliconias (local 1), sistema agroflorestal - monocultura, com Heliconias (local 2) e monocultura (somente Heliconias, local 3). Foi usado um delineamento em blocos casualizados com um arranjo de parcelas divididas (A x B) e seis repetições. Os fatores foram: A) Locais de cultivo *in situ*, correspondentes a três parcelas (locais) no município de Coapichapan, México, e B) Cultivares de Heliconias (*Heliconia psittacorum*, *Heliconia wagneriana* e *Heliconia bihai*). As variáveis avaliadas foram características de perfilhos e características de inflorescência. Os resultados mostram que, em um sistema agroflorestal com Heliconia, a *Heliconia bihai* apresentou melhor desempenho em oito variáveis, exceto no número de inflorescências e no número de brácteas. Em um sistema agroflorestal e de monocultura com Heliconia, a *Heliconia bihai* apresentou melhores resultados no comprimento da folha e no comprimento da inflorescência. Em um sistema agroflorestal e em monocultura com Heliconia, a *Heliconia wagneriana* apresentou melhor desempenho em número de brácteas, largura do pseudocaule e comprimento da folha. Em monocultura, a *Heliconia bihai* respondeu melhor ao comprimento da inflorescência. Devido à natureza tropical dessa planta ornamental, as melhores condições de cultivo da Heliconia são os sistemas agroflorestais. Devido às suas características fisiológicas, a *Heliconia bihai* mostra seu potencial agronômico nesse tipo de agricultura, mesmo em condições de monocultura. Portanto, as condições oferecidas por um sistema agroflorestal têm um efeito positivo no cultivo da Helicônia.
Palavras-chave: flores tropicais, plantas ornamentais, potencial ambiental, potencial comercial, sistemas agroflorestais, subgênero heliconia.

Introduction

Tropical flowers have positioned themselves over the years in the market taste, allowing people to differentiate the quality, adapted to budgets and diversifying in a market that appreciates them and demands better quality, durability and resistance (Díaz and Martínez, 2023). Within this ornamental group, heliconias stand out for their colors, sizes and post-harvest duration (Duque et al., 2022). In tropical America, Heliconias are commonly known as "wild bananas" or "tropical kings" and by native communities they are called "false birds of paradise". They are a monophyletic genus with about 380 species with high ornamental potential (Malakar and Biswas, 2022). Brazil, Colombia and México generate the most research, mainly on *H. psittacorum*, *H. bihai*, *H. spathocircinata* y *H. wagneriana* (Linares-Gabriel et al., 2020).

Mexico is breaking through in this segment. 43 species of heliconias have been identified, of which the main ones used in the market are *H. wagneriana*, *H. spittacorum*, *H. bihai* (Linares-Gabriel et al., 2023). In Veracruz there are approximately 50 ha^{-1} of crop with different species of heliconias such as *H. bihai*, *H. stricta*, *H. rostrata*, *H. collinsiana*, *H. latispatha*, *H. wagneriana* and *H. psittacorum* in 23 farms distributed in the municipalities of Catemaco, Amatlán de los Reyes, Omealca, Córdoba, Fortín, Tezonapa, San Andrés Tuxtla and Santiago Tuxtla (Carrera-Alvarado et al., 2023). Veracruz characterized by open field cultivation, established in diversified systems, mainly with coffee and native forest trees (agroforestry systems) (Baltazar-Bernal et al., 2018). In these conditions the propagation method is vegetative, however, it can be sexual or by biotechnological means (plant tissue culture) (Linares-Gabriel et al., 2023).

Some authors have analysed the relationship between biodiversity and ecosystem services in agroecosystems, stating that they should be part of comprehensive studies in the agroecological context, to demonstrate

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which practices are most effective for the sustainability of production (Ramírez-Suárez et al., 2024). Under these criteria, *Heliconia spp.*, has a wide genetic diversity within which it is sought to contribute to its conservation (Krause et al., 2023). Another characteristic is that they serve as soil protection thanks to their extensive rhizomatous root systems that allow the infiltration of rainwater into the groundwater, and provide pollen and habitats for numerous beneficial insects and other pollinators (Jácome-Chacón et al., 2018). In production, it is suggested to make foliar applications of kaolin and mineral nutrients such as boron and zinc on physiological aspects (Xavier et al., 2023). In the postharvest process, the vase life can exceed 30 days (Linares-Gabriel et al., 2019). These aspects can be evaluated from the of genotype-environment (GHG) interactions, as it is important to understand how crops behave in different environments and management systems (Kunze et al., 2024). In the field of Heliconia phylogeny, analysis has traditionally been based on the use of partially conserved chloroplasts and nuclear genes that serve as important markers for studying coevolution, thus serving as a valuable resource for further studies of Heliconia's evolutionary trajectory (Cheng et al., 2024). In that sense, the report of agronomic aspects can be used in programs in the selection of heliconias as cut flowers in the study area. Therefore, given the importance of this tropical ornamental, the objective was to compare the physiological and agronomic characteristics of three commercial cultivars of heliconias at three sites in a community in the municipality of Fortín in the Veracruz State, Mexico.

Materials and Methods

Location

The study was conducted in the community of Coapichapan in the municipality of Fortín, Veracruz, México (Fig. 1). It is located at coordinates 18° 53" N and 97° 0" W at 877 masl. Geographically, it is located in the central zone of the state of Veracruz, Mountain region.

Fig. 1. Location of the study site in Veracruz, Mexico.

Data collection sites

According to Farrell and Altieri (1999), trees can improve the productivity of an agroecosystem by influencing the characteristics of the soil, microclimate, hydrology and other associated biological components. In this sense, these characteristics were considered as a methodological evaluation, which are described below by the same authors.

Soil properties

Trees can affect soil nutrient levels by tapping into the deeper mineral reserves of the parent rock, recovering leachates and depositing them at the surface as humus. This organic matter increases the humus content of the soil, which in turn increases its cation exchange capacity and reduces nutrient losses. The added organic matter also moderates extreme soil reactions (pH) and the consequent availability of essential nutrients and toxic elements.

Microclimate

Trees moderate temperature changes, resulting in lower maximum temperatures and higher minimum temperatures under trees compared to open areas. The reduction in temperature and air movement due to the canopy reduces average evaporation. Relative humidity is also higher under trees than in open areas.

Hydrology

The water balance of a particular microsite, property or region is influenced by the functional and structural characteristics of the trees. To varying degrees, depending on the density of the foliage and the characteristics of the leaves, precipitation passes through the leaves to the ground, is intercepted and evaporated, or is redistributed to the base of the trunk by the flow itself. Moisture from the air can also be absorbed by the foliage and deposited as internal precipitation (drip fog), a significant potential source of water in areas of wet haze.

Associated biological components

All plants, insects and soil organisms can benefit from the presence of compatible trees. Although the specific mechanisms are poorly understood, they generally include a more favourable microclimate; favourable soil temperature, moisture regime and organic matter status; increased nutrient availability; and efficient nutrient use and recycling. This helped to carry out a characterisation to differentiate the community sites, as three plots with Heliconias were selected. These plots have different elements in terms of soil characteristics, availability of shade, humidity and variations in their microclimates. Visually, different characteristics can be observed between the same cultivars in the different sites (Table 1).

Table 1. Cultivars evaluated in the study sites.

	Site 1	Site 2	Site 3
Type of agriculture	Heliconia agroforestry system	Agroforestry and monoculture system, with heliconias	Monoculture (Heliconias only)
Soil characteristics	High presence of organic matter High availability of nutrients	Average presence of organic matter Average nutrient availability	Low presence of organic matter Low nutrient availability
Microclimate	Favourable temperature High relative humidity	Moderate favourable temperature Average relative humidity	Unfavourable temperature Low humidity
Hidrology	Wet haze areas (high)	Wet haze areas (moderate)	Wet haze areas (low/no haze)
Associated biological components	High biodiversity	Average biodiversity	Low biodiversity

The study considered species of the subgenus Heliconia, which includes robust species with erect inflorescences, thick, deeply cyme-like spathe and greenish flowers on untwisted pedicels. Seven species are recognised: (1) *H. bihai* (L.) L., (2) *H. rodriguensis* Aristeg., (3) *H. caribaea* Lam., (4) *H. bourgaeana* Peters., (5) *H. stricta* Huber, (6) *H. wagneriana* Peters and (7) *H. ortotricha* Anderss. *sp*. nov. (Andersson, 1981). Therefore, measurements of physiological and agronomic characteristics of three commercial cultivars of Heliconia were made; 1) *Heliconia bihai* (L.) L. (locally known as bihai red), 2) *Heliconia wageneriana* Peters (locally known as coloreta) and 3) *Heliconia psittacorum* cv. Tropics (locally known as (tropics). A randomised complete block design with a split-plot arrangement (A x B) and six replications was used. The factors are: A) the *in situ* location of the crop, corresponding to three plots (sites) in the municipality of Coapichapan, Fortin, Veracruz and B) the Heliconias cultivars (*Heliconia psittacorum, Heliconia wagneriana* and *H. bihai*). One seedling was considered per experimental unit, for a total of n=54 (place x cultivate). The variables assessed were tillers and inflorescence characteristics. Tiller traits: number of stems per tiller, height (tallest leaf), pseudostem height cm (inflorescences), pseudostem width cm, leaf length cm, leaf width cm, petiole length cm. Characteristics developing in inflorescences: number of inflorescences, length of inflorescences, number of bracts, number of flowers. Tukey analysis of variance and comparison of means ($p \leq 0.05$) was performed using the statistical package Statistical Analysis System (SAS).

Results and Discussion

A highly significant difference ($p \leq 0.05$) was found for the factor "site" in the variables inflorescences and height (highest leaf). For the "cultivar" factor, all the variables evaluated showed highly significant differences ($p \leq 0.05$) and in the site x cultivar interactions, a significant difference ($p \leq 0.05$) was found for the variables stems per tiller, inflorescences, height (tallest leaf), pseudostem height, leaf width, inflorescence length and bracts. According to the Tukey mean test ($p \leq 0.05$) with respect to the factor "site", site 3 showed the best results in the variable inflorescence (Table 2).

Table 2. Test of means for the site factor.

Site	Stems per tiller	Inflorescence	Bracts	Height (highest leaf)	Height pseudostem	Pseudostem width	Leaf length	Leaf width	Petiole length	Inflorescence length
				-- Cm --						
Site 1	24.4 a	4 b	4.4 a	316 a	122.6a	11.20 a	125 a	23.2 a	61.9 a	30.6 a
Site2	17 a	3.9 b	5.2 a	310 a	126.5a	11.56 a	126.7 a	24.4 a	61.6 a	27.8 a
Site 3	21.4 a	6.3 a	5.2 a	274 b	125.5a	10.86 a	108.3 a	22.93 a	54.8 a	29 a
DMS	6.34	1.53	0.9	27.4	13.6	0.83	19.18	2.4	10.4	4.23

Means with the same letter within each column do not differ statistically (Tukey, $P \leq 0.05$).

Sites 1 and 2 had greater plant height. This is consistent with the different characteristics of the sites, as sites with characteristics of an agroforestry or diversified agroforestry system and land use promote greater growth (Rangel et al., 2017). For the cultivar factor, according to the Tukey means test ($p \leq 0.05$), cultivar 1 had a better response for the variables number of stems per tillers, height (tallest leaf), pseudostem height, leaf length and width, petiole length and inflorescence length. Cultivar 2 had better results for the variables number of inflorescences, number of bracts, pseudostem width, leaf length and width, inflorescence length. Cultivar 3 had the best response to the variable number of stems per tillers (Table 3).

Table 3. Test of means for the cultivar factor.

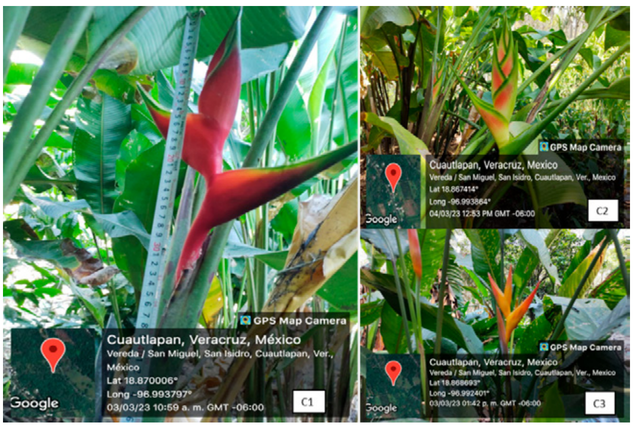
Cultivar	**Stems per tiller**	**Inflorescence**	**Bracts**	**Height (highest leaf)**	**Height pseudostem**	**Pseudostem width**	**Leaf length**	**Leaf width**	**Petiole length**	**Inflorescence length**
				-- Cm --						
Cultivar 1	25.8 a	3 b	4.8 b	371.3 a	145.4a	11.8 b	139.6 a	26.9 a	86.6 a	31.9 a
Cultivar 2	13.6 b	7.2 a	6.4 a	297.6 b	108.8b	12.8 a	141 a	26.1 a	43.3 b	31.5 a
Cultivar 3	23.5 a	4 b	3.6 c	231.6 c	120.4b	9 c	79.4 b	17.4 b	48.4 b	24 b
DMS	6.34	1.53	0.9	27.4	13.6	0.83	19.18	2.4	10.4	4.23

Means with the same letter within each column do not differ statistically (Tukey, $p \leq 0.05$).

As shown in the results, the best response for the greatest number of variables corresponds to *H. bihai* (L.), which is the species that presented the most relevant characteristics and is found in agroforestry systems with coffee (*Coffea arabica* L.). This represents an ecological importance (Rangel et al., 2017). The characteristics of this cultivar are; it is a plant with a muscoid habit, 2.0 to 5.0 m high. It is glabrous and the stems, petioles and undersides of the leaves and lower bracts of the inflorescence have an irregular whitish waxy coating. The inflorescence is erect, 30.0 to 60.0 cm long, depending on the variety, with an almost straight or more or less sinuous rachis, usually red, sometimes greenish-yellow. The persistent bracts, 5 to 15 per inflorescence, are usually arranged in the same plane, rarely in different planes due to the twisting of the rachis. Flowers are usually almost straight to slightly parabolic, 10-20 per bract, white to light green towards the tip (Andersson, 1981).

Cultivar 2, corresponding to *H. wagneriana* (Fig. 2), showed the best results in six variables. The results can be compared with *H. wagneriana* Red; plant height 224.40 cm, plant spread 246.84 cm, leaf length 112.20 cm, stem girth 15.92 cm and number of shoots per bush 13.27 (Kannan et al., 2019). Although the results are lower in terms of plant height and leaf length, they are consistent in terms of number of shoots per bush. With these results, Kannan et al. (2019) recommend that this crop meets the marketing criteria. On the other hand, when measuring ornamental traits in hanging Heliconias species (*H. chartacea*, *H. collinsiana*, *H. magnifica*, *H. pendula*, *H. platystachys*, *H. pogonantha*, *H. rostrata*, *H. rauliniana* and *H. vellerigera*), the number of bracts varies from 6 to 40 bracts per flowering stem. For inflorescence length, the results vary from 0.5 m - 2 m. pseudostem length from 1.5 m - 3.2 m (Loges et al., 2016).

Fig. 2. Cultivar evaluated.



Source: Photographs taken during field work.

In the site x cultivar interaction, according to the means test (Tukey, *p*

≤ 0.05), "site 1 x cultivar 1" showed better performance in eight variables, except for inflorescence and bract. For the interaction "site 2 x cultivar 1", better results were obtained for leaf length and inflorescence length, and for the interaction "site 2 x cultivar 2", the best results were obtained for bract number, pseudostem width and leaf length. Finally, the interaction "site 3 x cultivar 1" gave the best result for inflorescence length and the interaction "site 3 x cultivar 2" for inflorescence and bract length (Table 4).

Table 4. Test of the means of the interaction "site x variety".

Factors	Levels	Stems per tiller	Inflorescence	Bracts	Height (highest leaf)	Height pseudos-tem	Pseudostem width	Leaf length	Leaf width	Petiole length	Inflorescence length
					---------------------------------- Cm -----------------------------------						
Sitio 1	Cultivar 1	45.8a	4.8bc	3.8bc	466a	174a	12.8ab	147.8a	29.6a	101.8a	34.4a
	Cultivar 2	8c	2.8c	5.4ab	258de	87.8c	12.6ab	156a	24.4abc	39.4d	28.4abc
	cultivar 3	19.6bc	4.4bc	4.2bc	224e	106.2bc	8.2d	71.2c	15.6d	44.6cd	29.2abc
Sitio 2	Cultivar 1	11.2c	1.6c	5abc	370b	133b	11.2bc	144.6a	27.2ab	88.8ab	27.2a
	Cultivar 2	11.6c	6.6bc	7a	337bc	120.6b	13.7a	152a	29ab	47.2cd	35.2c
	Cultivar 3	28.2b	3.6bc	3.6bc	223e	126b	9.8cd	83.6bc	17d	49cd	21.2c
Sitio 3	Cultivar 1	20.4bc	2.8c	5.6ab	278cde	129.2b	11.4bc	126.4ab	24bc	69.4bc	34.2a
	Cultivar 2	21.2bc	12.2a	7a	298bcd	118.2bc	12.2ab	115abc	25abc	43.4cd	31ab
	cultivar 3	22.8bc	4bc	3.2c	248de	129.2b	9d	83.6bc	19.8cd	51.8cd	21.8bc

Means with the same letter within each column do not differ statistically (Tukey, $p \leq 0.05$).

The results show that under agroforestry conditions, the *Heliconia bihai* (L.) crop responds better in terms of the variables evaluated. Trees can improve the productivity of an agroecosystem by influencing soil characteristics, microclimate, hydrology and other associated biological components (Farrell and Altieri, 1999). Similarly, this species has the greatest potential to be used as a host for entomofauna in cocoa and coffee agroforestry systems. Similarly, the high availability of water in the bracts could play a very important role in the biology of entomofauna, especially in times of drought, as it can favour an increase in the population of its pollinators (Marquina et al., 2017), under conditions of agroforestry systems.

In countries with tropical conditions similar to Mexico, such as Brazil, cut flower growers develop Heliconia selections on their own farms, rejecting less productive ones (Fig. 3). This reflects an unmet need for research into a potential source of opportunities for the floricultural agro-industry in tropical areas (Loges et al., 2023). Avendaño-Arrazate et al. (2017), indicate that there is a great morphological diversity of native Heliconias in Mexico, and as germplasm sources they are important for genetic heritage, as they could be a source for the production of new materials with commercial traits. However, given the characteristics of the producers and the context in which they are grown, it is important to implement programmes oriented towards "tropical floriculture" in terms of production, post-harvest and marketing, as this type of floriculture is different from conventional floriculture (that developed in greenhouses) (Linares-Gabriel et al., 2023).

Fig. 3. Types of heliconia systems.

The ecological characteristics of Heliconias in agroforestry systems

Following severe forest loss in recent decades, some countries are increasingly using social forestry as a means of ensuring the sustainable development of their forest-dwelling communities. Given the potential of agroforestry to provide multiple ecosystem services, habitat for the maintenance of biodiversity and the economic and social development of the communities that cultivate them (Willmott et al., 2023). In that sense, agroforestry practices on degraded and marginal lands could replace the expansion of agricultural cropland (Kim et al., 2021).

With an emerging focus from sustainability in the cut flower sector, resource-efficient practices, circularity through environmental education and even social impact strategies are being explored. Therefore, it is recommended to make further progress in the integration of these sustainable practices, as well as to explore interdisciplinary approaches that address both environmental and social aspects (Villagran et al., 2024).

On the one hand, it is emphasised that agroforestry systems with heliconias allow for the sequestration of important amounts of carbon from the atmosphere, which would mean the generation of other income for the producer under the concept of payment for environmental services (Tórrez et al., 2023). The importance of the percentage of shading is also highlighted, under these conditions Heliconias develop better as it influences the content of photosynthesised pigments and growth (Gomes et al., 2016; Souza et al., 2016). That is, plants grown under the lowest photosynthetically active radiation (PAR) (30% to 35% of the open condition) show improved growth with increased biomass accumulation, plant height, suckering habit, flower bud emergence, inflorescence yield and light use efficiency (Nihad et al., 2019). In general, these species play an important role in the stability of the environment, as they act as natural soil protection thanks to their extensive rhizomatous root systems, allow the infiltration of rainwater into the water table, and provide pollen and habitats for numerous beneficial insects and other pollinators (Jácome-Chacón et al., 2018).

H. bihai is a species introduced in Mexico, as well as in different parts of the world, it develops in tropical forest climates, tropical monsoon climate, tropical savannah climate with dry summer to humid and dry tropical savannah climate (Rojas-Sandoval and Acevedo-Rodríguez, 2013). Therefore, it is confirmed that *H. bihai* meets the agronomic criteria for its development in monoculture environments and agroforestry systems. However, it is desirable to produce them in sustainable systems. However, more research is needed on Heliconia spp. for their management in agroforestry systems (Silvano et al., 2023).

Conclusions

Under monoculture conditions, better results were obtained for the number of inflorescences. Heliconia bihai responded better to number of stems per tillers, height, pseudostem height, leaf length and width, petiole length and inflorescence length. *Heliconia wagneriana* responded best to number of inflorescences, number of bracts, pseudostem width, leaf length and width, inflorescence length.

Heliconia psittacorum responded best for number of stems per tillers. In an agroforestry system with Heliconia, *Heliconia bihai* showed better performance in eight variables except for inflorescence number and bract number. In an agroforestry and monoculture system with Heliconia, *Heliconia bihai* showed better results in leaf length and inflorescence length.

In an agroforestry system and monoculture with Heliconia, *Heliconia wagneriana* performed better in bract number, pseudostem width and leaf length. In monoculture, *Heliconia bihai* responded better to inflorescence length and *Heliconia wagneriana* responded better to number of inflorescences and number of bracts. Due to the tropical nature of this ornamental plant, the best growing conditions for Heliconia are in agroforestry systems. Due to its physiological characteristics, *Heliconia bihai* stands out for its agronomic potential in this type of agriculture. However, it is suggested that for future research, a more detailed analysis should be carried out in relation to the cultivation of Heliconias in various systems and conditions.

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Author Contribution

ALG: Design of the research, data processing and writing of the manuscript. MAHC: Design of the research, data processing and writing of the manuscript. NRO: Data processing and writing of the manuscript.

Conflict of 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

Data Availability Statement

Data will be available on request.

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